Ecological studies

of the Bonaparte Archipelago and Browse Basin

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Edited by John Comrie-Greig and Linda Abdo

Published by INPEX on behalf of the Ichthys LNG Project

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The Ichthys LNG Project is a Joint Venture between INPEX group companies (the Operator), major partner Total and the Australian subsidiaries of Tokyo Gas, Osaka Gas, Chubu Electric Power and Toho Gas.

Foreword

On behalf of INPEX, and in cooperation with our Ichthys LNG Project joint venture participants Total, Tokyo Gas, Osaka Gas, Chubu Electric Power and Toho Gas, I am pleased to present this publication, *Ecological studies of the Bonaparte Archipelago and Browse Basin*.

The work contained in this book was conducted in the Kimberley region of Western Australia, in lands and waters that are important to Aboriginal communities. We would like to acknowledge the support that these communities have provided to us over the course of these studies.

When the Ichthys LNG Project was conceived in the early 2000s, there was little biological knowledge available on the Browse Basin and the Bonaparte Archipelago. However, in gathering baseline information for an environmental impact assessment, we were able to amass valuable ecological information about these remote areas.

As it happened, the development concept adopted in our final investment decision for the Project did not include the area around the Maret Islands, meaning that much of this work was no longer required.

Rather than archiving the information gained at the Maret Islands and several nearby islands in the Bonaparte Archipelago, in 2011 INPEX committed to publish the results so that they could be available to the broader community.

It is our hope that the release of this book will make a substantial contribution to the growing body of knowledge on this remote region and assist others in understanding and managing this unique environment.

We recognise our responsibility to help preserve the natural environment and proactively contribute to sustainable development; we see the publication of this book as an example of the Ichthys LNG Project's commitment to the principles of corporate social responsibility.

I would like to thank all those who have contributed to this book. I hope that it will prove to be of value to scientists, government departments and policy-makers, as well as to all Australians who wish to learn more about this uniquely beautiful and diverse region.

Seiya Ito
President Director INPEX Australia

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Preface

Prior to the global rise of sea level known to science as the Holocene transgression that reached its zenith about 6500 years ago, the sea floor of the inner continental shelf off the north-west Kimberley coast was a terrestrial land surface with high relief. Its present complex bathymetry is a consequence of erosion during the long terrestrial history of the ancient Kimberley's north-western margin before its inundation. That large area of coastal land, now submerged beneath the sea, was the country of the ancestors of the Aboriginal people who live in the north-western Kimberley today. Hints of that dramatic environmental event may be heard in their creation stories, but its profound ecological and cultural outcomes remain a scientific story which is still being unravelled. This is the context of the results of ecological studies by the Ichthys LNG Project in the Bonaparte Archipelago that are presented in this book.

The INPEX studies were carried out as part of the preparation of an environmental impact assessment required for the company's proposal to build infrastructure at the Maret Islands associated with development of the Browse Basin gas resource. In the event, the proposal did not proceed and the company decided instead to meet its requirements at a site near Darwin. Nevertheless, a very large commitment had been made to the environmental study at the Maret Islands and other islands in their vicinity and the Project committed to publish this information for the benefit of all who are interested in learning more about the Kimberley region.

The Maret Islands marine ecology study was handicapped by the paucity of pre-existing information and so must be regarded as a preliminary account. Nevertheless, it contains the first technical descriptions of the marine habitats and ecosystems of the northern Kimberley coast, including its extensive and species-rich coral reefs that are an extraordinary feature of this region. This book is therefore a significant contribution to development of scientific knowledge of this remote and poorly known region.

Because of the remoteness of the Kimberley coast from centres of scientific research, until recently very little marine science has been done in the region except for fish stock assessments and surveys of the marine flora and fauna that have produced provisional inventories of the species present. It is evident from these preliminary studies that the diverse coastal habitats of the Kimberley support exceptionally high species richness. The studies reveal features of the Kimberley coastal marine environment that are highly unusual, casting new light on coastal oceanographic, sedimentary and ecological processes that are of global scientific interest. For example, although the presence of coral reefs in the turbid coastal waters of the Kimberley has been known for many years, their extent and species richness is only now revealed.

Until now there has been little information on the geomorphological characteristics of Kimberley coral reefs, their extent and their biota. It had been assumed that, because of the extreme macrotidal and turbid conditions that prevail along this coast, the coral species diversity would probably be low. However, early in the study it became apparent that the coral fauna of these remarkable reefs is extremely diverse.

Taxonomic specialists were engaged to sample and identify the corals present and their preliminary findings are presented in this book. They show that the northern Kimberley reefs support more coral species and genera than any other part of the North West Shelf and that reef growth is vigorous and healthy. In fact, the Kimberley coast may be regarded as a global “hotspot” of coral reef development and coral species diversity. This outcome of the Project’s survey has international importance. That such prolific, biodiverse and actively growing coral reefs occur in such extreme macrotidal, turbid conditions is a challenge to some assumptions of contemporary coral-reef science.

As well as the first descriptions of the region’s coral reefs and other features of the Kimberley coastal marine flora and fauna that have great scientific interest, the Project’s ecological studies have produced a large body of new information that is directly relevant to the protection and management of the heritage values of the Kimberley. The coastal environment of the Kimberley is becoming increasingly accessible and there is an urgent need for a science base that will underpin environmental planning and management in this region that is so rich in features of high heritage significance.

The spectacular scenery of the north-west Kimberley, with its ria coastal landscapes created by inundation of the dissected escarpment, has become a major attraction for a burgeoning tourism industry. It is matched by the rich Aboriginal cultural heritage that is manifest so strongly in abundant rock art that adorns caves and rock walls throughout the region. The art is varied in both style and subject and is strikingly beautiful. It dates back tens of thousands of years, depicting spirit figures and creation events of the region, and it is fostered and maintained by Aboriginal custodians of the present day.

The cultural and natural heritage values of the west Kimberley were recognised recently by its placement on the National Heritage List. Large areas of the region have been reserved as national park, marine park and other categories of conservation reserve including Indigenous protected areas. The Prince Regent National Park is a listed biosphere reserve in UNESCO’s World Network of Biosphere Reserves.

In 2011 the Federal Court of Australia granted native title to traditional owners of the region over much of this part of the Kimberley, including the coastal marine zone and the islands of the Bonaparte Archipelago. At the time of writing, the Western Australian Government is preparing documentation for the declaration of a Great Kimberley Marine Park that is likely to include areas of the Bonaparte Archipelago that are the subject of this book.

This new focus on land-use issues in the Kimberley and its coastal waters is intended to lead to land management practices that are appropriate to an area with high heritage values. Implementation of effective management demands a high level of knowledge of physical and biological characteristics and the factors that influence its ecological processes, but this, regrettably, is inadequate for the Kimberley coastal marine environment at present. To rectify this situation, the Commonwealth and state governments have set up a multidisciplinary marine research program in the Kimberley involving some of the nation’s leading science institutions and industrial concerns, in support of the development of regional land (and sea) management plans for the region’s globally important conservation and heritage areas. It is intended that the new science program will also support Aboriginal groups that now have a significant voice in the management of their traditional lands.

The Ichthys LNG Project’s release of the results of its surveys for publication is an important contribution to the Kimberley Marine Research Program and other research projects that will be conducted in the area, as well as to the development of management plans for the proposed Great Kimberley Marine Park. It is a fine example of the contributions industry can make both to science and to government as well as to community environmental management programs of this kind.

Barry Wilson

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We would also like to acknowledge the scientists and support staff who took part in this research program and especially the Uunguu people who are the traditional owners of the Maret Islands. We offer our thanks to RPS Environment and Planning Pty Ltd for its work as the principal environmental consultancy for the study, and Ian Milliner and The Underwater Centre Fremantle Pty Ltd (TUCF) are thanked for providing the logistic support which facilitated the fieldwork component of the research.

We would like to thank Sjaak Lemmens for his project management contribution in the early stages of this project.

Finally, we would like to thank the INPEX colleagues who assisted with the collection of data, conducted reviews and in other ways contributed to the successful production of this book. Their support was invaluable and greatly appreciated.

1 General introduction

In 1998, INPEX CORPORATION was awarded a petroleum exploration permit in the northern Browse Basin about 200 km north-west of Western Australia's Kimberley coast. The exploration drilling program carried out by INPEX in 2000 and 2001 resulted in a significant gas and condensate discovery in what is now called the Ichthys Field. Based on that discovery, INPEX commenced the Ichthys Gas Field Development Project to produce liquefied natural gas (LNG), liquefied petroleum gases (LPGs) and condensate. In 2006 it was joined by Total in the Ichthys Joint Venture, with INPEX as the majority shareholder and Operator of the Ichthys LNG Project.

Following the appraisal of the Ichthys Field's hydrocarbon reserves, INPEX investigated the options to bring the hydrocarbon products to market, with site selection studies being conducted between 2002 and 2004 to assess a number of possible locations for the Project's onshore processing plant.

These studies indicated that the Maret Islands in the Kimberley region of Western Australia could be an appropriate location for the plant, and a range of oceanographic, environmental and geotechnical studies were initiated to assess the islands' suitability and to provide baseline information for the development of an environmental impact statement. The environmental studies included biodiversity inventories and habitat surveys of the Browse Basin and selected islands of the Bonaparte Archipelago.

Although these studies were completed in 2008 and achieved their objectives, they were no longer required for their original purpose when INPEX instead chose Darwin in the Northern Territory as the preferred site for the plant.

INPEX and its joint venture participants, however, recognise the importance to the scientific community, government environmental agencies and the general public, of the ground-breaking biological and ecological surveys that it commissioned along the Western Australian Kimberley coastline. Rather than archive the results of its work in the Browse Basin and the Bonaparte Archipelago, INPEX and the Ichthys LNG Project joint venture participants offer this book as a contribution to the scientific understanding of the Kimberley.

Photograph courtesy of David Abdo

Figure 1-1: A characteristic Kimberley coastline: Koolan Island

THE KIMBERLEY REGION

The Kimberley region is located in the northernmost part of Western Australia and covers a land area of around 424 500 km^2, almost twice the size of the state of Victoria. Its broad continental shelf supports over 2600 islands and numerous coral reefs, banks and shoals. Only 20 of these islands are larger than 1000 ha, but the largest, Augustus Island, is 18 990 ha in extent.

The coastline of the Kimberley is of global geoheritage significance. It is a large-scale ria coast—a drowned river landscape created by rising sea levels—and is considered to be one of the best examples of ria morphology in the world.

The region (Figure 1-2) has a tropical monsoonal climate which is characterised by two distinct seasons, a “wet” and a “dry”, with several transition periods within each season. Generally the wet season (summer) lasts from November to March and the dry season (winter) from April to October. The dry season is virtually rainless, with clear blue skies, easterly winds, balmy days and cooler nights; the wet season, however, can bring torrential rain and widespread flooding associated with cyclones and tropical thunderstorms. The average annual rainfall for the region is 950 mm, with almost all of this occurring during the wet season. Temperatures are high throughout the year, with monthly averages between 25 °C and 35 °C.

The prevailing winds in the dry season are the strong south-east trade winds from across central Australia, which alternate with periods of calm conditions, while the wet season is dominated by the north-west monsoon and is associated with frequent cyclones and electrical storms.

The Kimberley is a remote and relatively underpopulated area with a population of just over 40 000 people.

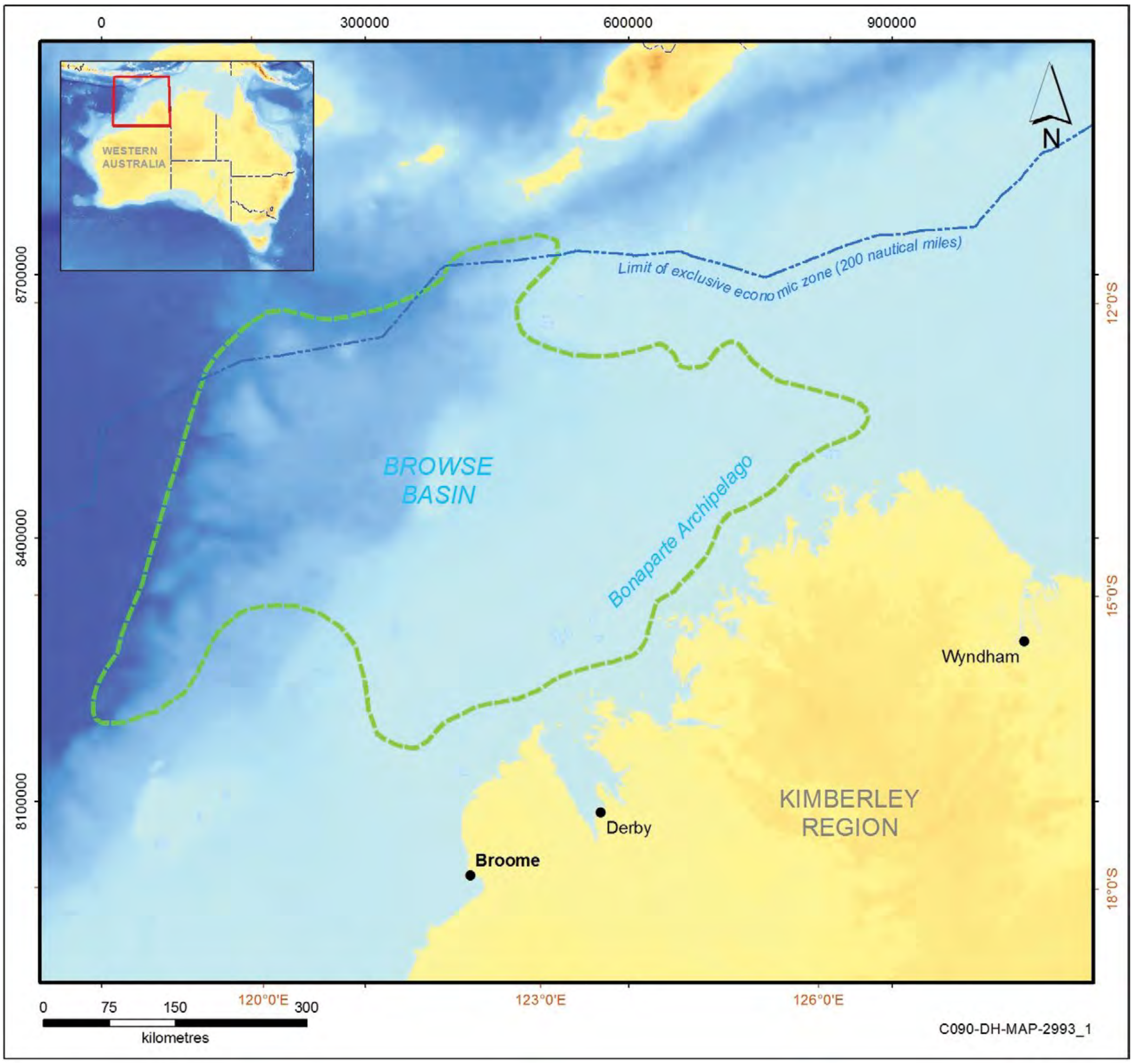


Figure 1-2: The Kimberley region and the Browse Basin of Western Australia

Although pastoral grazing and changed fire regimes have altered the landscape to some extent, the region still contains significant areas of wilderness in comparison with other areas of Australia.

The Australian Government considers the Kimberley, specifically the North Kimberley, to be one of Australia's 15 national biodiversity hotspots and internationally significant biodiversity, heritage, geology and wilderness areas are found across both the mainland and the islands off the coast. On a scale of 1 to 6, the "continental stress class" (a method of describing the landscape health of biogeographic regions in Australia) of the North Kimberley is 6 (near-pristine). However, the remoteness and sheer size of the region and its more than 2600 islands have resulted in knowledge of the biodiversity of the Kimberley being still far from comprehensive. Many of the islands in the Kimberley have never been assessed and, based on the results of the studies on the handful of islands that have been surveyed, they are expected to possess many species that have not yet been described.

BROWSE BASIN

The Browse Basin is one of seven major sedimentary basins in Western Australia and is located off the north-west coast of Western Australia at the western edge of the Timor Sea. It covers an area of approximately 140 000 km^2 and is bounded by the Leveque Shelf to the south, the Bonaparte Basin to the east, the Ashmore Platform to the north, and the offshore portion of the Canning Basin to the south-west. Water depths range from 20 m to over 2000 m.

The Browse Basin is also one of Australia's most hydrocarbon-rich offshore provinces. Exploration for hydrocarbons commenced there in 1964 and, since then, several large gas fields have been assessed and delineated and are currently proposed for natural gas and condensate extraction projects. Among the most significant of these are the Torosa, Brecknock, Calliance, Ichthys, Crux and Argus fields.

A significant amount of the research so far conducted on the biota of the Browse Basin has been conducted in conjunction with these and other hydrocarbon projects. The greater part of this information has yet to be published.

Figure 1-3: North Maret Island looking south to South Maret Island and to Turbin and Berthier islands in the distance

BONAPARTE ARCHIPELAGO

The islands of the Bonaparte Archipelago lie along a 200 km stretch of the Kimberley coastline between Kuri Bay in the south and Admiralty Gulf in the north (Figure 1-4). Although the archipelago consists of several hundred islands, most are small and many have areas of less than a square kilometre and are best described as small islets or emergent rocks. The archipelago also includes a number of submerged banks and shoals.

North Maret Island and South Maret Island, which were the primary focus of the surveys reported on in this book, lie within the Bonaparte Archipelago, to the north-west of Bigge Island. The Marets are 392.8 and 374.2 ha in extent respectively and are joined by an isthmus at low tide. Prior to the studies commissioned by the Ichthys LNG Project between 2006 and 2008, the biotas of the Maret Islands and their neighbours were largely unsurveyed and unknown.

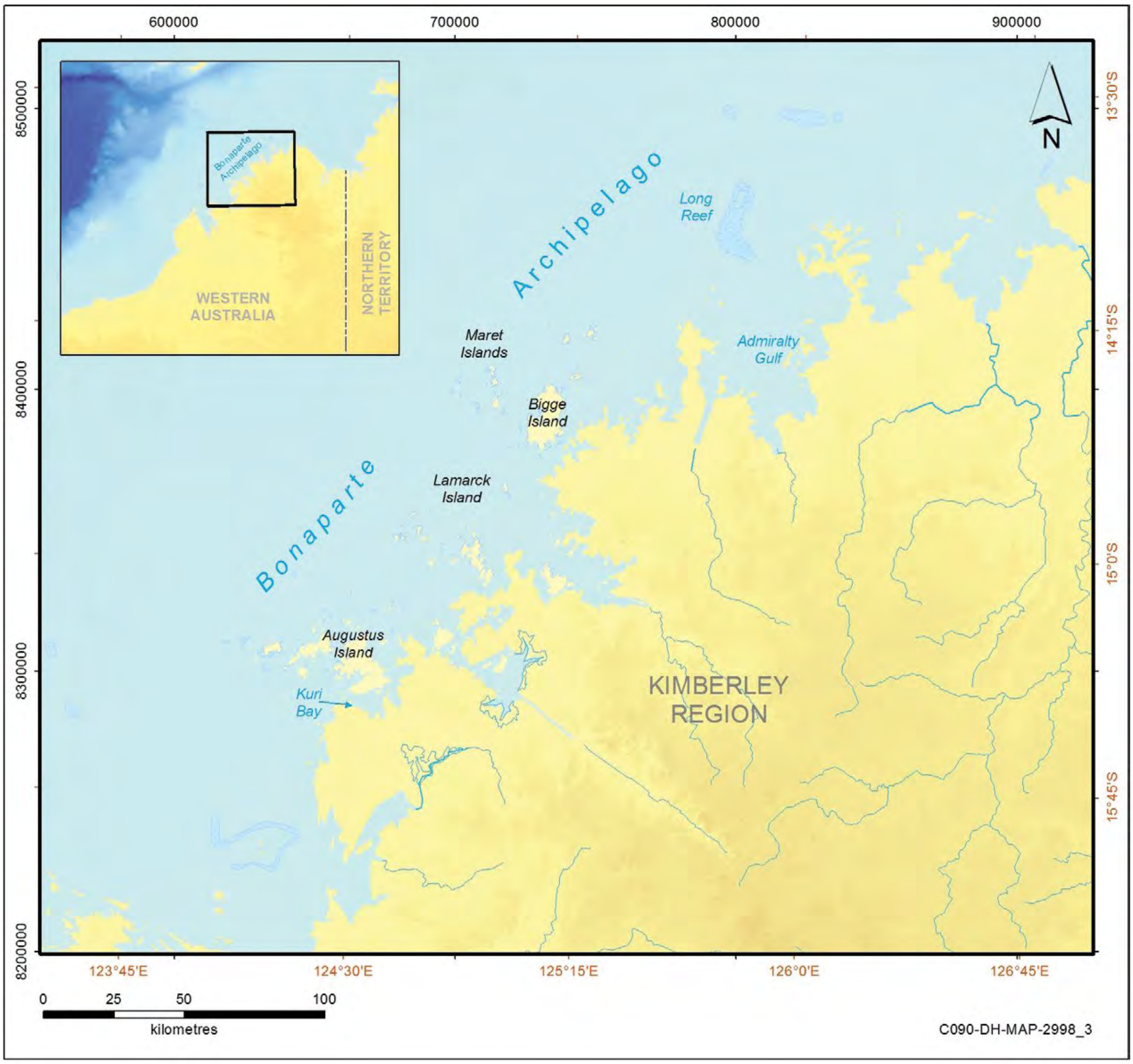
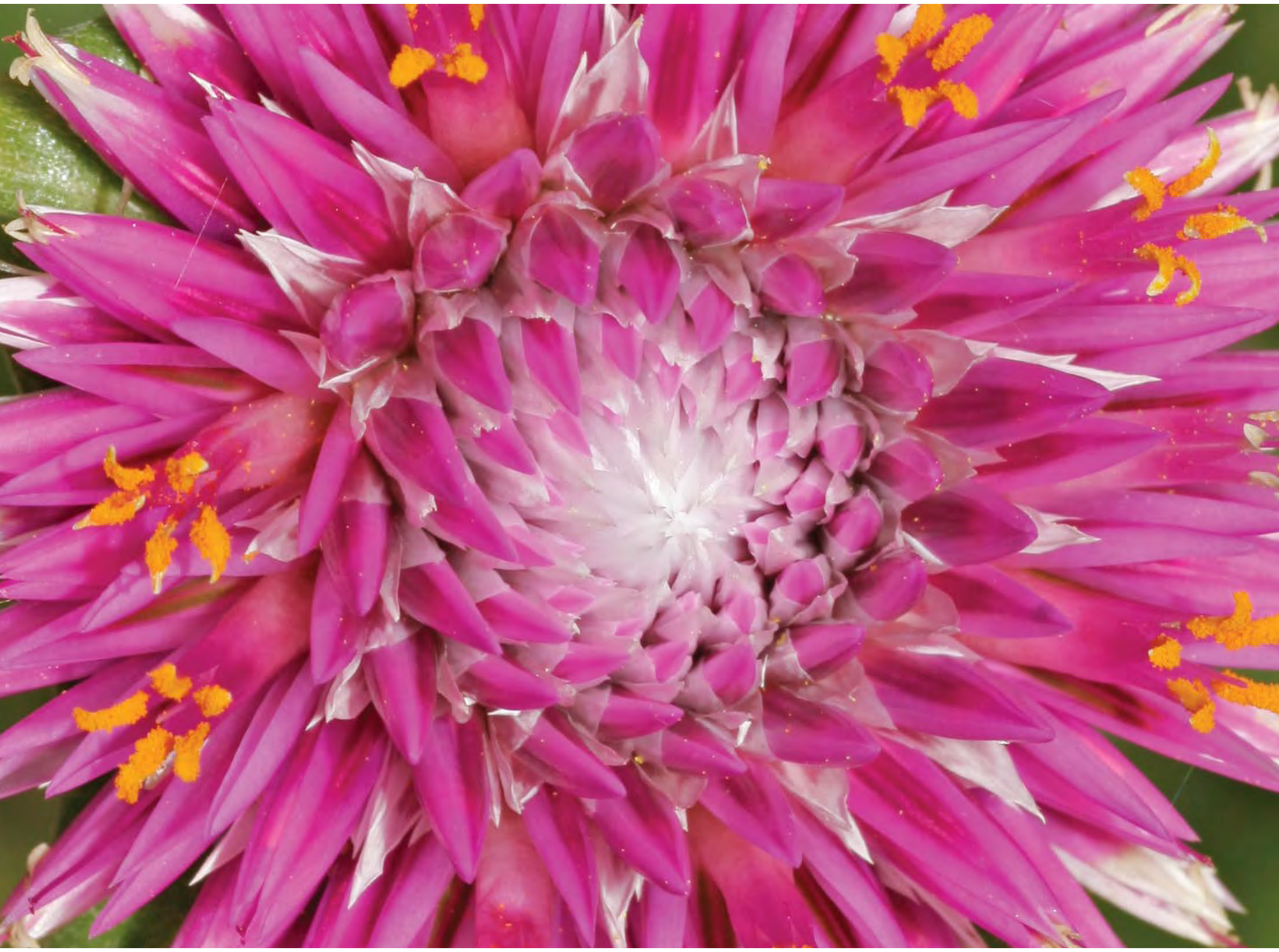


Figure 1-4: The Bonaparte Archipelago

Terrestrial



Photograph courtesy of Russell Barrett
(*Gomphrena* sp. Maret Islands)

Introduction to the terrestrial environment

2

Kevin Kenneally

Kenneally, K.F. 2014. Introduction to the terrestrial environment. pp. 13–17 in Comrie-Greig, J. and Abdo, L.J. (eds), *Ecological studies of the Bonaparte Archipelago and Browse Basin*. INPEX Operations Australia Pty Ltd, Perth, Western Australia.

SIGNIFICANT CHARACTERISTICS AND IMPORTANCE

The extensive archipelagos and island groups located off the northern Kimberley coast of Western Australia collectively support representative examples of most of the substrates and vegetation communities found on the adjacent mainland (Burbidge & McKenzie 1978). Over 2600 islands lie off the Kimberley coast. These were formed as a result of rising sea levels some 6500 years ago following the global thaw after the last Pleistocene glacial maximum, which occurred around 19 000 years ago (De Deckker & Yokoyama 2009).

Islands are centres of evolution because each island has its own story based on time, location, climate and geology, factors that form the matrix for the evolution of island organisms. The importance of islands in terms of biodiversity conservation has long been recognised, especially because they have been sheltered from many mainland disturbances (Burbidge, Williams & Abbott 1997; Woinarski, Milne & Wanganeen 2001).

Bigger islands tend to have greater numbers of habitats and can support a wider range of species. However, limitations to their resources, such as food, water and habitat, are likely to prevent the persistence of large animals. Studies on Kimberley islands undertaken by the Department of Parks and Wildlife and the Western Australian Museum (Gibson, Yates & Doughty 2012; How et al. 2006) show that islands in the higher rainfall zone (more than 1000 mm on average per year) typically had the greatest number of endemic species. The Bonaparte Archipelago is located in this high rainfall belt.

For the proper management of the Kimberley island ecosystems, biologists need to know “what occurs where”. This entails undertaking biodiversity surveys and compiling comprehensive species lists for each island. From these lists it is possible to determine biogeographic patterns that can assist in decisions on how to strike a balance between conservation, recreation and sustainable development and can provide baseline information for future ecological surveys and monitoring. The surveys of the Bonaparte Archipelago reported on in this publication will thus make a substantial contribution to the sum of biological knowledge of the region.

The archipelago is situated in the Mitchell Subregion of the Northern Kimberley Bioregion, which is the dissected plateau of the Kimberley Basin. The subregion consists of exposed basement strata that are heavily fractured and intersected by rivers, forming a rugged sunken coastline that includes extensive clusters of coastal islands.

More recently, the islands of the Kimberley have been occupied or visited not only by their traditional owners, the Aboriginal people, but by Macassans from Indonesia, beachcombers, pearlers, guano miners and members of the Australian and American military forces during the Second World War (Clement, Gresham & McGlashan 2012). It has been hypothesised by Abbott (1980) that islands occupied or visited by Aboriginal people in the north-west of Australia lack macropod species in modern times because of hunting pressure and by dingoes introduced by man, as well as from habitat alteration caused by the cultural use of fire by Aboriginal people.

The nearshore islands of the Bonaparte Archipelago are considered to be of high environmental conservation value as they support a range of near-pristine ecosystems and have high species diversity. In recent years, recommendations have been made to provide formal protection for the Maret Islands (the primary focus of the surveys reported on in this book), but to date this has not occurred (Burbidge, McKenzie & Kenneally 1991).

In recent times, the coastal region of the Kimberley has been exposed to increased human activity (Carwardine et al. 2011). While some of these activities offer potential economic benefits, they will also place ever greater pressure on the health of the islands' biota if not properly managed or mitigated to minimise impacts. Of particular concern is the increased risk of exotic pest species such as the cane toad or the black rat being introduced to the islands by visitors (Nias et al. 2010).

The islands of the archipelago play an important role in maintaining biodiversity over geological time scales because their isolation has given rise to differentiation of populations and to new, unique organisms. Specifically, they have the potential to support a wide range of endemic species as well as to provide secure breeding for seabirds, shorebirds and marine turtles.

Islands near Australia's continental margin are likely to be the refugia of the same or closely related species on the mainland as they are less likely to be affected by disturbance from invasion by non-native species (e.g. feral cats, donkeys, horses, cattle and pigs), or from anthropogenic impacts (e.g. pastoral agriculture) that are more significant on the mainland. The islands of the Bonaparte Archipelago that have been examined are essentially free of introduced plants and animals and have relatively intact ecosystems compared with the adjacent mainland. However, most plant and animal populations on the islands have not been evaluated systematically and all have the potential to provide important information on the evolutionary effects of isolation since the Pleistocene. Future molecular studies could document genetic variability throughout the archipelago and compare and contrast that with related mainland populations (How et al. 2006).

Figure 2-1: Basalt outcrops on South Maret Island (with North Maret Island in the background)

The Maret Islands and their neighbours are considered regionally important in terms of both landform and biodiversity. For example, the flora of the Maret Islands includes approximately 11% of the known floral inventory of the Northern Kimberley Bioregion. In addition, the vine-thicket (or monsoon-forest) closed-canopy communities on the Maret Islands are of significant ecological importance as they offer regionally important shelter and foraging habitat for many invertebrate and vertebrate species. They also provide habitat and wildlife corridors for bats and for migratory birds such as the rainbow bee-eater, fork-tailed swift and rufous fantail.

GEOLOGY

The islands of the Bonaparte Archipelago are remnants of the Mitchell Plateau, a dissected plateau of laterite and lateritic bauxite formed in the Tertiary, some 70 to 50 million years ago when Australia had a more tropical climate. The laterite has formed over basaltic volcanic rocks that contain aluminium. Geological features also include horizontally bedded sandstones and quartzites and intrusive dolerites. Significant geological groups include the Carson Volcanics, King Leopold Sandstone, Warton Sandstone and Hart Dolerite (Tyler 1996).

On the Maret Islands, for example, Tertiary duricrusts occur as mesas and dissected tablelands with breakaway cliffs and steep scree slopes around their edges. About 60% of the shore is rocky, comprising predominantly laterite boulders at the bottoms of the screes. The islands are composed of basalt of the Carson Volcanics overlain by Tertiary laterites. Basalt outcrops form rocky shores at several points along the eastern sides of both North Maret Island and South Maret Island. There are several short, sandy lunate beaches on the western shores relating to indentations in the cliff line, the largest being in Brunei Bay on North Maret Island. Longer beaches occur on the eastern shores which are located below cliff screes covered in vine thicket.

BIOLOGICAL CONNECTIVITY

Until recently, the connectivity and the extent of genetic mixing between the biotas of the Kimberley islands and the biota of the mainland have been poorly documented, with relatively few published studies. However, the long period of physical isolation of the islands from the mainland is likely to have resulted in some genetic and morphological divergence of most populations. This phenomenon is expected in isolated island populations, particularly with species which are less mobile and which have constrained habitats, such as invertebrate short-range endemics and certain terrestrial reptiles. In the case of the Maret Islands, some gene flow between terrestrial animal populations on the two islands is likely to occur, as they are connected by an isthmus at low tide.

While the surveys undertaken for the Ichthys LNG Project have contributed to the overall understanding of connectivity of the islands of the Bonaparte Archipelago, the knowledge of the relationships of the Kimberley island biotas with their counterparts on the mainland remains poor, or non-existent. However, a recent four-year study of 22 Kimberley islands by scientists from the Department of Parks and Wildlife has revealed that 74% of the mammal species, 70% of the frog species, 69% of the bird species and 56% of the plant species of the Northern Kimberley Bioregion are collectively now known to occur on the islands surveyed (Gibson 2013).

PLANT LIFE

The vegetation of the Northern Kimberley Bioregion is considered to be near-pristine and has a "continental stress class" rating of 6, the least stressed of the six classes (May & McKenzie 2003). The region is characterised by savannah woodland (dominated by the genera *Eucalyptus* and *Corymbia*) over high cane grass (*Sorghum* species) and hummock grasses (*Triodia* species). The drainage lines of the region support riparian forest vegetation and there are extensive mangal systems along the coast and the shores of estuaries. Small patches of vine thicket are scattered across the Kimberley with more than 1500 patches currently known (McKenzie, Johnston & Kendrick 1991). Patch size varies: the average size is 2.5 ha and only 343 are larger than 20 ha (Burbidge 2004).

The vine thickets are considered to be regionally significant, as a high proportion of the region's terrestrial biodiversity occurs within them. They harbour many short-range endemic invertebrate species with restricted ranges and habitat preferences (Harvey 2002). Vine thickets and mangroves provide a closed-canopy environment, an important feeding and breeding habitat for a wide range of animal species many of which may not be present in the surrounding savannah. They also allow some species to persist on islands where they might otherwise fail, and provide a refuge during the dry season. In addition, they provide a dense litter layer suitable for habitat specialists and short-range endemics such as camaenid land snails (Solem 1991), earthworms and mygalomorph spiders. Vine thickets occur on North Maret Island, South Maret Island and Berthier Island and the large continuous patch on South Maret Island is one of the largest recorded in the Kimberley region.

Figure 2-2: Vine thicket on South Maret Island

ANIMAL LIFE

A total of 57 species of native mammals and seven introduced species have been recorded from the North Kimberley Bioregion. The mammal fauna of the Kimberley is increasingly under threat as a result of a combination of factors, including changes in land use and fire regimes, and competition from and predation by introduced animals such as feral cats, cattle, donkeys and pigs. Little is known about the current conservation status of many mammal species in the region because of a general lack of research and survey effort. There is growing evidence that there are long-term changes occurring in mammal populations in the remote Kimberley mainland (Kenneally et al. 2003).

The reptile fauna of the Kimberley region is diverse and shows similarities with that found in the Northern Territory and Queensland. However, while the reptile fauna of the northern Queensland wet rainforests displays a high level of diversity, the vine thickets of the Kimberley region are generally species-poor. In addition, no species appear to be restricted to the vine-thicket vegetation community.

In contrast to the reptile fauna, the avifauna of the vine thickets of the Kimberley is similar to that found in the vine thickets of the Northern Territory and northern Queensland. Vine thickets are generally rich in plant species that produce fleshy fruits, attracting many frugivorous birds and bats. A large number of migratory birds are also expected across the region as the Kimberley lies on the East Asian – Australasian Flyway.

In summary, the near-pristine Kimberley islands are home to plants and animals that are unique to the islands. They also provide refuge to species that are potentially under threat on the mainland from changed fire regimes, introduced animals and weed invasion. Almost all of the islands are free of introduced animals and weeds and they are less subject to uncontrolled fire than the mainland. Nevertheless, as human impacts upon formerly remote areas seem destined to increase, a greater effort will be necessary to ensure that the islands can be managed sustainably for the benefit of future generations.

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Terrestrial flora

3

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Henson, M., Kenneally, K.F., Griffin, E.A. and Barrett, R.L. 2014. Terrestrial flora. pp. 19–102 in Comrie-Greig, J. and Abdo, L.J. (eds), *Ecological studies of the Bonaparte Archipelago and Browse Basin*. INPEX Operations Australia Pty Ltd, Perth, Western Australia.

ABSTRACT

This chapter describes studies carried out on the terrestrial flora of the Maret Islands and adjacent islands in the Bonaparte Archipelago and, on a broader scale, in the Mitchell Subregion of the Northern Kimberley Bioregion as delineated in the Interim Biogeographic Regionalisation for Australia (IBRA). It is based on the results of surveys carried out in 2006 and 2007 by a team of botanists and environmental consultants to provide the baseline biological data necessary for the preparation of an environmental impact statement for the establishment of an industrial operation on the Maret Islands.

The surveys focused on the Maret Islands (the main study site), with secondary studies carried out on Berthier Island, East Montalivet Island and West Montalivet Island (the "reference islands") for comparative purposes. These three islands lie close to the Maret Islands, are of comparable size, have elements of similar lateritic geology and were expected to have similar floras and vegetation communities. A dry-season survey was later conducted on Lamarck Island to the south of the Maret Islands, again for comparative purposes because it has dissimilar (sandstone) geology. A total of 334 plant species from 67 families were collected across all survey locations.

The vegetation of the Maret Islands comprises dune associations above the beaches, coastal vine thickets on the slopes around the edges of the laterite plateaux and savannah woodland on the plateau surfaces. While these vegetation types are well represented in the wider region, the extent of the contiguous vine thicket on South Maret Island makes it one of the largest intact thickets in the Kimberley region. Preliminary observations of the vine thickets on sandstone islands in the region indicate that they contain different species assemblages and structures from the vine thickets on the lateritic islands.

Floristically, there are many similarities among the islands. Although community composition varies between islands, much of the flora is widely distributed in the region. No Western Australian "Declared Rare Flora" were found on any of the surveyed islands. Two "Priority" species were collected on the Maret Islands and appear to be in stable populations in the region. Four "new" (= undescribed) plant taxa (and a number of others that require further investigation) were collected from the Maret Islands and the four reference islands. While none of these plant taxa are likely to be restricted to these islands, further taxonomic and survey work is needed to determine their conservation significance.

While not a required aspect of the survey effort, opportunistic collections were made of fungi encountered during the survey program. One new fungus variety of the genus *Protoxerula* was described from specimens collected during the 2007 survey on North Maret Island; the variety was also collected on South Maret Island and is known from similar habitats on mainland Australia.

INTRODUCTION

This chapter summarises the findings of the terrestrial flora and vegetation studies carried out in 2006 and 2007 on a group of islands in the Bonaparte Archipelago in the Kimberley region of Western Australia. It is based on unpublished reports by environmental consultants RPS Environment Pty Ltd. (RPS 2007, 2008).

Background information

Vegetation

The Northern Kimberley Bioregion is characterised by shallow sandy soil on outcrops of Proterozoic siliceous sandstone that supports savannah woodland over high sorghum grassland and hummock grasses. Riparian forests occur along drainage lines. There are extensive mangal systems along the shores of estuaries and embayments and there are numerous small patches of vine thicket or monsoon forest.

The "continental stress class", a means of describing the landscape health of biogeographic regions in Australia (on a scale of 1 to 6), is 6 (near-pristine) (May & McKenzie 2003). A more recent assessment places the region in stress class 5, but keeps the Maret Islands and their neighbouring islands as stress class 6 (Mr Norman McKenzie, Principal Research Scientist, Department of Environment and Conservation, Perth, Western Australia, pers. comm. December 2007). An explanation of the criteria used in arriving at a continental stress class rating is provided by Morgan (2000).

Little is known about the current conservation status of many individual species and ecosystems in the Kimberley because of a general lack of research in the area.

There are more than 1500 rainforest patches scattered across the Kimberley, each with a distinct structure and floristic composition. Most of the patches are in high-rainfall areas of the remote north-west Kimberley. Patch size varies: the average size is 2.5 ha and only 343 are larger than 20 ha (Burbidge 2004). They support many animal taxa not found in the surrounding savannah habitats. The rainforest patches provide a haven for animals during the dry season and allow some species to persist in areas where they might otherwise fail.

Despite covering only a small proportion of the total land area, rainforest patches are a highly significant component of the floristic diversity of the Kimberley region (Kenneally, Keighery & Hyland 1991).

Flora

Collections of plant specimens in the Kimberley began in 1819 and have continued, boosted in the 1960s by improvements in transportation and access to the region. The most complete records of the flora of the Kimberley are contained in the books *Flora of the Kimberley region* (Wheeler et al. 1992) and *Broome and beyond* (Kenneally, Edinger & Willing 1995).

In 1998, the Kimberley vascular flora was considered to comprise 2025 native species of which 230 were considered to be endemic to the region. Wheeler et al. (1992) recorded 167 plant families and 660 genera from the Kimberley, and noted that the flora is dominated by grasses, pea flowers, sedges, eucalypts, paperbarks and wattles. Beard, Chapman and Gioia (2000) rate endemism in the Kimberley as low. In 2007 the Western Australian Herbarium's FloraBase database listed nearly 2650 native species of vascular plants in the Kimberley region (DEC 2007).

Many species are poorly known and collected and therefore it is difficult to determine the true level of endemism in the Kimberley flora; however the rate of species discovery in the region suggests that the level will rise. The region's flora bears strong similarities to vegetation systems across the "Top End" in the Northern Territory (Clarkson & Kenneally 1988).

There are 18 species of mangrove tree in the Kimberley, with different species and assemblages from those in the Pilbara and Gascoyne regions (Pedretti & Paling 2001). Ten of these species do not extend south of the Kimberley. Well-developed and structurally complex mangals are present around the mainland coast of the Kimberley and are particularly well developed in estuaries, larger bays and inlets. Mangals are less well developed in coastal bays and on nearshore islands and are uncommon on outer islands.

Accounts of Kimberley mangroves date back to the early seagoing explorations in colonial times (e.g. King 1827; Stokes 1846). More recent accounts have been published by Johnstone (1990), Messel et al. (1977), Saenger (1996), Semeniuk (1980, 1982, 1985), and Thom, Wright and Coleman (1975). Their zonation and structure are described by Semeniuk, Kenneally and Wilson (1978), Wells (1982), Hutchings and Saenger (1987), Johnstone (1990) and Wells and Slack-Smith (1981). The distribution of mangroves around the Western Australian coast has been assessed by Pedretti and Paling (2001) and by Bridgewater and Cresswell (1999).

The conservation significance of islands

Island populations play an important role in maintaining biodiversity over geological time-scales. The Kimberley islands contain floristic populations that have been isolated from the mainland as a result of increasing sea levels starting about 19 000 years before present. In fact, sea levels have fluctuated from about 120 metres below to a few metres above present levels over the past 1.8 million years of the Pleistocene epoch. During this time there have been about 20 cycles, leading to extended alternating periods of isolation and reassociation. Throughout the world this phenomenon has given rise to differentiation of new taxa (for examples see Kitchener & Suyanto 1996 and Schmitt, Kitchener & How 1995).

Offshore islands are important refuges for species that are affected by competition with introduced species or by human activities and impacts on the mainland. Each Kimberley island population of plants and animals potentially represents a unique reservoir of genetic information that could play a major role in maintaining biodiversity in a region that is increasingly under threat. The Kimberley islands are essentially free of introduced plants and animals and have relatively intact ecosystems compared with the mainland.

The biota of the Kimberley islands is poorly documented although there have been a few published surveys (Beard, Clayton-Greene & Kenneally 1984; Burbidge & McKenzie 1978; How et al. 2006). These have drawn attention to biodiversity on islands of the Bonaparte Archipelago, while in the Buccaneer Archipelago reports are so far available only for Koolan Island (Keighery et al. 1995; McKenzie et al. 1995). Despite the potential for divergence among long-separated island populations, few taxa on Kimberley islands have so far been described as taxonomically distinct. This is in contrast to island populations in other archipelagos off the Pilbara coast to the south-west, which have a number of endemic taxa. Little is known about the relationships between the biotas of the Buccaneer Archipelago and the Bonaparte Archipelago to the north-east, and those of adjacent localities on the Kimberley mainland.

Koolan Island is a rugged sandstone island about 130 km north of Derby and has a long history of mining and exploration. As a consequence, its wildlife is the most thoroughly inventoried of any of the islands in the Kimberley region. Keighery et al. (1995) described its flora as comprising 282 taxa in five major vegetation units, with 12 weed species introduced during human occupation of the island. The vegetation structure and underlying geology were similar to that found on the mainland in nearby sites. Only one native plant species was thought to be restricted to Koolan Island; otherwise the flora comprised species that occur widely across the Kimberley.

While there are obviously strong affinities between the sandstone Koolan Island and adjacent mainland floras, the Kimberley islands in general are considered to be of high conservation value as the variety of ecosystems and high species diversity they support are likely to persist in the absence of the impacts and disturbances caused by human activities on the mainland (Burbidge & McKenzie 1978).

Rationale for the research

The research studies on the six islands in 2006 and 2007 were carried out to provide baseline environmental data for a proposal by INPEX Browse, Ltd. to establish its onshore natural-gas processing plant on the Maret Islands as part of its Ichthys Gas Field Development Project. However, in 2008 INPEX selected Darwin in the Northern Territory as the preferred site for the plant and the plans to develop the Maret Islands were abandoned.

Before the focus of the Project turned to Darwin, however, INPEX's original Maret Islands option required that information be gathered on how the Project might impact upon the islands' terrestrial flora and vegetation. At the time, little was known about the botany of the Maret Islands and the surrounding islands and the survey reported in this chapter therefore represents the most thorough survey of the Maret Islands, Berthier Island, the Montalivet Islands and Lamarck Island to date.

The comprehensive baseline surveys on the flora and vegetation assemblages of the main study area, the Maret Islands, was carried out as a "Level 2 survey" in accordance with the Environmental Protection Authority's Guidance Statement No. 51; this consisted of background research and a reconnaissance survey followed by detailed seasonal surveys (EPA 2004). This level of survey was considered appropriate for the Northern Kimberley IBRA Bioregion under the Environmental Protection Authority's Position Statement No. 3 (EPA 2002).

The survey methods were also selected to be consistent with the Kimberley regional surveys planned at the time by Western Australia's Department of Environment and Conservation (Mr G. Keighery, Principal Research Scientist, Department of Environment and Conservation, Perth, pers. comm. 2006). Surveys were conducted when fertile plant material was likely to be available and after significant rainfall when ephemeral species were expected to appear. Repeated wet-season surveys of the same area were necessary to account for the considerable interspecific differences in reproductive timing and ephemeral growth rates.

Study objectives

The objectives of the study program were as follows:

- to map the distribution of native vegetation associations on the Maret Islands and selected areas of the four "reference islands" (Berthier Island, the Montalivet Islands and Lamarck Island)
- to determine the ecological and conservation significance of the vegetation and flora in the study area
- to search for Declared Rare Flora and Priority Flora species within the study area (see Table 3-1)
- to collect voucher specimens and lodge these with the Western Australian Herbarium to facilitate future research in the region.

Conservation codes and definitions for Declared Rare Flora and Priority Flora in Western Australia (DEC 2012) are listed in Table 3-1. On each occasion on which a Priority Flora species is mentioned in this chapter, its name is followed by its conservation code (e.g. "(P2)", "(P4)").

Table 3-1: Conservation codes and definitions for Declared Rare Flora and Priority Flora in Western Australia

Conservation code	Declared Rare Flora and Priority Flora category definitions
T	**Declared Rare Flora—extant taxa:** Taxa which have been adequately searched for and are deemed in the wild to be either rare, in danger of extinction, or otherwise in need of special protection, and have been gazetted as such.
1	**Priority One—poorly known taxa:** Taxa that are known from one or a few collections or sight records (generally less than five), all on lands not managed for conservation … and under threat of habitat destruction or degradation. Taxa may be included if they are comparatively well known from one or more localities but do not meet adequacy-of-survey requirements and appear to be under immediate threat from known threatening processes.
2	**Priority Two—poorly known taxa:** Taxa that are known from one or a few collections or sight records, some of which are on lands not under imminent threat of habitat destruction or degradation … Taxa may be included if they are comparatively well known from one or more localities but do not meet adequacy-of-survey requirements and appear to be under threat from known threatening processes.
3	**Priority Three—poorly known taxa:** Taxa that are known from collections or sight records from several localities not under imminent threat, or from few but widespread localities with either large population size or significant remaining areas of apparently suitable habitat, much of it not under imminent threat. Taxa may be included if they are comparatively well known from several localities but do not meet adequacy-of-survey requirements and known threatening processes exist that could affect them.
4	**Priority Four—rare, near-threatened and other taxa in need of monitoring:** a. **Rare:** Taxa that are considered to have been adequately surveyed, or for which sufficient knowledge is available, and that are considered not to be currently threatened or in need of special protection, but could be if present circumstances change. These taxa are usually represented on lands managed for conservation. b. **Near-threatened:** Taxa that are considered to have been adequately surveyed and that do not qualify for “conservation-dependent” status (Priority Five), but that are close to qualifying for “vulnerable” status. c. Taxa that have been removed from the list of threatened species during the past five years for reasons other than taxonomy.
5	**Priority Five—conservation-dependent taxa:** Taxa that are not threatened but are subject to a specific conservation program, the cessation of which would result in them becoming threatened within five years.

THE STUDY AREA

The islands of the Bonaparte Archipelago selected for botanical surveys were as follows:

- North Maret Island—Phase 1 (RPS 2007)
- South Maret Island—Phase 1 (RPS 2007)
- East Montalivet Island—Phase 1 (RPS 2007)
- Berthier Island—Phase 1 (RPS 2007)
- West Montalivet Island—Phase 1 (RPS 2007)
- Lamarck Island—Phase 2 (RPS 2008).

The Maret Islands, the Montalivet Islands and Berthier Island form part of the Bonaparte Archipelago, which is made up of several hundreds of small islands and islets lying close to the north-west Kimberley mainland coast. Most of the islands within this group are made up of dissected laterite and are considered to be remnants of the Mitchell Plateau. The age of the laterite is tentatively regarded as Tertiary and it consists of bauxitic and ferruginous components. The complete bauxitic laterite profile is 3–15 m thick over volcanics (basalt) but forms only a thin ferruginous layer on sandstone.

The Maret Islands, Berthier Island and the Montalivet Islands are all characterised by laterite plateaux overlying a clay and saprolite layer on a bed of basalt of variable height above mean sea level. North Maret Island and South Maret Island are respectively 392.8 ha and 374.2 ha in extent and have a combined vegetated surface area of approximately 654 ha. The plateau surface of these islands lies approximately 20–40 m above sea level and the edges of the plateaux are variably eroded into steep boulder-strewn slopes. Sandy beaches and associated sand dunes have formed in depositional areas around the islands. With an area of 556.3 ha, Berthier Island is larger than either of the Maret Islands, whereas East Montalivet Island (384.0 ha) and West Montalivet Island (370.0 ha) are approximately the same size as each of the Maret Islands.

The smaller sandstone Lamarck Island has an area of 292.1 ha.

MATERIALS AND METHODS

Sampling plan

The flora and vegetation surveys required a reconnaissance study to gain a high-level understanding of the community types on each island and to guide the detailed surveys. The detailed surveys involved a combination of Declared Rare Flora and Priority Flora searches and quantitative community surveys using permanent quadrats and transects. Relevés were also used to provide vegetation descriptions where the terrain or vegetation was not conducive to establishing quadrats.

As a consequence of the difficulties of accessing the islands and the limited time available, it was decided that a reconnaissance survey to Lamarck Island was not practicable and that proposed survey sites should be chosen from high-resolution aerial photography.

Sufficient quadrats and transects were surveyed to represent all of the vegetation communities that were identified during the reconnaissance surveys and subsequently identified during the ongoing surveys.

Fungi and slime mould specimens were also collected opportunistically during the vegetation surveys.

Study sites

The locations of the quadrats and transects sampled on each of the six islands are shown in figures 3-1 to 3-6.

Survey schedule

Two reconnaissance surveys were conducted from 25 June to 5 July 2006 and from 19 July to 8 August 2006. These were followed by a dry-season qualitative survey of proposed geotechnical sites and four qualitative surveys of the Maret Islands spanning different seasons, in order to compile an inventory of taxa and to collect flowering and fruiting material of a number of species as an aid to identification during the detailed phase of the survey. The detailed phase took place in the period March–May 2007 and covered the Maret Islands and the three reference islands with lateritic geology (Berthier, East Montalivet and West Montalivet islands). Subsequent to the final quantitative survey a small team revisited the sites proposed for geotechnical investigation on the Maret Islands and neighbouring islands to map locations and count the number of plants of the undescribed taxon *Gomphrena* sp. Maret Islands (A.A. Mitchell 5414). The Osborn Islands group, including selected areas of Cape Bougainville, was also visited in July 2007 to check for its occurrence.

To provide an indication of the level of effort, the survey dates and personnel numbers were as follows:

- 30 September – 7 October 2006 two
- 22–30 October 2006 two
- 13–21 December 2006 two
- 1–8 February 2007 two
- 26 February – 3 March 2007 four
- 19–28 March 2007 twelve
- 15–26 April 2007 six
- 14–28 May 2007 ten
- 26 May – 2 June 2007 four
- 5–12 July 2007 four.

Sampling methods and equipment

Level of survey

The Environmental Protection Authority's Guidance Statement 51 (EPA 2004) was used to determine the level of survey effort required to adequately support the necessary environmental impact statement.

Reconnaissance surveys revealed that the vegetation on the Maret Islands was in pristine condition and that the level of pre-existing clearing or degradation within the study area was low. As noted above, it was determined that a Level 2 survey was appropriate for the preparation of the environmental impact statement.

The three designated stages of the project's Level 2 survey are described below:

1. *The background research or "desktop" study.* A literature search was carried out and all relevant references available at the time were collected and examined.

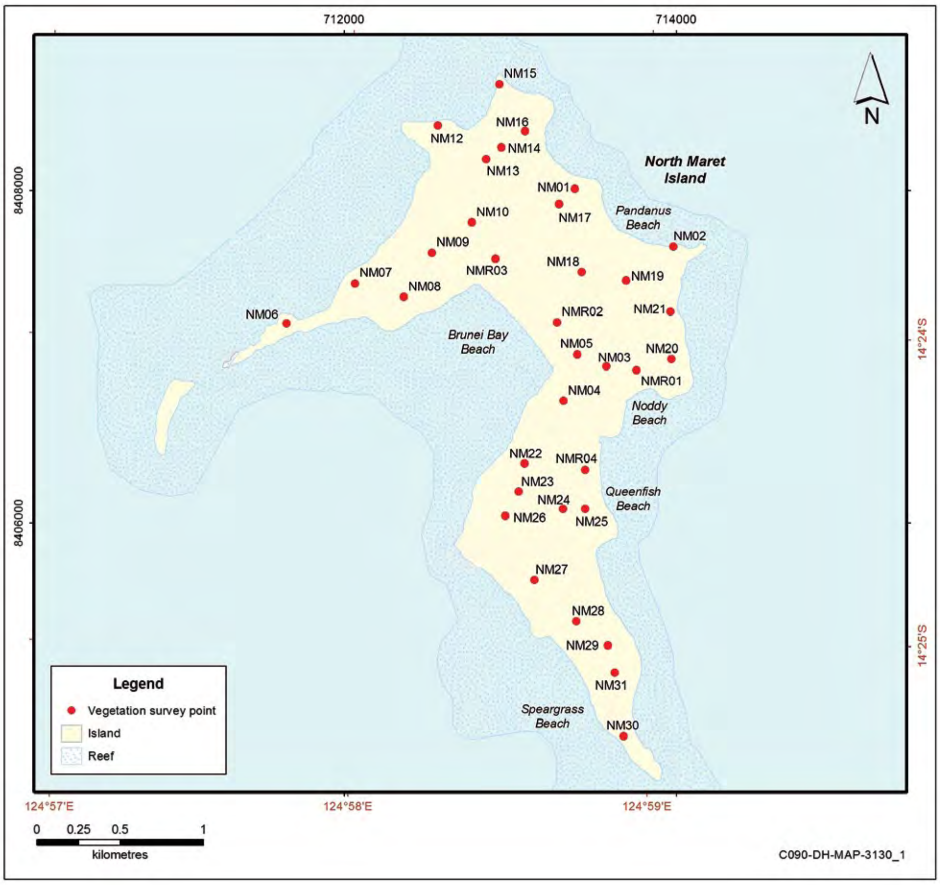


Figure 3-1: Flora and vegetation sampling sites on North Maret Island

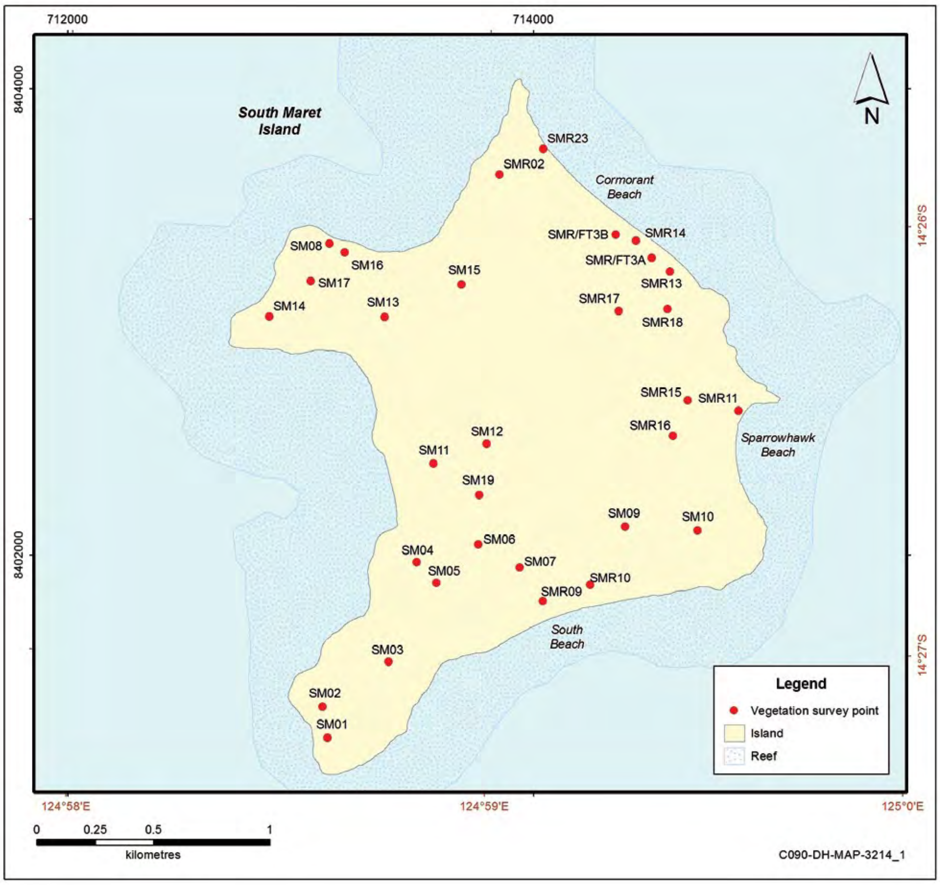


Figure 3-2: Flora and vegetation sampling sites on South Maret Island

3 TERRESTRIAL FLORA

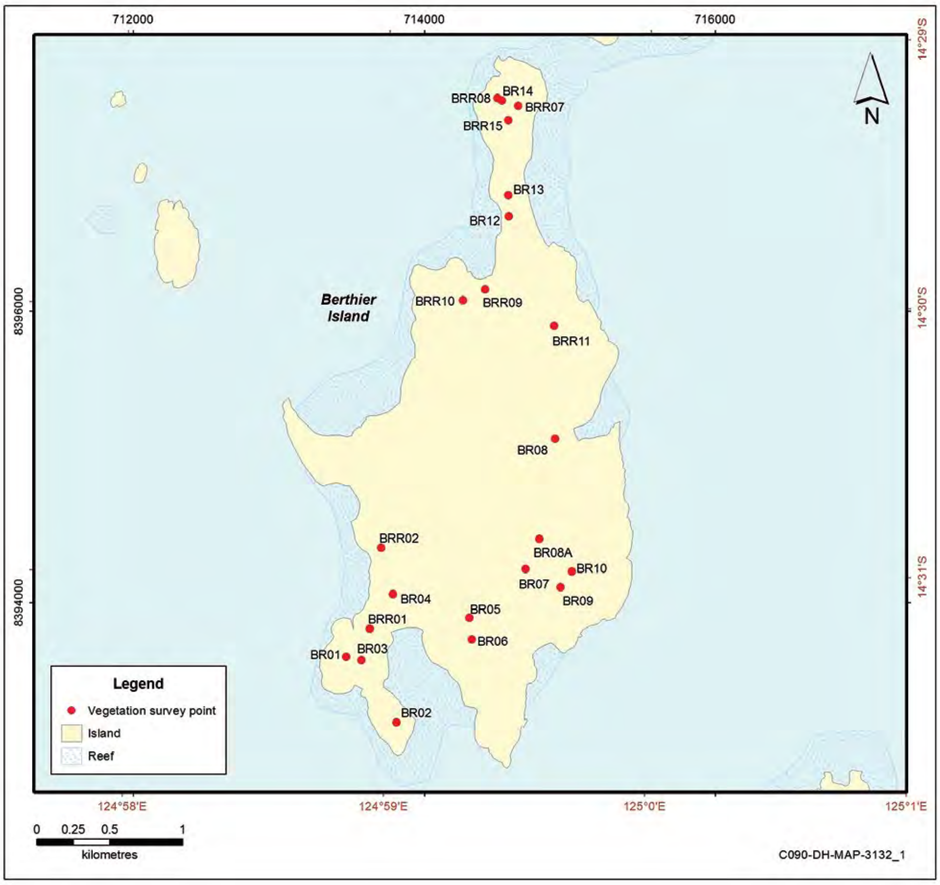


Figure 3-3: Flora and vegetation sampling sites on Berthier Island

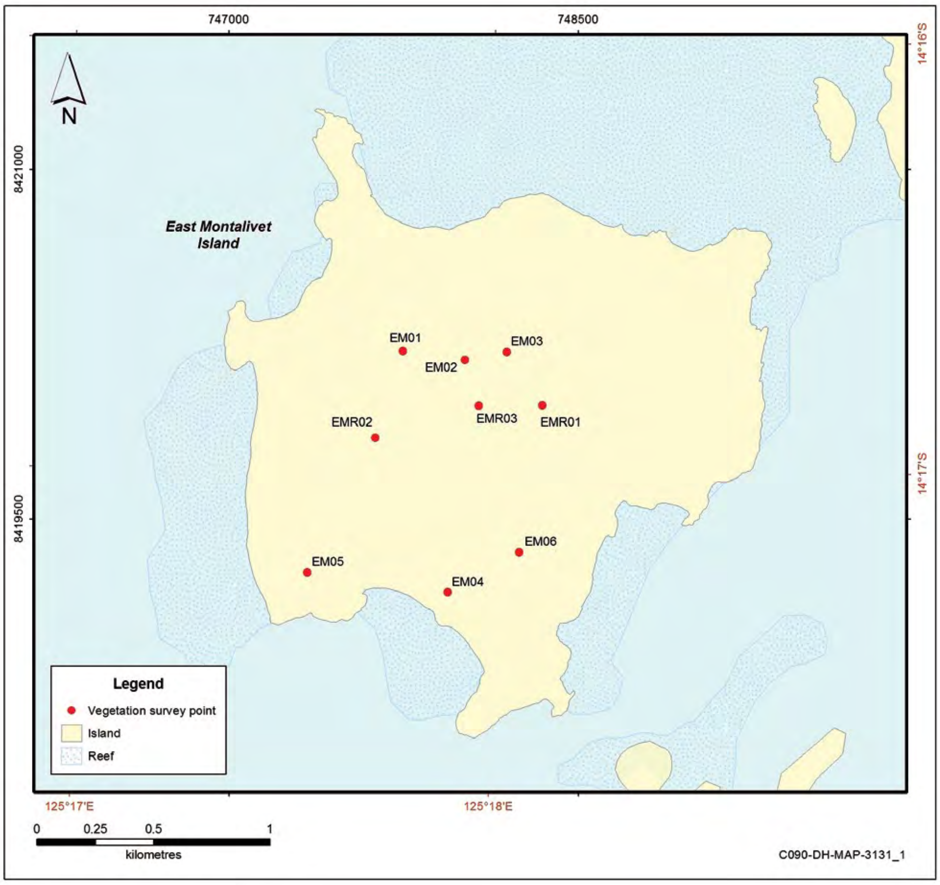


Figure 3-4: Flora and vegetation sampling sites on East Montalivet Island

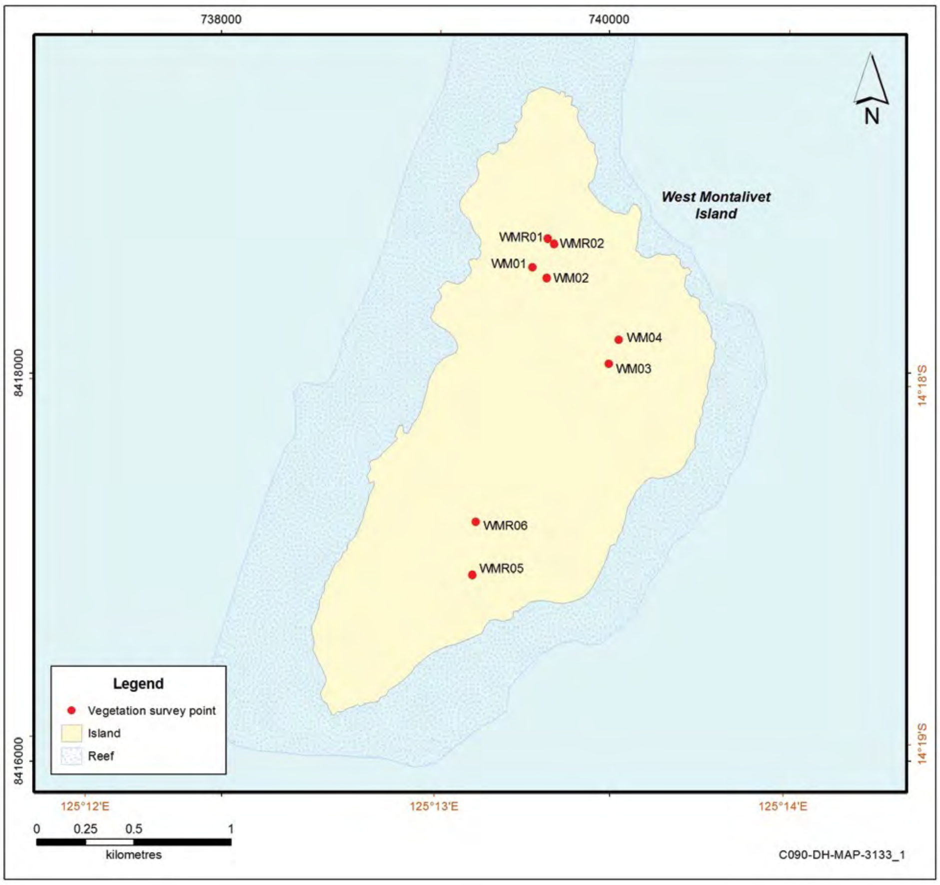


Figure 3-5: Flora and vegetation sampling sites on West Montalivet Island

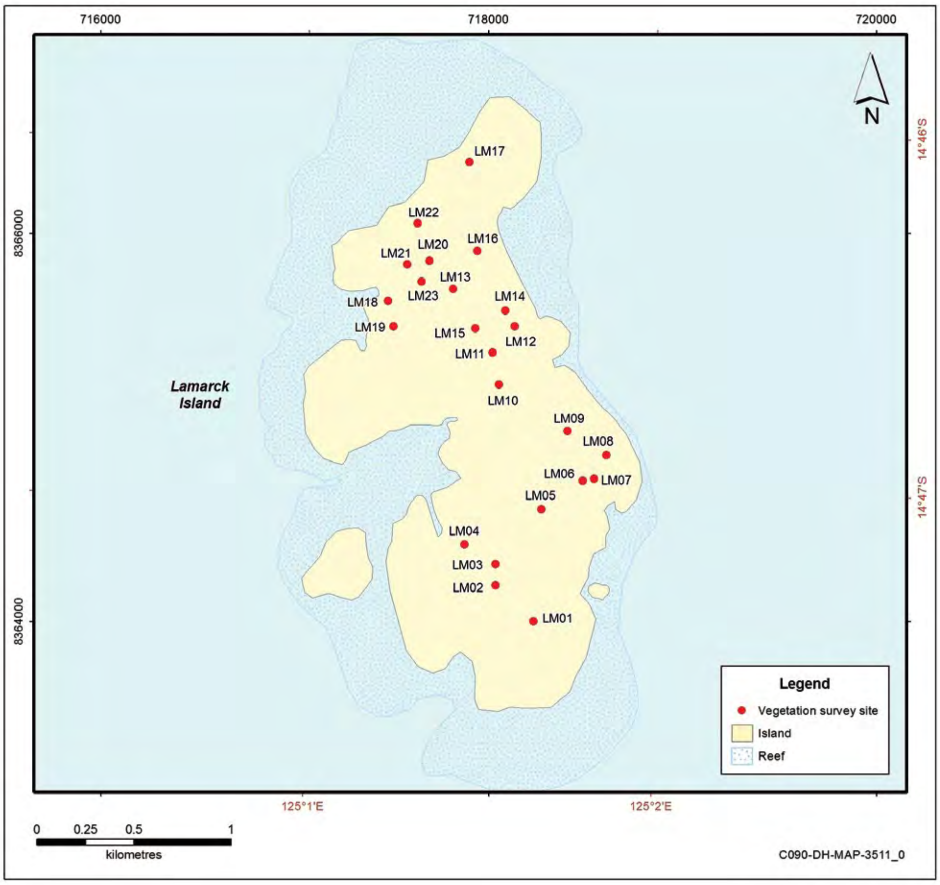


Figure 3-6: Flora and vegetation sampling sites on Lamarck Island

TERRESTRIAL FLORA

2. *The reconnaissance survey*. During the June–August 2006 reconnaissance surveys, seven islands were visited: North Maret Island, South Maret Island, Berthier Island, Turbin Island, Albert Island[1], East Montalivet Island and Walker Island. Of these, four were chosen for the detailed survey work: North Maret Island and South Maret Island because they were the proposed sites for the development of the Ichthys Project's onshore processing plant, and Berthier Island and East Montalivet Island because of their geological and landform similarities to the Maret Islands. West Montalivet Island was later added to this group. As time and access to the islands were both constrained, it was determined that a reconnaissance survey to Lamarck Island would not be practicable. For these reasons, proposed survey sites on Lamarck Island were chosen from high-resolution aerial photography.
3. *The detailed survey*. A detailed survey involves surveying both the locality and parts of the local area at the same intensity, over a longer term and with several visits. After the reconnaissance surveys, an initial Level 1 survey was carried out on the Maret Islands in September and October 2006 on sites proposed for geotechnical drilling, in support of a vegetation-clearing permit application. This survey was hampered by the desiccated state of the vegetation in the late dry season but was later supplemented by information collected during the early wet season.

   The Level 2 survey in March–April 2007 constituted the wet-season component of the survey. The rains associated with Cyclone George in February 2007 were considered sufficient to extend the wet season through to April of that year. All of the permanent quadrats were revisited and resurveyed in May 2007, in the early dry season. At this time, additional quadrats were established on West Montalivet Island and Berthier Island. West Montalivet Island was originally excluded from the survey plan because it is primarily of sandstone geology. However, the island does have two small lateritic plateaux and it was added to the survey as progress on the surveys on East Montalivet Island was faster than expected. The quadrats on West Montalivet Island and the extra quadrats on Berthier Island, however, were only visited once in the early dry season.

Flora

A list of the plant taxa registered with the Western Australian Herbarium for the Maret Islands was compiled from the herbarium's FloraBase database (DEC 2007). This was examined before the surveys began in order to familiarise the team with the plant species expected to be found.

[1] Albert Island is the unofficial name used during this study for the largest island of the Albert Islands group.

This list represented an incomplete collection of the Maret Island flora from collections made from opportunistic surveys.

A search of FloraBase revealed one known Priority species from the Maret Islands: *Pittosporum moluccanum* (P4). This shrub or small tree to 6 m was previously known from only 10 collections in Western Australia.

Quantitative surveys

After the reconnaissance surveys of the Maret Islands, Berthier Island, East Montalivet Island and West Montalivet Island in 2006 and in discussion with the Department of Environment and Conservation, it was decided that the survey methods would be tailored to the different vegetation structures.

Vegetation on the plateaux of the islands was generally open enough to allow the placement of quadrats. However, the vine thicket on the slopes and much of the vine thicket – *Corymbia* woodland association across the plateau of South Maret Island was far too dense to establish quadrats without substantial clearing.

It was decided, in consultation with Mr Greg Keighery, Principal Research Scientist, Department of Environment and Conservation, Perth, and Prof. Kevin Kenneally, AM, Centre for Regional Development, University of Western Australia, Perth, to use 50 m × 50 m quadrats on the plateaux of the islands where possible and 50 m × 10 m transects in vine-thicket vegetation.

Permanent 50 m × 50 m quadrats were established and marked out with tape measures to facilitate quantitative estimates of the cover of various plants within each quadrat. Global positioning system (GPS) coordinates[2] for the north-west corner of each quadrat are given in Table 3-2 (North Maret Island), Table 3-3 (South Maret Island), Table 3-4 (Berthier Island), Table 3-5 (East Montalivet Island) and Table 3-6 (Lamarck Island).

No quadrats were established on West Montalivet Island as the entire island was not surveyed. Units have been extrapolated from quadrat and transect data on aerial photography for those areas mapped, but their exact extent has not been ground-truthed.

A description of the vegetation within each quadrat is provided in Table 3-13. The quadrats were marked at each corner with a stainless-steel pin and at the north-west corner with an aluminium fence dropper.

[2] Coordinates provided relative to the World Geodetic System 1984 (WGS84), utilised by the global positioning system (GPS), have been referenced in this text as relative to the Geocentric Datum of Australia 1994 (GDA94) to provide a consistent coordinate reference system (CRS) throughout this volume. For all practical purposes, GDA94 coordinates can be considered to be coincident with those of WGS84.

Table 3-2: Survey-site coordinates—North Maret Island

Type	Quadrat or transect	Easting	Northing
Quadrats	NM01	713388	8408012
	NM02	713980	8407662
	NM03	713577	8406942
	NM04	713288	8406692
	NM05	713450	8407010
	NM06	711636	8407212
	NM07	712088	8407442
	NM08	712371	8407341
	NM09	712559	8407615
	NM10	712814	8407738
	NM11	712610	8498096
	NM12	712604	8408354
	NM13	712845	8408180
	NM14	713035	8408262
	NM15	713013	8408550
	NM16	713158	8408391
	NM17	713300	8407880
	NM18	713445	8407461
	NM19	713735	8407442
	NM20	713992	8406929
	NM21	713977	8407220
	NM22	713097	8406336
	NM23	713091	8406139
	NM24	713357	8406065
	NM25	713485	8406015
	NM26	712932	8405996
	NM27	713202	8405583
	NM28	713421	8405408
	NM29	713528	8405170
	NM30	713771	8404724
	NM31	713637	8404997
Transects	NMR01	713177	8406857
	NMR02	713178	8407484
	NMR03	712858	8407520
	NMR04	713469	8406403

Table 3-3: Survey-site coordinates—South Maret Island

Type	Quadrat or transect	Easting	Northing
Quadrats	SM01	713158	8401234
	SM02	713109	8401339
	SM03	713385	8401510
	SM04	713487	8401916
	SM05	713601	8401840
	SM06	713803	8402027
	SM07	713951	8401951
	SM08	713021	8403293
	SM09	714449	8402117
	SM10	714720	8402072
	SM11	713578	8402384
	SM12	713789	8402435
	SM13	713360	8402991
	SM14	712884	8402989
	SM15	713720	8403119
	SM16	713226	8403254
	SM17	713085	8403145
	SM18	713057	8402958
	SM19	713764	8402253
Transects	SMR01	713972	8403883
	SMR02	713859	8403731
	SMR03	713682	8403592
	SMR04	713916	8403620
	SMR05	713982	8403731
	SMR06	713548	8402186
	SMR07	713759	8403168
	SMR08	713720	8401630
	SMR09	714060	8401817
	SMR10	714542	8401877
	SMR11	714795	8402561
	SMR13	714586	8403214
	SMR14	714440	8403348
	SMR15	714662	8402662
	SMR16	714600	8402510
	SMR17	714366	8403044
	SMR18	714577	8403054
	SMR19	713767	8402255
	SMR21	714498	8403268
	SMR22	714613	8403197
	SMR23	714042	8403742

Table 3-4: Survey-site coordinates—Berthier Island

Type	Quadrat or transect	Easting	Northing
Quadrats	BR01	713419	8393625
	BR02	713819	8393120
	BR03	713567	8393598
	BR04	713789	8394122
	BR05	714309	8393890
	BR06	714323	8393742
	BR07	714693	8394226
	BR08	714897	8395120
	BR08A	714790	8394432
	BR09	714935	8394100
	BR10	715011	8394208
	BR12	714577	8396648
	BR13	714533	8396849
	BR14	714532	8397444
Transects	BRR01	713622	8393816
	BRR02	713700	8394372
	BRR07	714643	8397408
	BRR08	714499	8397460
	BRR09	714415	8396146
	BRR10	714265	8390674
	BRR11	714889	8395896
	BRR15	714575	8397310

Table 3-5: Survey-site coordinates—East Montalivet Island

Type	Quadrat or transect	Easting	Northing
Quadrats	EM01	747746	8420218
	EM02	748012	8402180
	EM03	748202	8420214
	EM04	747938	8419182
	EM05	747336	8419267
Transects	EMR01	748345	8419986
	EMR02	747627	8419846
	EMR03	748071	8419984

Table 3-6: Survey-site coordinates—Lamarck Island

Type	Quadrat or transect	Easting	Northing
Quadrats	LM01	718232	8363993
	LM02	718036	8364178
	LM03	718035	8364289
	LM04	717874	8364389
	LM05	718271	8364570
	LM06	718486	8364717
	LM07	718544	8364728
	LM08	718608	8364849
	LM09	718106	8365290
	LM10	718053	8365214
	LM11	718021	8365379
	LM12	718135	8365514
	LM13	717817	8365707
	LM14	718085	8365593
	LM15	717931	8365502
	LM16	717942	8365902
	LM17	717900	8366359
	LM18	717482	8365646
	LM19	717509	8365514
	LM20	717696	8365852
	LM21	717580	8365833
	LM22	717634	8366043
	LM23	717655	8365743

As the vegetation in vine thickets was surveyed using transects instead of quadrats, less emphasis was placed on percentage cover values. The species diversity of the thickets obscured the patterns of structural dominance and made estimating cover values problematic. Instead, descriptions were based on the species present, their heights, and their perceived structural and floristic dominance.

All specimens were labelled and pressed in the field. After collection, they were kept in air-conditioned surroundings (at approximately 20 °C) to prevent the development of destructive fungal moulds under the humid ambient conditions.

Pressed specimens were air-dried. Once dry, they were sorted into broad taxonomic groups before the detailed identification process commenced. Various taxonomic keys, floras and collections at the Western Australian Herbarium were used to identify the specimens.

Lamarck Island

The Level 2 survey of Lamarck Island conducted in October 2007 made up the dry-season component of the required two-part survey. Twenty-three permanent quadrats were established in broad-scale vegetation units identified from aerial photography. Each 50 m × 50 m quadrat was marked permanently in the north-west corner and a GPS location to an accuracy of within 5 m was recorded.

The information recorded for each quadrat included the following:

- a photograph
- a list of the species present, including their height and density
- a description of the landform, aspect and soil
- an estimate of the ratio of bare ground to litter
- an assessment of the condition of the vegetation
- the structure of the vegetation.

Specimens of all plants were collected under permits issued by the Department of Environment and Conservation and were pressed, dried and labelled according to Western Australian Herbarium procedures. Within established quadrats, all species were either identified in the field or collected and referred back to by the original collection number. Species were identified by comparing them with specimens held in the herbarium, by using appropriate keys and floras, and by consulting experts. Representative specimens of all species collected have been lodged with the Western Australian Herbarium.

Vegetation structural classes were assigned to vegetation units using the scale outlined in Western Australia's "Bush Forever" plan (DEP 2000) as shown in Table 3-8 below. Vegetation was mapped from high-resolution aerial photography along with ground-truthed survey data.

Data analysis

Multivariate analyses were used to determine statistical dissimilarities between sites in terms of the flora presence-or-absence data from the quadrats and transects. Dissimilarity scores were used to separate or combine the various quadrats into vegetation units for mapping.

Several modules of the pattern analysis software package PATN[3] (Belbin 1987) were used for the analyses.

The PATN modules used were ASO (calculation of similarity matrix), FUSE (classification based on the results of ASO), DEND (representation of classification), NNB (determination of sites most similar to each site—"nearest neighbours") and SSH MDS (semi-strong hybrid multidimensional scaling analysis, a form of ordination to show the relationships of sites to the whole data set).

Unlike other dissimilarity measures (for example the Bray–Curtis coefficient), SSH MDS is able to provide a measure of "ecological distance" between sites when there are few or no common species (Belbin 1991), as was expected to occur between grassland and vine-thicket sites, the two extremes of the sites sampled during this study.

[3] PATN is a software package developed in Australia by L. Belbin and the CSIRO for extracting and displaying patterns in any type of complex (multivariate) data. It is used in fields such as botany, chemistry, ecology, fisheries management and genetics.

Floristic analyses

Floristic analyses were carried out to provide classification to assist in the recognition of plant communities under study on several Kimberley islands.

The data for the 108 sites used were reviewed for consistency of nomenclature. Table 3-7 lists the reconciliations required to run the classification.

Table 3-7: Species reconciliation for analysis

Species	Lookup
Riccia sp. (liverwort)	omitted
Eriachne sp.	omitted
Paspalidium sp.	omitted
Bulbostylis sp.	omitted
Fimbristylis sp.	omitted
Ficus sp.	omitted
Amyema sanguinea var. *sanguinea*	*Amyema sanguinea*
Amyema sp.	omitted
Gomphrena canescens subsp. *canescens*	*Gomphrena canescens*
Gomphrena sp.	omitted
Ptilotus polystachyus var. *longistachyus*	*Ptilotus polystachyus*
Ptilotus polystachyus var. *polystachyus*	*Ptilotus polystachyus*
Ptilotus sp.	omitted
Portulaca sp.	omitted
Pittosporum phillyreoides	*Pittosporum moluccanum*
Cajanus sp.	omitted
Crotalaria montana var. *angustifolia*	*Crotalaria montana*
Crotalaria sp.	omitted
Indigofera monophylla	*Indigofera linifolia*
Indigofera sp.	omitted
Rhynchosia minima var. *australis*	*Rhynchosia minima*
Rhynchosia sp.	*Rhynchosia minima*
Euphorbia sp.	omitted
Triumfetta sp.	omitted
Hibiscus sp.	omitted
Terminalia sp.	omitted
Corymbia sp.	omitted
Eucalyptus polycarpa	*Corymbia polycarpa*
Marsdenia sp.	omitted
Bonamia sp.	omitted
Evolvulus alsinoides var. *decumbens*	*Evolvulus alsinoides*
Ipomoea sp.	omitted

(continued overleaf)

Table 3-7: Species reconciliation for analysis (continued)

Species	Lookup
Heliotropium cunninghamii	*Heliotropium cunninghamii* complex
Heliotropium glabellum	*Heliotropium glabellum* complex
Heliotropium sp.	omitted
Buchnera sp.	omitted
Spermacoce sp.	omitted

The assembled data were run as one data set, with the species being considered as either present or absent from a site. Presence or absence has been proved to be appropriate for assessing the regional nature of the variation in site composition of quadrat data in earlier analyses of Pilbara Bioregion data. Data that include the cover of species at sites tend to be more useful when analysing data sets from smaller areas.

PATN analysis

As noted above, the modules used for the PATN analysis were ASO, FUSE, DEND, NNB and SSH MDS. The default parameter settings were used. The results of the analyses were imported into a database so that site characteristics could be joined with the groups formed in the analysis.

For the data set the modules were run twice:

- with "sites" as the classified objects (i.e. with the species as the attributes)
- with "species" as the classified objects (i.e. with the sites as the attributes).

In this way both site and species groups were generated. The whole data matrix could then be presented with the rows being ordered by the species groupings and the columns ordered by the site groupings. This provided a way of inspecting how well the data conformed with the classifications. Most of the interpretation was made from the classification of sites. The species groups were used to support the interpretations more than to identify species that might have been expected to occur in similar habitats.

The way the classified rows (sites or species in the respective data sets) fuse can be represented in a dendrogram. This can be used to construct groups of rows by "cutting" at a particular value or cutting to obtain a particular number of groups. For the purpose of this study, three "cuts" were made for the sites to form "Group 10", "Group 20" and "Group 40" classifications and for the species to form "Group 20", "Group 40" and "Group 80" classifications. While these are arbitrary, they provide an opportunity to make interpretations of the nature of the classification.

In addition to the classifications described above, an ordination of the site and species data was carried out using the SSH MDS module of the PATN package (Belbin 1987). This was performed to diagrammatically present some of the relationships between sites. Commonly, there is too much variation in the data sets to allow useful interpretations to be made using this technique. However, interpretation from this analysis suggested that in this case it was useful to some degree.

The results were imported into a Microsoft Access database where they were joined and summarised with Access queries. Key portions were exported to a Microsoft Excel database in which the two-way table was formatted for easier visualisation and charts of ordination distributions were constructed.

Some of the functions of the PATN software package

The PATN package provides a suite of useful techniques that have been developed over a number of years (Belbin 1987). These have involved significant investigations of the robustness of techniques and appropriateness of use (e.g. Faith, Minchin & Belbin 1987). PATN is a PC-based graphical interface which runs on Windows operating systems.

The options available in this package are wide. However, there is a commonly used set which, through the extensive research of the developers of PATN, is recognised to be reasonably robust. The set was used by Gibson et al. (1994) and Weston, Griffin and Trudgen (1993) and was used in this analysis partly because of the desire to follow the same methodology.

Classification

Many mathematical methods have been developed to group (classify) abstract (floristic) units. Some of these attempt to identify discriminating attributes (species) that might be used as if in a dichotomous key to define progressively (and hierarchically) more and more homogeneous (floristic) units. Typically, these are called divisive classifications and may use one (monothetic) or a number (polythetic) of attributes (species) in each division. This tends to not be favoured for species-rich vegetation with low numbers of dominant species.

Other classifications tend to start from the object (or site) and aggregate these with the most similar objects. Fundamental to the technique is the association matrix that describes how similar each object (or site) is to each other object (or site). Similarity between pairs of objects is a function of the attributes (species) they share and the attributes (species) they do not share. It may also include or ignore abundance measures (cover, biomass, frequency scores for species). Different formulas have been found to emphasise different characteristics of the data that might, therefore, be useful in different situations. It is implicit that the formula should generate a similarity coefficient that reflects "ecological distances". Detailed studies of the robustness and suitability of these methods are numerous (e.g. Faith, Minchin & Belbin 1987).

The association matrix (or at least an association coefficient) is just the first step in agglomerative techniques. There are as many methods of agglomerating as there are methods for calculating similarity coefficients. Two basic systems are used: hierarchical and non-hierarchical.

Hierarchical agglomeration techniques progressively create fewer and fewer abstract groups of objects until all are grouped into one. The groups take on the "combined" attributes of the objects. These new groups by definition become more and more heterogeneous as new objects are joined. Once an object joins a group, it remains with it until there is just one group of all sites.

Non-hierarchical methods attempt to divide up ecological space by identifying nodes or areas of concentrations of objects, effectively by using a series of cookie cutters. One such technique involves many iterations to "place" the cookie cutters in such a way as to achieve an "optimal solution". Different sizes of cookie cutters imply different degrees of similarity. While there might be an expectation that objects grouped together at a certain similarity will stay together when the similarity is widened (to include objects that are less similar), this need not be the case—hence its being described as non-hierarchical.

Ordination

Implicit in any ordination technique, and there are many, is that a coefficient can be calculated to represent the ecological distance between objects. The variation between objects can be represented in multidimensional space. This abstract space is defined to have $n - 1$ axes where n is the number of objects. Also implicit is that the distribution of objects in this space is not random and therefore optimum solutions can be computed which show that many of the differences can be represented on just a few axes.

This technique is particularly useful in attempting to describe the influence of environmental variables. However it has difficulty in representing relationships between data sets that contain objects that have little or nothing in common.

Main programs

For each data set, ASO created a symmetric association matrix, made up of pair-wise calculations of similarity "distance". The "distance" was 1 minus the Czekanowski coefficient, that is, the number of species in common divided by the average number of species in the two sites being compared. The more similar the sites, the smaller the distance. This can therefore vary, from 0 for absolutely identical, to 1 for absolutely different. The latter is a very common occurrence but the former is very rare, except in very simple communities with just a few species. In moderately rich shrub communities, sites from the same stand have values ranging from about 0.25 to 0.4.

Just as the sites can be grouped according to the similarity of their species composition, so too can the species be grouped according to the number of sites in which they occur. To do so, the data matrix was transposed (i.e. the species in rows and the sites in columns). A big difference in classifying species is how a sensible similarity coefficient is calculated, between a species that, for example, occurs at very few sites, and one that occurs at most. This stretches the meaning of the "average" number of species that is used in the numerator of the Czekanowski coefficient.

TWOSTEP is an alternative method that attempts to generate a more "sensible" measure of similarity. This was used in the current analysis, following Gibson et al. (1994). Once the association matrix had been generated, the same routines used for the sites were performed.

Using each of these matrices, the routine FUSE classified the sites, using the "unweighted pair-group mean average" fusion method. This hierarchical, agglomerative classification "fuses" the most similar sites first in such a way that all sites (by definition) are eventually fused together. FUSE both determines the fusion order and calculates a measure of the distance between the sites (or groups of sites).

Since the group "average" calculation is influenced by its contributing sites, it needs to be appreciated that the addition or subtraction of sites from the data set will change the overall fusion. Some of the fusion strategies tend to create groups of odd sites (ones with little in common), especially if there are many similar sites in other groups.

DEND (representation of classification) provides a one-dimensional, graphic (dendritic or tree) representation of the fusions. Within a "branch", the site sequence is arbitrary, and sites can be swapped and branches can be rotated as long as no branches cross. The greater the distance (along a branch) between junctions, the more distinct the fusing components are from each other. Belonging to a branch implies a relative affinity. However, care must be taken in assigning meaning to higher-order branches, since these fusions can often be arbitrary. This is particularly the case where the data set is highly heterogeneous, and these branches (groups of sites) may have almost nothing in common.

A number of summary routines were used to assist in the interpretation. GDF provides group membership from the output of FUSE for a user-defined number of groups. NNB provides from the association matrix a list of "nearest neighbours" for each site.

SSH MDS is a general-purpose multidimensional scaling algorithm. This group of techniques is believed to be the most robust form of ordination available and the algorithm available in PATN has been shown to be superior to a wide range of other ordination methods, such as principal components or coordinates, reciprocal averaging and detrended correspondence analysis.

Limitations of floristic analyses

The results are a presentation—a view—of the data structure. The classifications have been prepared to provide a basis for interpreting variation in site floristic composition. The absolute composition of groups, as defined by these analyses, should not be interpreted as real communities. A process of review and refinement aided by field knowledge is required. This has not been done as part of the present study.

Vegetation descriptions and units

Mapping

Vegetation community maps were drawn from aerial photographs of the Maret Islands and the reference islands. Polygons were drawn around visible vegetation boundaries and these were then classified according to ground-truthed data and the results of the multivariate community analyses.

Descriptions of the vegetation at each site, by island, were compiled and sorted by dominant floristics and structural categories to provide groups of similar vegetation. These groupings were examined for further significant differences, and descriptions of each were combined into a unit that attempted to cover the variation present, including the major floristic and structural elements. The dendrogram produced as part of the PATN analysis and the dissimilarity coefficients produced as part of the "nearest neighbour" analysis were used in this process.

Parentheses were used in the unit descriptions to indicate a qualifying term for occasional variants to the main unit description. For example "(low) shrubland" indicates that within the category of "shrubland" there are areas of vegetation that would more accurately be described as "low shrubland" but that they are not sufficiently different to justify creating a separate unit.

Vegetation structural classes

Field survey data were recorded in accordance with existing structural classes (Table 3-8) with minor modifications. Taxa covering areas greater than 2% of each quadrat were included in the description of each unit. Occasionally, a taxon with a lesser coverage was included in combination with another to provide a more rounded description; however, this was avoided where possible as it creates unwieldy unit descriptions, especially in the vine thickets. The 2% level was chosen as a cut-off point as species present below this density are considered to be "scattered" and have little influence on vegetation structure.

Table 3-8: Vegetation structural classes (layers)*

Life form and height class	Canopy cover			
	100%–70%	70%–30%	30%–10%	10%–2%
Trees >30 m	Tall closed forest	Tall open forest	Tall woodland	Tall open woodland
Trees 10–30 m	Closed forest	Open forest	Woodland	Open woodland
Trees <10 m	Low closed forest	Low open forest	Low woodland	Low open woodland
Tree mallee	Closed tree mallee	Tree mallee	Open tree mallee	Very open tree mallee
Shrub mallee	Closed shrub mallee	Shrub mallee	Open shrub mallee	Very open shrub mallee
Shrubs >2 m	Closed tall scrub	Tall open scrub	Tall shrubland	Tall open shrubland
Shrubs 1–2 m	Closed heath	Open heath	Shrubland	Open shrubland
Shrubs <1 m	Closed low heath	Open low heath	Low shrubland	Low open shrubland
Grasses	Closed grassland	Grassland	Open grassland	Very open grassland
Herbs	Closed herbland	Herbland	Open herbland	Very open herbland
Sedges	Closed sedgeland	Sedgeland	Open sedgeland	Very open sedgeland

* These vegetation structural classes are the ones defined and used in Western Australia's "Bush Forever" plan (DEP 2000, p. 46 (Table 11) and p. 493) to describe vegetation in Bush Forever sites.

Assessment of conservation significance

In Australia, the conservation status of plant species and communities is addressed under both Commonwealth and state legislation. Thus, in Western Australia threatened species and threatened ecological communities requiring special protection are listed under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (the EPBC Act) and the *Wildlife Conservation Act 1950* (WA). Other categories of conservation significance include taxa listed by Western Australia's Department of Environment and Conservation as Priority Flora species and others that have been identified in this study as requiring special attention.

Criterion 2 of the Commonwealth guidelines for listing ecological communities under the EPBC Act and Regulations uses a total area of occupancy of 1000 ha or less as an indicative threshold for identifying terrestrial vegetation communities with small distributions as "very restricted" (TSSC undated).

As the Maret Islands are in total less than 1000 ha in area, this criterion would classify all vegetation units mapped as "very restricted". However, it is clear that categorising units of less than 1000 ha in this way implies that the study scale is greater than that covered by the current survey, possibly more of a regional size. As this survey was not conducted on a regional scale the vegetation was studied in finer detail, hence the number of much smaller vegetation units.

When measuring total areas of mapped units on the Maret Islands, there is an apparent division in sizes. The majority of units cover either less than 10 ha or more than 20 ha with only three units in between these sizes. For this reason it was decided to concentrate on the units that cover less than 10 ha as "significant", owing to their limited distribution on the islands.

Three levels of conservation significance[4] are recognised in this report:

Conservation significance 1

This category includes species or communities listed as Declared Rare Flora or as "threatened ecological communities". Plant taxa listed as Declared Rare Flora under the *Wildlife Conservation Act 1950* (WA) or the EPBC Act are species that have been identified as being under threat of extinction or otherwise in need of special protection. They are listed in the *Wildlife Conservation (Rare Flora) Notice 2006(2)* (Government of Western Australia 2006). "Threatened ecological communities" are listed under state or Commonwealth Acts.

Conservation significance 2

This category includes species or infraspecific taxa that may be rare or threatened but that have not been sufficiently well surveyed for a decision to be made to have them listed as Declared Rare Flora. New species known only from the current survey and limited in areal extent are considered likely to be Priority Flora. The Department of Environment and Conservation maintains a list of Priority Flora species (see Table 3-1).

Conservation significance 3

This category includes species or infraspecific taxa not listed under the Western Australian or Commonwealth Acts or in publications, but which are of conservation value for reasons consistent with the intent of the EPA's Guidance Statement 51 (EPA 2004).

[4] Note: the definitions of these three levels of conservation significance (for any possibly undescribed or genetically distinct species-group taxon collected on the survey) were developed by the RPS scientific team in recognition of the published conservation status of previously named species of plants and animals, the perceived ecological importance of the taxon, the rarity of the taxon in the study area and the likelihood of it being part of a genetically distinct and localised population.

These include the following:

- taxa that are potentially new or unrecognised
- taxa with distributions known to be restricted
- taxa with significant range extensions
- taxa that have been poorly collected
- taxa that are new records for Western Australia.

Also included in this category are vegetation units considered significant because they have only limited representation in the survey area, with a combined area of less than 10 ha.

Limitations

Repeatability

Vine-thicket surveys were not repeatable as the dense vegetation made the definition of transect boundaries extremely difficult. This contrasts with the quadrats set out on the plateaux of the islands where boundaries were defined more easily. The approach in this study is consistent with accepted survey methods.

This is not considered to have had a significant effect on the quality of the data collected as particular care was taken to survey the vine thickets with thoroughness.

Timing considerations

Targeted surveys were conducted throughout the main growing seasons to ensure that ephemeral plants were collected and also to ensure that different flowering periods were represented. Despite this, some species might not have been present or identifiable at the times of the surveys, for example species which flower outside the main growing season, or which do not flower every year, or which are not identifiable or even visible except for short periods before, during and after flowering. Some species flower more, or will flower only for a few seasons after a fire.

The survey on Lamarck Island was conducted during the late part of the dry season. No ephemerals were collected and very few species were in flower at the time of the survey. A complete Level 2 vegetation assessment requires at least one survey during the main flowering season with a follow-up survey in an out-of-season flowering period. This requirement is usually met in the Kimberley region by surveying during the wet and dry seasons. The Lamarck Island species list should therefore be taken as an incomplete inventory of the flora of the island as no wet-season survey was carried out.

In spite of the incompleteness of the Lamarck Island data, the species list presented in Table 3-10 for the six islands may be regarded as relatively comprehensive in respect of the sites where collections were made. It is estimated that more than 90% of the species present on the islands have been collected and identified.

Survey accuracy

Representative areas of vegetation were systematically sampled by means of quadrats and transects. Other areas of interest were surveyed opportunistically. Despite attempting to cover all of the vegetation types, the species lists will be incomplete to some degree, particularly on the reference islands.

The vegetation map was based on interpretation of aerial photography combined with analyses of the field-survey data. Extrapolation from survey sites to other areas that appear similar on the aerial photography always engenders a level of uncertainty in classification accuracy. The vegetation maps of the Maret Islands have been ground-truthed by walking them several times, with the one exception being the area behind Brunei Bay Beach on North Maret Island (Figure 3-1) for Aboriginal cultural reasons (see below).

Access difficulty

The difficulty of access into some sections of the survey area placed additional restrictions on the coverage of the surveys. This was in part addressed by extensive foot traverses, although in very dense vegetation even this was difficult. For safety reasons, most vegetation on cliff edges had to be surveyed from a boat using binoculars.

The part of Brunei Bay Beach behind the foredune was not surveyed as this area possesses Aboriginal cultural heritage significance.

Taxonomic constraints

Some specimens could not be identified to genus or species level because of a lack of taxonomic features in juvenile or sterile specimens. Where these specimens are referred to in the text of this document, they may be described by family (e.g. “Apocynaceae sp. ‘A’”), by genus (e.g. “*Spermacoce* sp. ‘Blue’”), or include qualifications such as “?” (e.g. “*Helicteres ?rhynchocarpa*”) or “aff.” (e.g. “*Tephrosia* sp. aff. *rosea*”).

The relative lack of detailed and systematic study of the taxonomy of the Kimberley flora has led to some plant groups, for example of the genus *Corymbia*, not being well defined (Prof. Kevin Kenneally, AM, Centre for Regional Development, University of Western Australia, pers. comm. August 2007), and some taxa are known only from a few specimens. Future work may result in revisions of some of the species names used in this study.

Fungi, slime moulds, lichen and algae were sampled opportunistically. However, the lack of taxonomists specialising in lichen and algae precluded identification of these two groups to a level suitable for inclusion in this chapter.

Reference islands

The vegetation maps for Berthier Island and the Montalivet Islands are necessarily incomplete, as these islands were not fully surveyed. Units have been extrapolated from quadrat and transect data for those areas mapped, but their exact extent has not been ground-truthed. The maps should therefore be considered to be provisional only.

In the absence of a reconnaissance trip to Lamarck Island, survey sites there were selected on the basis of observations in the field and by analysing high-resolution aerial photography. For this reason, and as a consequence of access and time constraints during the survey, two of the island's vegetation units, TmG (*Triodia microstachya* grassland) and UVU (undescribed vegetation unit), were recognised only during data analysis and were therefore not adequately surveyed in the first part of this survey.

Additional sites

Extra, unplanned, sites were surveyed on West Montalivet Island and Berthier Island. Because these sites were visited only once, the data obtained can be considered provisional only. The information has proved useful for comparative purposes, however, and has therefore been included in analyses and as part of this report.

RESULTS

A total of 334 species from 67 families were collected across all survey locations. Berthier Island was the most species-rich of the islands sampled, with 208 species located, while East Montalivet Island was the least species-rich of the islands where the surveys were completed, with only 142 species sampled[5] (Table 3-9).

Table 3-9: Summary table of the number of species found at each island

Island	Number of species
North Maret	162
South Maret	185
Berthier	208
East Montalivet	142
West Montalivet	121
Lamarck	140

Two fern species (from 1 family), 44 monocotyledon species (from 9 families) and 288 dicotyledon taxa (from 57 families) were identified during the surveys (Table 3-10). Tree and shrub species were most numerous (143 species) followed by herbaceous plants (93 species).

Forty-seven taxa were found at all six of the islands sampled, while 123 taxa were only found at a single island.

[5] Fewer species were found on West Montalivet Island and Lamarck Island because only one survey was carried out on each, and in the case of Lamarck Island the survey was carried out in the late dry season.

Table 3-10: Flora species inventory for the six islands surveyed (RPS 2007, 2008)

Family	Species	Life form	Distribution
FERNS			
Pteridaceae	*Cheilanthes caudata*	Perennial herb	BER, EMI
	Cheilanthes contigua	Perennial herb	BER
MONOCOTYLEDONS			
Pandanaceae	*Pandanus spiralis*	Tree	NMI, SMI, BER, LAM
Poaceae	*Bothriochloa ewartiana*	Grass	BER
	Cenchrus elymoides var. *elymoides*	Grass	NMI, SMI, BER, EMI, LAM
	Cenchrus elymoides var. *brevisetosus* (now *Cenchrus brevisetosus*)	Grass	NMI, SMI, BER, EMI, LAM
	Chrysopogon fallax	Grass	BER
	Cymbopogon procerus	Grass	LAM
	Enneapogon pallidus	Grass	NMI, SMI, BER
	Enneapogon purpurascens	Grass	SMI
	Eragrostis ?spartinoides (SM13-16)	Grass	SMI
	Eragrostis cumingii	Grass	NMI
	Eriachne avenacea	Grass	NMI, SMI, BER, EMI
	Eriachne burkittii	Grass	EMI
	Eriachne ciliata	Grass	NMI, SMI, BER, EMI, WMI, LAM
	Eriachne pauciflora	Grass	SMI, BER, EMI
	Eriachne sulcata	Grass	SMI, LAM
	Heteropogon contortus	Grass	NMI, SMI, WMI
	Leptochloa fusca	Grass	BER
	Mnesithea formosa	Grass	NMI, SMI, BER, EMI
	Paspalidium rarum	Grass	NMI
	Schizachyrium fragile	Grass	LAM
	Sehima nervosum	Grass	SMI, BER, WMI
	Sorghum amplum	Grass	EMI
	Sorghum plumosum	Grass	WMI
	Sorghum timorense	Grass	NMI, SMI, BER, EMI, WMI, LAM
	Spinifex longifolius	Grass	NMI, SMI, BER, EMI, WMI, LAM
	Sporobolus virginicus	Grass	SMI, LAM
	Triodia bynoei	Grass	NMI, SMI, BER, EMI, WMI, LAM
	Triodia microstachya	Grass	NMI, WMI, LAM
	Yakirra pauciflora	Grass	BER, EMI, WMI
Cyperaceae	*Bulbostylis barbata*	Sedge	NMI, SMI, WMI, LAM
	Fimbristylis cymosa	Sedge	NMI
	Fimbristylis sp. "E"	Sedge	EMI
	Fimbristylis trigastrocarya	Sedge	NMI, SMI, WMI
	Fuirena ciliaris	Sedge	LAM
	Scleria brownii	Sedge	SMI, BER, WMI
Flagellariaceae	*Flagellaria indica*	Climber or herb	NMI, SMI, BER, EMI, WMI, LAM
Commelinaceae	*Cartonema spicatum*	Herb	LAM
	Commelina ensifolia	Herb	NMI, SMI, BER, EMI, WMI, LAM
Asparagaceae	*Asparagus racemosus*	Climber	NMI, SMI, BER, EMI, WMI, LAM
Amaryllidaceae	*Crinum angustifolium*	Herb	NMI, SMI, BER, EMI
Taccaceae	*Tacca leontopetaloides*	Herb	NMI, SMI, BER, EMI, LAM
	Tacca maculata	Herb	EMI
Dioscoreaceae	*Dioscorea bulbifera*	Climber	NMI, SMI, BER
	Dioscorea transversa	Climber	SMI, BER, EMI

Notes: NMI = North Maret Island; SMI = South Maret Island; BER = Berthier Island; EMI = East Montalivet Island; WMI = West Montalivet Island; LAM = Lamarck Island.

The use of an asterisk (*) preceding a species name is a botanical convention indicating a taxon that is introduced or considered to be introduced.

Table 3-10: Flora species inventory for the six islands surveyed (RPS 2007, 2008) (continued)

Family	Species	Life form	Distribution
DICOTYLEDONS			
Cannabaceae	*Celtis philippensis*	Tree or shrub	NMI, SMI, BER, EMI, WMI, LAM
	Trema tomentosa	Tree or shrub	BER
Moraceae	*Fatoua pilosa* (now *Fatoua villosa*)	Herb	BER
	Ficus aculeata var. *aculeata*	Tree or shrub	NMI, SMI, BER, LAM
	Ficus aculeata var. *indecora*	Tree or shrub	NMI
	Ficus atricha	Tree or shrub	LAM
	Ficus brachypoda	Tree or shrub	LAM
	Ficus podocarpifolia	Shrub	LAM
	Ficus sp. aff. *podocarpifolia* (BOpp1)	Shrub	BER
	Ficus virens	Tree	SMI, LAM
	Trophis scandens (now *Malaisia scandens*)	Tree, shrub or climber	NMI, SMI, BER, EMI, WMI, LAM
Proteaceae	*Grevillea agrifolia*	Tree or shrub	WMI
	Grevillea heliosperma	Tree or shrub	BER
	Grevillea pyramidalis subsp. *pyramidalis*	Tree or shrub	NMI, SMI, BER, LAM
	Grevillea refracta subsp. *refracta*	Tree or shrub	WMI
	Hakea arborescens	Tree or shrub	EMI
Santalaceae	*Exocarpos latifolius*	Tree or shrub	NMI, SMI, BER, EMI, WMI, LAM
Opiliaceae	*Opilia amentacea*	Climber or shrub	LAM
Loranthaceae	*Amyema benthamii*	Mistletoe	NMI, SMI, BER, LAM
	Amyema sanguinea var. *sanguinea*	Mistletoe	NMI, SMI, BER, WMI
	Dendrophthoe acacioides subsp. *acacioides*	Mistletoe	LAM
	Lysiana subfalcata	Mistletoe	LAM
Chenopodiaceae	*Salsola tragus* (now = *S. australis* sensu lato)	Herb	NMI, SMI, BER, LAM
Amaranthaceae	*Achyranthes aspera*	Herb	NMI, SMI, BER, EMI, LAM
	Amaranthus pallidiflorus	Herb	SMI
	Gomphrena affinis	Herb	LAM
	Gomphrena canescens subsp. *canescens*	Herb	NMI, SMI, BER
	Gomphrena connata	Herb	EMI
	Gomphrena flaccida	Herb	NMI, SMI, BER, EMI
	Gomphrena parviflora	Herb	NMI, SMI, BER, EMI, WMI
	Gomphrena sp. Maret Islands (A.A. Mitchell 5414)	Herb	NMI, SMI, BER, WMI
	Ptilotus conicus	Herb	NMI, SMI, BER, EMI
	Ptilotus exaltatus	Herb	WMI
	Ptilotus fusiformis	Herb	NMI, BER
	Ptilotus polystachyus	Herb	NMI, SMI, BER, EMI, WMI, LAM
	**Pupalia micrantha*	Herb	SMI, BER, EMI, LAM
Nyctaginaceae	*Boerhavia dominii*	Herb	NMI, SMI, BER
	Boerhavia sp.	Herb	NMI, SMI, LAM
	Commicarpus chinensis subsp. *chinensis*	Perennial, climber or herb	SMI, BER
	Pisonia aculeata	Herb	NMI, SMI, BER, EMI

Table 3-10: Flora species inventory for the six islands surveyed (RPS 2007, 2008) (continued)

Family	Species	Life form	Distribution
Portulacaceae	*Calandrinia quadrivalvis*	Herb	NMI, SMI
	Calandrinia uniflora	Herb	NMI, SMI, BER, EMI
	Portulaca clavigera	Herb	NMI, SMI, BER
	Portulaca filifolia	Herb	NMI
	Portulaca sp. “River Mud” (R.L. Barrett 3285)	Herb	NMI, SMI, BER
Caryophyllaceae	*Polycarpaea involucrata*	Herb	NMI, SMI, BER
Menispermaceae	*Pachygone ovata*	Climber	NMI, SMI, BER, EMI
	Tinospora smilacina	Climber	NMI, SMI, BER, EMI, WMI, LAM
Annonaceae	*Polyalthia australis*	Tree	WMI
Lauraceae	*Cassytha candida*	Herbaceous climber	NMI, SMI, BER, EMI, WMI
	Cassytha capillaris	Herbaceous climber	NMI, SMI, EMI, LAM
	Cassytha filiformis	Herbaceous climber	NMI, SMI, BER, EMI, WMI, LAM
Hernandiaceae	*Gyrocarpus americanus* subsp. *americanus*	Tree	EMI, LAM
Capparaceae	*Cadaba capparoides*	Shrub	NMI, SMI, BER, EMI, WMI, LAM
	Capparis jacobsii	Shrub or tree	BER, LAM
	Capparis quiniflora	Climber, shrub or tree	BER, WMI
	Capparis sepiaria	Climber, shrub	NMI, SMI, BER, EMI, WMI, LAM
	Capparis spinosa var. *nummularia*	Shrub	NMI, SMI, BER
Cleomaceae	*Cleome viscosa*	Herb	SMI
	Cleome sp. Bonaparte Archipelago (A.A. Mitchell 4774)	Herb	NMI, SMI, BER, EMI, LAM
Pittosporaceae	*Pittosporum moluccanum* (P4)	Shrub or tree	NMI, SMI, BER
Fabaceae (subfamily Mimosoideae)	*Acacia deltoidea* subsp. *ampla* (P2)	Shrub	WMI
	Acacia deltoidea subsp. *deltoidea*	Shrub	LAM
	Acacia gonocarpa	Shrub or tree	LAM
	Acacia retinervis	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
	Acacia stigmatophylla	Shrub	NMI, SMI, BER
	Cathormion umbellatum subsp. *moniliforme*	Shrub or tree	SMI, BER
	Neptunia gracilis f. *gracilis*	Shrub	SMI, BER, EMI, WMI
	Vachellia pachyphloia subsp. *brevipinnula*	Shrub or tree	BER
Fabaceae (subfamily Caesalpinioideae)	*Bauhinia cunninghamii* (now *Lysiphyllum cunninghamii*)	Shrub or tree	BER
	Chamaecrista absus	Herb	NMI, SMI, BER, EMI
	**Chamaecrista nigricans*	Shrub	EMI
	Erythrophleum chlorostachys	Shrub or tree	LAM

Table 3-10: Flora species inventory for the six islands surveyed (RPS 2007, 2008) (continued)

Family	Species	Life form	Distribution
Fabaceae (subfamily Faboideae)	*Abrus precatorius*	Climber	NMI, SMI, BER, EMI, WMI, LAM
	Alysicarpus schomburgkii	Herb	NMI, SMI, BER, EMI
	Austrodolichos errabundus var. *errabundus*	Herb or climber	BER
	Cajanus acutifolius	Shrub	SMI, LAM
	Cajanus marmoratus	Herb	BER
	Cajanus pubescens	Shrub	EMI
	Canavalia papuana	Climber	NMI, LAM
	Canavalia rosea	Herb or climber	NMI, SMI, BER, EMI, WMI, LAM
	Christia australasica	Herb	SMI, BER, EMI, WMI
	Crotalaria medicaginea var. *neglecta*	Herb	SMI, BER, EMI
	Crotalaria montana var. *angustifolia*	Herb	NMI, SMI, BER, EMI
	Crotalaria retusa	Herb	BER
	Crotalaria verrucosa	Herb	BER
	Crotalaria sp. “White” (EM6-11)	Herb	EMI
	Cullen badocanum	Shrub	NMI, BER
	Cullen leucanthum	Shrub	EMI
	Desmodium filiforme	Herb	NMI, SMI, BER, EMI, WMI, LAM
	Galactia tenuiflora	Herb or climber	NMI, SMI, BER, EMI, WMI
	Glycine tomentella	Herb or climber	SMI, BER, EMI, WMI
	Indigastrum parviflorum	Herb	BER, EMI
	Indigofera colutea	Herb	SMI, BER, EMI
	Indigofera linifolia	Herb	NMI, SMI, BER, EMI, WMI
	Indigofera polygaloides	Herb	EMI, WMI
	Indigofera trifoliata	Herb	BER
	Mucuna diabolica subsp. *kenneallyi*	Climber	NMI, EMI
	Rhynchosia minima var. *australis*	Herb or climber	NMI, SMI, BER, EMI, WMI, LAM
	Tephrosia leptoclada	Herb	NMI, SMI, BER, EMI
	Tephrosia remotiflora	Shrub	BER
	Tephrosia rosea var. *rosea*	Shrub	NMI, SMI, BER, EMI, WMI, LAM
	Tephrosia sp. aff. *rosea* (BR1-R01)	Shrub	BER
	Tephrosia sp. aff. *stipuligera* (EM5-R09)	Herb or shrub	EMI
	Uraria cylindracea (now *U. lagopodioides*)	Herb or shrub	SMI, BER, WMI
	Vigna sp. cf. *lanceolata* (BR3-06)	Herb or climber	BER, EMI
	**Vigna radiata* var. *setulosa*	Herb or climber	NMI, SMI, BER
Zygophyllaceae	*Tribulopis pentandra*	Herb	NMI, SMI
	Tribulus cistoides	Herb	NMI, SMI, BER, LAM
Rutaceae	*Glycosmis macrophylla*	Shrub	LAM
	Glycosmis trifoliata	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
	Harrisonia brownii	Shrub or tree	LAM
	Luvunga monophylla	Shrub or climber	SMI, BER, EMI, WMI
	Zanthoxylum parviflorum	Tree	NMI, SMI, BER, LAM
Burseraceae	*Canarium australianum* var. *glabrum*	Tree	LAM
	Canarium australianum var. *velutinum*	Tree	LAM
	Garuga floribunda var. *floribunda*	Tree	NMI, SMI, BER, EMI, WMI, LAM
Meliaceae	*Aglaia elaeagnoidea*	Tree	BER, LAM
	Turraea pubescens	Shrub or tree	WMI

Table 3-10: Flora species inventory for the six islands surveyed (RPS 2007, 2008) (continued)

Family	Species	Life form	Distribution
Polygalaceae	*Polygala linariifolia*	Herb	NMI
	Polygala sp. aff. *linariifolia* form “A” (EM5-R12)	Herb	NMI, SMI, BER, EMI
	Polygala sp. aff. *linariifolia* form “B” (SM10-05) (now *P. galeocephala*)	Herb	SMI
	Polygala sp. aff. *linariifolia* form “C” (EM5-R02)	Herb	EMI
Euphorbiaceae	*Acalypha pubiflora* subsp. *australica*	Shrub	WMI
	Croton habrophyllus	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
	Euphorbia distans	Herb	NMI, SMI, BER, EMI, WMI, LAM
	Euphorbia drummondii	Herb	NMI
	Euphorbia schultzii	Herb	NMI, SMI, EMI
	Microstachys chamaelea	Herb or shrub	BER, EMI
Phyllanthaceae	*Breynia cernua*	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
	Bridelia tomentosa	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
	Flueggea virosa subsp. *melanthesoides*	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
	Glochidion disparipes	Shrub or tree	LAM
	Glochidion perakense var. *supra-axillare*	Tree	LAM
	Leptopus decaisnei var. *decaisnei* (now *Notoleptopus decaisnei*)	Herb	NMI, SMI, BER, EMI, WMI
	Phyllanthus exilis	Herb	NMI, SMI, BER, EMI, WMI
	Phyllanthus maderaspatensis	Herb	NMI, SMI, BER, EMI, WMI
	Phyllanthus reticulatus	Climber, shrub or tree	LAM
	Sauropus trachyspermus	Herb	BER, LAM
Putranjivaceae	*Drypetes deplanchei*	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
Anacardiaceae	*Buchanania oblongifolia*	Shrub or tree	NMI, SMI, BER, WMI, LAM
	Buchanania sp. aff. *obovata*	Shrub or tree	LAM
	Buchanania obovata	Shrub or tree	LAM
Celastraceae	*Elaeodendron melanocarpum*	Shrub or tree	LAM
	Stackhousia intermedia	Herb	EMI, WMI
Sapindaceae	*Alectryon connatus*	Shrub or tree	NMI, SMI, BER, WMI
	Atalaya salicifolia	Shrub or tree	SMI, BER, EMI, WMI
	Distichostemon hispidulus var. *phyllopterus* (now *Dodonaea hispidula* var. *phylloptera*)	Shrub	NMI, SMI, BER, EMI, WMI, LAM
	Dodonaea lanceolata var. *lanceolata*	Shrub	NMI, BER
	Ganophyllum falcatum	Tree	NMI, SMI, BER, EMI, WMI, LAM
Vitaceae	*Ampelocissus acetosa*	Climber	NMI, SMI, BER, EMI, WMI, LAM
	Cayratia maritima	Herb or climber	NMI, BER, EMI, LAM
	Cissus reniformis	Climber	NMI, SMI, BER, EMI, LAM

Table 3-10: Flora species inventory for the six islands surveyed (RPS 2007, 2008) (continued)

Family	Species	Life form	Distribution
Malvaceae	*Abutilon indicum*	Shrub	NMI, SMI, BER, LAM
	Bombax ceiba	Tree	BER
	Brachychiton diversifolius	Tree	NMI, SMI, BER
	Brachychiton tridentatus (P3)	Tree	LAM
	Brachychiton xanthophyllus (P4)	Tree	NMI, EMI, WMI
	Corchorus aestuans	Herb	BER
	Corchorus pumilio	Herb or shrub	NMI, SMI, BER
	Fioria vitifolia (now *Hibiscus vitifolius*)	Shrub	NMI, SMI, BER, EMI
	Grewia breviflora	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
	Grewia glabra	Shrub or tree	SMI, BER, EMI, WMI
	Grewia oxyphylla	Climber, shrub or tree	NMI, SMI, BER, WMI, LAM
	Helicteres cana	Shrub	LAM
	Helicteres ?rhynchocarpa (WM03-07)	Shrub	WMI
	Helicteres rhynchocarpa	Shrub	LAM
	Hibiscus fryxellii	Shrub	EMI, WMI
	Hibiscus geranioides	Herb or shrub	NMI, WMI, LAM
	Hibiscus leptocladus	Herb or shrub	NMI, SMI, BER, LAM
	Hibiscus peralbus	Herb or shrub	NMI, SMI, BER, EMI, WMI
	Melhania oblongifolia	Herb or shrub	NMI, SMI, BER, EMI, WMI, LAM
	Melochia umbellata	Shrub or tree	BER, EMI
	Sida sp. A Kimberley Flora (P.A. Fryxell & L.A. Craven 3900)	Shrub	WMI
	Sterculia quadrifida	Shrub or tree	NMI, SMI, BER, EMI, LAM
	Triumfetta aquila	Shrub	NMI, SMI, BER, EMI, LAM
	Triumfetta coronata	Shrub	NMI, SMI, BER, EMI, WMI, LAM
	Triumfetta plumigera	Shrub	LAM
	Triumfetta triandra	Shrub	LAM
	Waltheria indica	Herb or shrub	NMI, SMI, BER, EMI
Bixaceae	*Cochlospermum fraseri*	Shrub or tree	BER
Passifloraceae	*Adenia heterophylla*	Climber	NMI, SMI, BER, EMI, WMI, LAM
	**Passiflora foetida*	Climber	BER, LAM
Combretaceae	*Terminalia canescens*	Shrub or tree	NMI, SMI, BER, EMI, WMI
	Terminalia carpentariae	Tree	BER, LAM
	Terminalia ferdinandiana	Tree	SMI
	Terminalia petiolaris	Tree	NMI, SMI, BER, EMI, WMI, LAM
Myrtaceae	*Corymbia bleeseri*	Tree	SMI
	Corymbia clavigera	Tree	NMI, SMI, BER, EMI, WMI
	Corymbia greeniana	Tree	WMI
	Corymbia polycarpa	Tree	NMI, SMI, BER, LAM
	Syzygium eucalyptoides subsp. *bleeseri*	Shrub or tree	NMI, BER
	Melaleuca leucadendra	Tree	LAM
	Melaleuca viridiflora	Shrub or tree	LAM
Onagraceae	*Ludwigia perennis*	Herb	LAM
Haloragaceae	*Gonocarpus leptothecus*	Herb or shrub	SMI, WMI, LAM
Araliaceae	*Trachymene didiscoides*	Herb	NMI, SMI, BER, WMI, LAM

Table 3-10: Flora species inventory for the six islands surveyed (RPS 2007, 2008) (continued)

Family	Species	Life form	Distribution
Plumbaginaceae	*Plumbago zeylanica*	Shrub	LAM
Sapotaceae	*Mimusops elengi*	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
	Pouteria sericea (now *Sersalisia sericea*)	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
Ebenaceae	*Diospyros rugosula*	Tree	SMI, BER, EMI
	Diospyros humilis	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
	Diospyros maritima	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
Oleaceae	*Jasminum didymum* subsp. *didymum*	Climber	NMI, SMI, BER, EMI, WMI, LAM
	Jasminum molle	Shrub or climber	BER, LAM
Loganiaceae	*Mitrasacme connata*	Herb	EMI
	Strychnos lucida	Shrub or tree	NMI, SMI, BER, EMI, WMI
Apocynaceae	Apocynaceae sp. “A” (SM10-22) (indet.)[6]	Climber	SMI
	Apocynaceae sp. “B” (BR1-R105) (indet.)	Climber	BER
	Alyxia spicata	Shrub or climber	NMI, SMI, BER, EMI
	Carissa lanceolata	Shrub	LAM
	Carissa lanceolata – C. ovata intergrade (NM10-15)	Shrub	NMI, SMI, BER, EMI, WMI
	Gymnanthera oblonga	Shrub or climber	BER
	Marsdenia angustata	Shrub	SMI
	Marsdenia geminata	Climber	SMI
	Marsdenia velutina	Climber	WMI
	Marsdenia viridiflora subsp. *tropica*	Climber	LAM
	Parsonsia velutina	Climber	SMI, BER, EMI, WMI, LAM
	Sarcostemma viminale subsp. *australe* (now *Cynanchum viminale* subsp. *australe*)	Shrub	NMI, SMI, BER, EMI, WMI
	Sarcostemma viminale subsp. *brunonianum* (now *Cynanchum viminale* subsp. *brunonianum*)	Climber	SMI, BER, EMI, WMI, LAM
	Secamone elliptica subsp. *elliptica*	Climber	SMI, BER, EMI
	Secamone timoriensis	Climber	SMI, BER, WMI, LAM
	Tylophora flexuosa (now *Vincetoxicum flexuosum*)	Climber	BER
	Wrightia pubescens	Shrub or tree	EMI
	Wrightia saligna	Shrub or tree	SMI
Convolvulaceae	*Bonamia media*	Herb	NMI, BER
	Bonamia pannosa	Herb	NMI, BER
	Cuscuta sp.	Herb or climber	LAM
	**Cuscuta campestris*	Herb or climber	WMI
	Evolvulus alsinoides	Herb	LAM
	Evolvulus alsinoides var. *decumbens*	Herb	NMI, SMI, BER, EMI, WMI
	Evolvulus sp. “White Flower” (NM14-05) (now known to be *Evolvulus alsinoides* var. *alsinoides*)	Herb	NMI, SMI, BER, WMI
	Ipomoea eriocarpa	Herb or climber	NMI, SMI, EMI, WMI
	Ipomoea macrantha	Herb or climber	BER
	Ipomoea nil	Herb or climber	BER, EMI
	Ipomoea pes-caprae subsp. *brasiliensis*	Herb or climber	NMI, SMI, BER, EM, WMI, LAM

6 The two apocynaceous species recorded here from South Maret Island (SM10-22) and Berthier Island (BR1-R105) were seedlings which could not be identified to genus or species level during the survey period.

Table 3-10: Flora species inventory for the six islands surveyed (RPS 2007, 2008) (continued)

Family	Species	Life form	Distribution
Convolvulaceae (continued)	*Ipomoea trichosperma*	Herb or climber	SMI, BER, EMI, WMI
	Jacquemontia paniculata	Herb or climber	NMI, SMI, BER, EMI, WMI, LAM
	Merremia incisa	Herb	WMI
	Merremia quinata	Herb or climber	SMI, WMI
	Operculina brownii	Herb or climber	WMI
	Polymeria ambigua	Herb	NMI, SMI, BER, WMI
	Xenostegia tridentata	Herb or climber	NMI, SMI, BER, EMI, WMI, LAM
Boraginaceae	*Cordia subcordata*	Shrub or tree	SMI
	Heliotropium cunninghamii complex 1	Herb	NMI, SMI
	Heliotropium cunninghamii complex 2	Herb	EMI, WMI
	Heliotropium glabellum	Herb	NMI, SMI, WMI
	Heliotropium sp. aff. *dichotomum*	Herb	NMI, SMI
	Trichodesma zeylanicum	Herb or shrub	BER, LAM
Lamiaceae	*Callicarpa candicans*	Shrub or tree	BER
	Clerodendrum floribundum	Shrub or tree	LAM
	Clerodendrum floribundum var. *angustifolium*	Shrub or tree	LAM
	Clerodendrum floribundum var. *coriaceum*	Shrub or tree	BER, LAM
	Clerodendrum floribundum var. *floribundum*	Shrub or tree	BER
	Clerodendrum floribundum var. *ovatum*	Shrub or tree	NMI, SMI, BER, LAM
	Premna acuminata	Shrub or tree	NMI, SMI, BER, EMI, WMI
	Vitex glabrata	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
	Vitex acuminata	Shrub or tree	LAM
Solanaceae	*Solanum heteropodium*	Shrub	LAM
Orobanchaceae	*Buchnera asperata*	Herb	NMI, SMI, BER, EMI, WMI
	Buchnera linearis	Herb	SMI
	Buchnera ramosissima	Herb	BER, WMI
	Buchnera urticifolia	Herb	BER
	Striga curviflora	Herb	NMI, SMI, BER
Plantaginaceae	*Stemodia lythrifolia*	Herb	LAM
Acanthaceae	*Dicliptera armata*	Herb	BER, LAM
	Hypoestes floribunda var. *suaveolens*	Herb or shrub	BER, EMI, WMI
	Thunbergia arnhemica	Herb or climber	BER, SMI
Rubiaceae	*Morinda citrifolia*	Shrub or tree	NMI, EMI
	Oldenlandia galioides	Herb	NMI, SMI, LAM
	Pavetta muelleri	Shrub or tree	NMI, SMI, BER, EMI, WMI, LAM
	Spermacoce brachystema	Herb	NMI
	Spermacoce sp. "Blue" (NM31-13)	Herb	NMI, SMI
	Spermacoce sp. "White" (NM21-01)	Herb	NMI, SMI, BER, EMI
	Spermacoce sp. Berthier Dunes (R.L. Barrett RLB 5753) (P3)	Herb	BER, LAM
	Synaptantha scleranthoides	Herb	NMI, SMI, EMI, WMI, LAM
	Tarenna dallachiana	Tree	WMI
	Tarenna pentamera	Shrub or tree	SMI, EMI
Cucurbitaceae	*Diplocyclos palmatus*	Herb or climber	BER
	Mukia maderaspatana (= *Cucumis maderaspatanus*)	Herb or climber	NMI, SMI, BER, LAM
	**Cucumis melo*	Herb or climber	BER, EMI

Table 3-10: Flora species inventory for the six islands surveyed (RPS 2007, 2008) (continued)

Family	Species	Life form	Distribution
Goodeniaceae	*Goodenia* sp. aff. *arachnoidea* (WM02-08)	Herb	BER, WMI
	Goodenia sp. aff. *microptera* (NM27-19)	Herb	NMI, SMI, BER
	Goodenia sepalosa var. *sepalosa*	Herb	NMI, SMI, BER
Stylidiaceae	*Stylidium pachyrrhizum*	Herb	NMI, SMI, BER
Asteraceae	**Bidens pilosa*	Herb	SMI, BER, WMI
	Cyanthillium cinereum	Herb	BER
	Pterocaulon verbascifolium	Herb	BER
	Wedelia asperrima (= *Apowollastonia cylindrica*)	Herb	NMI, SMI, BER, EMI

Species densities

Of the five islands analysed (North Maret, South Maret, Berthier, East Montalivet and West Montalivet), Berthier Island had the greatest density of species (Table 3-11). It is, however, the largest of the five and is approximately 50% larger in vegetated area than South Maret Island, the second largest of the surveyed islands. As the remaining four islands are similar in size to one another, with only approximately 23 ha separating the largest and the smallest in vegetated area, the species-density comparisons were more applicable.

Table 3-11: Species densities on survey quadrats and transects for the five islands analysed

Island	Mean number of species per quadrat	Mean number of species per transect	Mean number of species (combined)	Vegetated area (ha)
North Maret	27.6	24.6	27.36	320.8
South Maret	42.9	35.4	39.5	333.8
Berthier	56.9	45.4	50.4	510
East Montalivet	45	31.7	40.5	333
West Montalivet	35.25	32.25	33.75	311

Significant species

Declared Rare Flora

No Declared Rare Flora species was identified during the course of the surveys.

Priority Flora

Four Priority Flora taxa were recorded during the surveys:

- *Acacia deltoidea* subsp. *ampla* (P2)
- *Brachychiton tridentatus* (P3)
- *Brachychiton xanthophyllus* (P4)
- *Pittosporum moluccanum* (P4).

The known Western Australian distribution ranges of each are described in the Western Australian Herbarium's FloraBase database (DEC 2007–2013). The shrub *Acacia deltoidea* subsp. *ampla* (P2) and the small trees *Brachychiton tridentatus* (P3) and *B. xanthophyllus* (P4) are all restricted entirely to the Shire of Wyndham – East Kimberley in the north-eastern corner of the state, while the small tree *Pittosporum moluccanum* (P4) occurs in the shires of Wyndham – East Kimberley and Broome but has a wider distribution in the Northern Territory, Taiwan, the Philippines and Malesia.

For images of these taxa, refer to figures 3-7 to 3-10.

Photographs courtesy of Russell Barrett

Figure 3-7: Flowering branches and fruit of *Acacia deltoidea* subsp. *ampla* (P2)

Photographs courtesy of Russell Barrett

Figure 3-8: Leaves, fruit and a flower of *Brachychiton tridentatus* (P3)

Photographs courtesy of Russell Barrett

Figure 3-9: Leaves, fruit and flowers of *Brachychiton xanthophyllus* (P4)

Photographs courtesy of Russell Barrett

Figure 3-10: Leaves, fruit and flowers of *Pittosporum moluccanum* (P4)

Significant species: potential Priority Flora species

During the surveys, 20 taxa were found that appear not to have been previously collected from the survey area and for this reason are considered significant:

- *Cathormion umbellatum* subsp. *moniliforme*
- *Cayratia maritima*
- *Cleome* sp. Bonaparte Archipelago (A.A. Mitchell 4774)
- *Commicarpus chinensis* subsp. *chinensis*
- *Cordia subcordata*
- *Corymbia bleeseri*
- *Corymbia clavigera*
- *Eriachne sulcata*
- *Evolvulus* sp. “White Flower”[7] (NM14-05)
- *Glochidion perakense* var. *supra-axillare*
- *Gomphrena* sp. Maret Islands (A.A. Mitchell 5414)
- *Goodenia* sp. aff. *microptera* (NM27-19)
- *Heliotropium* sp. aff. *dichotomum*
- *Hibiscus peralbus*
- *Mucuna diabolica* subsp. *kenneallyi*
- *Pavetta muelleri*
- *Portulaca* sp. “River Mud” (R.L. Barrett 3285)
- **Pupalia micrantha*
- *Spermacoce* sp. Berthier Dunes (R.L. Barrett RLB 5753)
- *Spermacoce* sp. “Blue” (NM31-13)
- *Spermacoce* sp. “White” (NM21-01).

For images of these taxa, refer to figures 3-11 to 3-31.

Most of these taxa have not yet been classified by the Department of Environment and Conservation, but have the potential to be listed as Priority Flora because of their apparent scarcity.

Voucher specimens of a number of taxa have been lodged with the Western Australian Herbarium, identified under phrase names until they can be properly described and named. Their broader distribution is generally unknown.

[7] Later identified as *Evolvulus alsinoides* var. *alsinoides*.

Photographs courtesy of Russell Barrett

Figure 3-11: *Cathormion umbellatum* subsp. *moniliforme*: leaves, spined branchlets and new growth

Photographs courtesy of Russell Barrett

Figure 3-12: *Cayratia maritima*: trifoliate leaves, fruit and flowers

Photographs courtesy of Russell Barrett

Figure 3-13: *Cleome* sp. Bonaparte Archipelago (A.A. Mitchell 4774): leaves, fruit and flowers

Photographs courtesy of Russell Barrett

Figure 3-14: *Commicarpus chinensis* subsp. *chinensis*: leaves, fruit and flowers

Photographs courtesy of Russell Barrett

Figure 3-15: *Cordia subcordata*: plant, fruit and flowers

Photographs courtesy of Russell Barrett

Figure 3-16: *Corymbia bleeseri*: bark, fruit and buds

Photographs courtesy of Russell Barrett

Figure 3-17: *Corymbia clavigera*: tree, leaves and fruit

Photographs courtesy of Russell Barrett

Figure 3-18: *Eriachne sulcata*: tussocks and inflorescence

Photographs courtesy of Russell Barrett

Figure 3-19: *Evolvulus* sp. "White Flower"[8] (NM14-05): plant, fruit and flower

Photographs courtesy of Russell Barrett

Figure 3-20: *Glochidion perakense* var. *supra-axillare*: tree (left-hand trunk in left image)

Photographs courtesy of Russell Barrett

Figure 3-21: *Gomphrena* sp. Maret Islands (A.A. Mitchell 5414): habit and flowers

Photographs courtesy of Russell Barrett

Figure 3-22: *Goodenia* sp. aff. *microptera* (NM27-19): habit, leaves and flowers

[8] Later identified as *Evolvulus alsinoides* var. *alsinoides*.

Photographs courtesy of Russell Barrett

Figure 3-23: *Heliotropium* sp. aff. *dichotomum*: habit, fruit and flower

Photographs courtesy of Russell Barrett

Figure 3-24: *Hibiscus peralbus*: habit, fruit and flower

Photographs courtesy of Russell Barrett

Figure 3-25: Vines of *Mucuna diabolica* subsp. *kenneallyi*: massed growth, fruit and leaves

Photographs courtesy of Russell Barrett

Figure 3-26: *Pavetta muelleri*: leaves, fruit and flowers

Photographs courtesy of Russell Barrett

Figure 3-27: *Portulaca* sp. “River Mud” (R.L. Barrett 3285): flowering plant, fruit and flowers

Photographs courtesy of Russell Barrett

Figure 3-28: **Pupalia micrantha*: leaves, fruit and flowers

Photographs courtesy of Russell Barrett

Figure 3-29: *Spermacoce* sp. Berthier Dunes (R.L. Barrett RLB 5753) (P3): habit, fruit and flowers

Photographs courtesy of Russell Barrett

Figure 3-30: *Spermacoce* sp. “Blue” (NM31-13): habit and flowers

Photographs courtesy of Russell Barrett

Figure 3-31: *Spermacoce* sp. “White” (NM21-01): habit, fruit and flowers

Introduced species

The vegetation of the surveyed islands has been minimally disturbed by introduced species. No introduced taxa were recorded for North Maret Island, while South Maret Island had two introduced taxa, or 0.4% of its flora inventory. Berthier Island had four introduced taxa (1.9%), East Montalivet Island had three (2.1%), West Montalivet Island had two (1.6%), and Lamarck Island had three (2.0%).

At less than 2% of the total species richness, the proportions of introduced species on the Maret Islands and the reference islands are extremely low. By comparison, in 1987 the Northern Territory’s Kakadu National Park had an introduced flora of 5.3% (Cowie & Werner 1987, not seen, cited in Woinarski et al. 2000), while 9.3% of the Northern Territory’s flora as a whole consists of introduced taxa (Kerrigan & Albrecht 2007) and 8.75% of Western Australia’s Kimberley flora is introduced (DEC 2007). In total, approximately 15% of the flora of Australia is made up of introduced species (Bean 2007).

In total, six taxa classified as introduced or with uncertain status were recorded during the surveys. They are listed in Table 3-12 with codes showing how often and in what situation they were found.

Both **Pupalia micrantha* and **Cucumis melo* have previously been classified as introduced but are now considered by some to be native, although there remains some uncertainty about their status. All of the species listed in the table, except **P. micrantha*, are reasonably well collected and widespread. Before the survey took place, **P. micrantha* was represented in the Western Australian Herbarium by only four collections, although one further collection is held in Canberra (CHAH 2007). During the survey, however, it was collected on four of the six islands surveyed.

Environmental weeds

The *Environmental weed strategy for Western Australia* (CALM 1999) gives **Passiflora foetida* a “High” rating. This means it scored on three criteria describing its invasiveness, distribution and environmental impacts. This weed was only recorded from Berthier and Lamarck islands and is considered a priority for control and/or research. None of the other weeds above are listed as environmental weeds.

Table 3-12: Potentially introduced species

Species	Presence on surveyed islands (number of records and nature of record)	Notes
**Bidens pilosa*	SMI (1 O), BER (1 Q), WMI (1 Q)	An erect annual herb, which is possibly an introduction pre-dating European settlement of Australia.
**Chamaecrista nigricans*	EMI (1 Q)	This shrub is treated as an introduced species in the *Flora of Australia* (ABRS 1981–ongoing) but some questions still remain.
**Cucumis melo*	BER (7 Q, 1 R), EMI (1 Q)	A trailing annual herb or climber. Still listed as a weed in the Western Australian Herbarium's FloraBase database, but generally accepted as native (Hussey et al. 2007).
**Cuscuta campestris*	WMI (1 O), LAM (as "*Cuscuta* sp.")	Parasitic, twining, annual herb or climber. Cosmopolitan with debatable natural distribution.
**Passiflora foetida*	BER (1 O), LAM	Woody climber. Weed.
**Pupalia micrantha*	SMI (2 R), BER (1 Q, 6 R), EMI (1 R), LAM	Low slender shrub. Almost certainly naturalised since it is a pre-European introduction.

O = from opportunistic collection (RPS 2007).
R = recorded from relevé (transect) (RPS 2007).
Q = recorded from quadrat (RPS 2007).
BER = Berthier Island (RPS 2007).
EMI = East Montalivet Island (RPS 2007).
SMI = South Maret Island (RPS 2007).
WMI = West Montalivet Island (RPS 2007).
LAM = Lamarck Island (RPS 2008).

Fungi and slime moulds

While not a required aspect of the survey effort, opportunistic collections were made of fungi encountered during the survey. Little is known of fungi in tropical Australia (May 2001) and many of the collections made during this survey have not been fully identified because of a lack of taxonomic knowledge of tropical Australian fungi, which remain very poorly collected.

A number of identifiable species are discussed and illustrated below (figures 3-32 to 3-43). They were identified by Dr Matt Barrett (Botanic Gardens and Parks Authority, Perth, Western Australia). Most fungi located during the surveys were found in vine thickets following prolonged periods of rainfall.

Family Ceratiomyxaceae (order Ceratiomyxales)
Ceratiomyxa fruticulosa (Müll.) Mac.
This is a slime mould that grows on moist bark in vine thickets. It is a cosmopolitan species.

Photographs courtesy of Russell Barrett

Figure 3-32: *Ceratiomyxa fruticulosa* in vine thicket on South Maret Island

Family Auriculariaceae (order Auriculariales)

Auricularia cornea Ehrenb.

The "pig's ear" fungus is relatively common in vine thickets, where it grows on dead bark. It has a tropical distribution.

Photographs courtesy of Russell Barrett

Figure 3-33: *Auricularia cornea* in vine thicket on South Maret Island

Family Xylariaceae (order Xylariales)

Daldinia eschscholtzii (Ehrenb.) Rehm

This is a woody fungus with a pantropical distribution. When broken open, the fruiting body shows distinct concentric rings inside (Figure 3-34, left).

Family Agaricaceae (order Agaricales)

Podaxis pistillaris (L.) Fr.

This common, cosmopolitan fungus holds its spores inside the elongated cap. It grows on the roots of plants, usually in loam soils in arid and seasonally arid areas (Figure 3-34, centre).

Family Marasmiaceae (order Agaricales)

Marasmius sp.

This is a tiny fungus that grows on dead leaves and wood. There is insufficient information on this genus to allow identification to species level (Figure 3-34, right).

Photographs courtesy of Russell Barrett

Figure 3-34: *Daldinia eschscholtzii* in vine thicket on South Maret Island (left), *Podaxis pistillaris* photographed on the plateau of North Maret Island (centre), and *Marasmius* sp. photographed in vine thicket on South Maret Island (right)

Family Pluteaceae (order Agaricales)

Volvopluteus earlei (Murrill) Vizzini, Contu & Justo

This is the first published record of this pantropical species occurring in Australia.

Photographs courtesy of Russell Barrett

Figure 3-35: *Volvopluteus earlei* in vine thicket on South Maret Island

Family Psathyrellaceae (order Agaricales)

Coprinopsis clastophylla (Maniotis) Redhead, Vilgalys & Moncalvo

This species, which grows on dead wood, is only rarely collected in Australia and is so far known only from the Kimberley region (Barrett 2006). This is the non-agaricoid form widely known as *Rhacophyllus lilacinus* Berk. & Broome (the agaricoid form is known only in culture).

Photographs courtesy of Russell Barrett

Figure 3-36: *Coprinopsis clastophylla* in vine thicket on South Maret Island

Family Polyporaceae (order Polyporales)

Hexagonia tenuis (Hook.) Fr.

This is a woody bracket fungus with distinct, somewhat hexagonal pores on the lower surface of its fruiting body. It is one of the most common bracket fungi in the tropics.

Photographs courtesy of Russell Barrett

Figure 3-37: *Hexagonia tenuis* in vine thicket on South Maret Island

Polyporus arcularius (Batsch) Fr.

The fruiting body of this relatively common cosmopolitan fungus has distinct hairs around the margin of the cap. It grows on dead wood.

Photographs courtesy of Russell Barrett

Figure 3-38: *Polyporus arcularius* in vine thicket on North Maret Island

Polyporus tricholoma Mont.

This species is found on dead wood in vine thickets in the tropics.

Photographs courtesy of Russell Barrett

Figure 3-39: *Polyporus tricholoma* in vine thicket on South Maret Island

Trametes muelleri Berk.

The colourful woody fruiting body of this bracket fungus grows on tree trunks. It is common throughout tropical Australia.

Photographs courtesy of Russell Barrett

Figure 3-40: *Trametes muelleri* in vine thicket on South Maret Island

Truncospora ochroleuca (Berk.) Pilát

This bracket fungus is a widespread species, common throughout Australia.

Photographs courtesy of Russell Barrett

Figure 3-41: *Truncospora ochroleuca* in vine thicket on South Maret Island

Family Ramalinaceae (order Lecanorales)

Ramalina subfraxinea Nyl.

This is a pendulous lichen that grows on the branches of trees along the coastline, in both vine thickets and mangroves.

Photographs courtesy of Russell Barrett

Figure 3-42: *Ramalina subfraxinea* in coastal vine thicket on North Maret Island

Family Physalacriaceae (order Agaricales)

Protoxerula flavo-olivacea var. *kimberleyana* (R.H. Petersen & M.D. Barrett) R.H. Petersen

This is a new fungus variety that was described from specimens collected on North Maret Island on basaltic soil in deep litter under the tree *Garuga floribunda* on 24 March 2007. This relatively large fungus, to 200 mm tall, whose fruiting body has a green to yellow cap up to 50 mm across, has a large distinctive underground stem that gradually tapers into the soil. It was found in dense leaf litter in vine thickets on both North Maret Island and South Maret Island. It is also known from similar habitats on mainland Australia.

Fungal taxonomy is being transformed by advances in DNA sequencing and this variety has undergone two name changes since being described in 2008. It is currently placed in the genus *Protoxerula*, which is endemic to tropical Australia, but was originally placed in *Xerula* (Petersen 2008) and then *Oudemansiella* (Yang et al. 2009).

The synonymy is as follows:

Protoxerula flavo-olivacea var. *kimberleyana* (R.H. Petersen & M.D. Barrett) R.H. Petersen in R.H. Petersen & K.W. Hughes, *Beihefte zur Nova Hedwigia* 137: 322 (2010).

Xerula flavo-olivacea var. *kimberleyana* R.H. Petersen & M.D. Barrett in R.H. Petersen, *Nova Hedwigia* 87(1–2): 23 (2008); *Oudemansiella flavo-olivacea* var. *kimberleyana* (R.H. Petersen & M.D. Barrett) Z.-L. Yang, G.M. Mueller, G.W. Kost & K.-H. Rexer, *Mycosystema* 28(1): 7 (2009).

Type: Western Australia: On basaltic soil in deep litter under *Garuga floribunda*, North Maret Island, 24 March 2007, *R.L. Barrett* (holotype: PERTH).

Photographs courtesy of Russell Barrett

Figure 3-43: *Protoxerula flavo-olivacea* var. *kimberleyana* in vine thicket on South Maret Island

Vegetation units

The species found at each island were grouped into vegetation units (Table 3-13). Sixty-seven different vegetation units were described. Of these, only three—ArTb (Figure 3-44), TbG (Figure 3-45) and CpcTASt (Figure 3-46)—were found on two islands, North Maret Island and South Maret Island (which are linked by an isthmus at low tide). The vegetation unit Gmi containing the undescribed new taxon *Gomphrena* sp. Maret Islands (A.A. Mitchell 5414) was found on North Maret Island, South Maret Island, Berthier Island and West Montalivet Island.

Table 3-13: Vegetation unit codes and descriptions for each of the islands surveyed

Vegetation unit code	Description	Island					
		NMI	SMI	BER	EMI	WMI	LAM
AddFa	***Acacia deltoidea* subsp. *deltoidea***, ***Ficus atricha***, *Sterculia quadrifida* and *Pavetta muelleri* closed tall scrub over *Acacia gonocarpa* low shrubland over *Triodia bynoei* very open hummock grassland, and *Sorghum timorense* annual grassland with *Flagellaria indica* lianas.	–	–	–	–	–	x
Addg	***Acacia deltoidea* subsp. *deltoidea*** tall scrub over ***Acacia gonocarpa*** scrub or shrubland over *Triodia microstachya* and *Triodea bynoei* hummock grassland.	–	–	–	–	–	x
AgTm	***Acacia gonocarpa*** closed heath to tall open scrub over ***Triodia microstachya*** and *Triodia bynoei* (open) hummock grassland, *Cenchrus elymoides* var. *brevisetosus* (= *C. brevisetosus*) and *Sorghum timorense* annual grassland.	–	–	–	–	–	x
AiTSpC	***Abutilon indicum***, ***Tephrosia rosea* var. *rosea*** low (open) shrubland over ***Spinifex longifolius*** and *Sorghum timorense* grassland over *Commelina ensifolia* and *Tribulus cistoides* (very) open herbland with lianas of ***Canavalia rosea***, *Ipomoea pes-caprae* subsp. *brasiliensis*, *Cassytha filiformis* and *Rhynchosia minima* var. *australis*.	x	–	–	–	–	–
ArGa	***Acacia retinervis*** and ***Grevillea agrifolia*** tall shrubland over *Acacia deltoidea* subsp. *ampla* (P2) low shrubland over *Triodia bynoei* hummock grassland over *Synaptantha scleranthoides* herbland.	–	–	–	–	x	–
ArGfDh	***Acacia retinervis***, ***Ganophyllum falcatum***, ***Diospyros humilis*** and *Drypetes deplanchei* tall open scrub or shrubland over *Celtis philippensis* and *Gyrocarpus americanus* subsp. *americanus* (low) shrubland over *Cenchrus elymoides* var. *brevisetosus* (= *C. brevisetosus*) (closed to open) grassland, and *Triodia bynoei* and *Triodia microstachya* (closed to open) hummock grassland.	–	–	–	–	–	x
ArGS	***Acacia retinervis***, ***Grevillea heliosperma*** and ***Strychnos lucida*** tall open scrub over *Premna acuminata*, *Buchanania oblongifolia* and *Croton habrophyllus* low shrubland over *Distichostemon hispidulus* var. *phyllopterus* (= *Dodonaea hispidula* var. *phylloptera*) scattered low shrubs over *Triodia bynoei*, *Cenchrus elymoides* var. *brevisetosus* (= *C. brevisetosus*), *Eriachne ciliata* and *Scleria brownii* annual grassland.	–	–	x	–	–	–
ArgTb	***Acacia retinervis*** tall scrub (or scattered low trees) over ***Acacia gonocarpa*** scattered shrubs or open scrub over *Cenchrus elymoides* var. *brevisetosus* (= *C. brevisetosus*) annual grassland, and ***Triodia bynoei*** and *Triodia microstachya* hummock grassland over *Gonocarpus leptothecus* and *Trachymene didiscoides* herbland.	–	–	–	–	–	x
ArsTbS	***Acacia retinervis*** and ***Acacia stigmatophylla*** low open shrubland over ***Triodia bynoei*** hummock grassland and ***Sorghum timorense*** open annual grassland.	x	–	–	–	–	–
ArTb	***Acacia retinervis*** scattered shrubs or low open shrubland over ***Triodia bynoei*** hummock grassland over *Gomphrena parviflora* and *Ptilotus conicus* very open herbland.	x	x	–	–	–	–
ArTcTb	***Acacia retinervis*** (or with ***Terminalia canescens***) (tall) open shrubland over ***Triodia bynoei*** open hummock grassland over *Gomphrena canescens* subsp. *canescens*, *Gomphrena parviflora* and *Synaptantha scleranthoides* very open herbland.	–	x	–	–	–	–

Note: NMI = North Maret Island; SMI = South Maret Island; BER = Berthier Island; EMI = East Montalivet Island; WMI = West Montalivet Island; LAM = Lamarck Island.

Table 3-13: Vegetation unit codes and descriptions for each of the islands surveyed (continued)

Vegetation unit code	Description	Island					
		NMI	SMI	BER	EMI	WMI	LAM
ArVT	***Acacia retinervis***, ***Vitex glabrata***, ***Terminalia canescens*** and *Croton habrophyllus* tall open scrub over open heath over *Diospyros humilis*, *Pavetta muelleri*, *Distichostemon hispidulus* var. *phyllopterus* (= *Dodonaea hispidula* var. *phylloptera*) and *Mimusops elengi* open shrubland over *Triodia microstachya* hummock grassland over *Xenostegia tridentata* very open herbland.	–	–	–	–	x	–
AsSt	***Acacia stigmatophylla*** low open shrubland over ***Sorghum timorense*** annual grassland.	x	–	–	–	–	–
AsTb	***Acacia stigmatophylla*** low open shrubland over ***Triodia bynoei*** hummock grassland over *Gomphrena parviflora* very open herbland.	x	–	–	–	–	–
AsTm	***Acacia stigmatophylla*** open shrubland over *Flueggea virosa* subsp. *melanthesoides* low open shrubland over *Sorghum timorense* (closed) annual grassland and ***Triodia microstachya*** open grassland.	x	–	–	–	–	–
BcBd	***Bombax ceiba***, ***Brachychiton diversifolius***, *Vitex glabrata* and *Zanthoxylum parviflorum* (low) open woodland over *Cochlospermum fraseri*, *Bridelia tomentosa*, *Pavetta muelleri*, *Flueggea virosa* subsp. *melanthesoides* and *Grewia glabra* shrubland over *Melhania oblongifolia* and *Tephrosia rosea* var. *rosea* scattered low shrubs over *Sorghum timorense* and *Sehima nervosum* grassland over *Polymeria ambigua* and *Commelina ensifolia* scattered herbs.	–	–	x	–	–	–
BdGff	***Brachychiton diversifolius*** and ***Garuga floribunda* var. *floribunda*** scattered low trees over *Cochlospermum fraseri*, *Capparis quiniflora* and *Grewia glabra* tall open shrubland over *Pavetta muelleri*, *Flueggea virosa* subsp. *melanthesoides*, *Premna acuminata* and *Bridelia tomentosa* open heath over *Cenchrus elymoides* var. *elymoides* (or with *Sorghum timorense*) (closed) annual grassland with *Ampelocissus acetosa*, *Jasminum didymum* subsp. *didymum* and *Cissus reniformis* scattered lianas.	–	–	x	–	–	–
BtTpTcS	***Brachychiton xanthophyllus*** (P4), ***Terminalia petiolaris*** and ***Terminalia canescens*** tall open scrub (or low open forest) over *Bridelia tomentosa*, *Vitex glabrata*, *Grewia breviflora* and *Croton habrophyllus* shrubland over *Indigastrum parviflorum*, *Ptilotus conicus* and *Gomphrena parviflora* open herbland over *Triodia bynoei* hummock grassland, and *Eriachne avenacea*, *Eriachne burkittii*, ***Sorghum timorense*** and *Cenchrus elymoides* var. *brevisetosus* (= *C. brevisetosus*) (open) annual grassland.	–	–	–	x	–	–
CcAr	***Corymbia clavigera*** scattered low trees over ***Acacia retinervis*** and *Vitex glabrata* tall open scrub over *Croton habrophyllus* and *Buchanania oblongifolia* open shrubland over *Premna acuminata* and *Pavetta muelleri* low open shrubland over *Triodia bynoei* open hummock grassland, and *Eriachne ciliata* very open annual grassland over *Desmodium filiforme* very open herbland.	–	–	x	–	–	–
CcArTb	***Corymbia clavigera*** low open woodland over ***Acacia retinervis*** tall open shrubland over *Bridelia tomentosa*, *Breynia cernua* and *Vitex glabrata* open shrubland over ***Triodia bynoei*** closed hummock grassland and *Eriachne ciliata* very open annual grassland.	–	–	–	x	–	–
CcGAr	***Corymbia clavigera*** scattered low trees over ***Grevillea refracta* subsp. *refracta*** tall shrubland over ***Acacia retinervis*** open shrubland over *Acacia deltoidea* subsp. *ampla* (P2) and *Buchanania oblongifolia* low open shrubland over *Sorghum timorense* very open annual grassland and *Triodia bynoei* hummock grassland over *Synaptantha scleranthoides* and *Trachymene didiscoides* open herbland with scattered lianas of *Cassytha filiformis.*	–	–	–	–	x	–

Table 3-13: Vegetation unit codes and descriptions for each of the islands surveyed (continued)

Vegetation unit code	Description	Island					
		NMI	SMI	BER	EMI	WMI	LAM
CcpAr	***Corymbia clavigera*** (or with ***Corymbia polycarpa***), ***Acacia retinervis*** woodland (or low open forest) over *Celtis philippensis*, *Diospyros maritima*, *Strychnos lucida*, *Pittosporum moluccanum* (P4), *Vitex glabrata* and *Sterculia quadrifida* closed tall scrub (or open shrubland) over *Pavetta muelleri*, *Croton habrophyllus*, *Mimusops elengi*, *Breynia cernua*, *Sterculia quadrifida* and *Tarenna pentamera* closed shrubland over *Corchorus pumilio* low open shrubland over *Sorghum timorense* grassland with lianas of *Adenia heterophylla*, *Asparagus racemosus*, *Flagellaria indica* and *Jacquemontia paniculata*.	–	x	–	–	–	–
CcPmVg	***Corymbia clavigera*** low open woodland over ***Pittosporum moluccanum*** (P4), *Premna acuminata*, *Zanthoxylum parviflorum*, ***Vitex glabrata*** and *Drypetes deplanchei* tall open scrub over *Capparis sepiaria*, *Mimusops elengi*, *Bridelia tomentosa*, *Capparis jacobsii*, *Croton habrophyllus*, *Alyxia spicata*, *Flueggea virosa* subsp. *melanthesoides*, *Pavetta muelleri* and *Carissa lanceolata* – *C. ovata* intergrade (NM10-15) open heath over *Glycine tomentella* low open shrubland over *Sorghum timorense* open annual grassland.	–	–	x	–	–	–
CcpVTSt	***Corymbia clavigera*** and ***Corymbia polycarpa*** low open forest over *Acacia retinervis*, *Flueggea virosa* subsp. *melanthesoides*, ***Vitex glabrata***, *Alectryon connatus* and *Diospyros maritima* tall open shrubland over *Croton habrophyllus*, *Premna acuminata*, *Pavetta muelleri*, *Acacia stigmatophylla* and *Distichostemon hispidulus* var. *phyllopterus* (= *Dodonaea hispidula* var. *phylloptera*) (open) shrubland over *Carissa lanceolata* – *C. ovata* intergrade (NM10-15), *Galactia tenuiflora* and ***Triumfetta aquila*** low open shrubland over ***Sorghum timorense***, *Cenchrus elymoides* var. *brevisetosus* (= *C. brevisetosus*) and *Sehima nervosum* annual grassland.	–	x	–	–	–	–
CcTpV	***Corymbia clavigera*** and ***Terminalia petiolaris*** low open woodland over *Acacia retinervis*, *Croton habrophyllus*, *Premna acuminata*, *Pavetta muelleri*, *Mimusops elengi*, *Exocarpos latifolius* and ***Vitex glabrata*** closed tall scrub over *Grewia breviflora*, *Grewia oxyphylla*, *Bridelia tomentosa* and *Hibiscus fryxellii* open shrubland over *Carissa lanceolata* – *C. ovata* intergrade (NM10-15), *Distichostemon hispidulus* var. *phyllopterus* (= *Dodonaea hispidula* var. *phylloptera*), *Hibiscus peralbus* and *Sida* sp. A Kimberley Flora (P.A. Fryxell & L.A. Craven 3900) low open shrubland over *Eriachne ciliata* and *Sorghum plumosum* annual grassland, and *Triodia microstachya* open hummock grassland over *Ptilotus polystachyus* very open herbland with lianas of *Cassytha filiformis*, *Jacquemontia paniculata*, *Tinospora smilacina*, *Flagellaria indica*, *Luvunga monophylla*, *Abrus precatorius* and *Capparis sepiaria*.	–	–	–	–	x	–
CcVTSt	***Corymbia clavigera*** low open forest over *Pittosporum moluccanum* (P4), *Garuga floribunda* var. *floribunda*, *Buchanania oblongifolia*, *Celtis philippensis*, *Diospyros maritima* and *Croton habrophyllus* tall shrubland over *Ficus aculeata* var. *aculeata*, *Distichostemon hispidulus* var. *phyllopterus* (= *Dodonaea hispidula* var. *phylloptera*) and *Triumfetta aquila* open shrubland over ***Sorghum timorense*** very open grassland.	x	–	–	–	–	–
CgTp	***Corymbia greeniana*** and ***Terminalia petiolaris*** low open woodland over *Mimusops elengi*, *Drypetes deplanchei*, *Celtis philippensis* and *Grewia breviflora* tall shrubland (or open scrub) over *Croton habrophyllus*, *Capparis quiniflora* and *Pavetta muelleri* shrubland over *Indigofera polygaloides* scattered herbland with *Heteropogon contortus* and *Sehima nervosum* very open grassland with lianas of *Jacquemontia paniculata*, *Luvunga monophylla*, *Abrus precatorius*, *Asparagus racemosus*, *Ampelocissus acetosa* and *Rhynchosia minima* var. *australis*.	–	–	–	–	x	–

Table 3-13: Vegetation unit codes and descriptions for each of the islands surveyed (continued)

Vegetation unit code	Description	Island					
		NMI	SMI	BER	EMI	WMI	LAM
CpAbSp	***Corymbia polycarpa***, ***Aglaia elaeagnoidea***, *Ficus virens* and *Erythrophleum chlorostachys* woodland over *Diospyros maritima*, *Drypetes deplanchei*, *Elaeodendron melanocarpum*, *Ganophyllum falcatum*, *Garuga floribunda* var. *floribunda* and *Terminalia petiolaris* low open forest over *Pavetta muelleri*, *Acacia deltoidea* subsp. *deltoidea* (tall) open shrubland over *Triodia microstachya* hummock grassland, and ***Spinifex longifolius*** and *Sporobolus virginicus* very open grassland over *Spermacoce* sp. Berthier Dunes (R.L. Barrett RLB 5753) (P3) and *Ipomoea pes-caprae* subsp. *brasiliensis* open herbland with *Capparis sepiaria* and *Opilia amentacea* lianas.	–	–	–	–	–	x
CpAr	***Corymbia polycarpa*** and ***Acacia retinervis*** woodland (or low open forest) over *Celtis philippensis*, *Diospyros maritima*, *Strychnos lucida*, *Pittosporum moluccanum* (P4), *Vitex glabrata* and *Sterculia quadrifida* closed tall scrub (or open shrubland) over *Pavetta muelleri*, *Croton habrophyllus*, *Mimusops elengi*, *Breynia cernua*, *Sterculia quadrifida* and *Tarenna pentamera* closed shrubland over *Corchorus pumilio* low open shrubland over *Sorghum timorense* grassland with lianas of *Adenia heterophylla*, *Asparagus racemosus*, *Flagellaria indica* and *Jacquemontia paniculata.*	–	–	x	–	–	–
CpArg	***Corymbia polycarpa*** and ***Acacia retinervis*** low open forest over ***Acacia gonocarpa***, *Diospyros maritima* and *Pavetta muelleri* tall shrubland over *Cenchrus elymoides* var. *brevisetosus* (= *C. brevisetosus*) annual grassland or closed grassland.	–	–	–	–	–	x
CpArG	***Corymbia polycarpa*** and ***Acacia retinervis*** low (open) woodland over ***Grevillea heliosperma***, *Pittosporum moluccanum* (P4), *Mimusops elengi* and *Vitex glabrata* tall shrubland over *Croton habrophyllus*, *Alyxia spicata* and *Pavetta muelleri* open heath over *Acacia stigmatophylla*, *Distichostemon hispidulus* var. *phyllopterus* (= *Dodonaea hispidula* var. *phylloptera*) and *Carissa lanceolata* – *C. ovata* intergrade (NM10-15) low (open) shrubland over *Cenchrus elymoides* var. *elymoides* and *Sorghum timorense* very open grassland.	–	–	x	–	–	–
CpcGSt	***Corymbia polycarpa*** (or with ***Corymbia clavigera***) (low) open woodland over *Pittosporum moluccanum* (P4), *Ficus aculeata* var. *aculeata*, ***Grevillea pyramidalis* subsp. *pyramidalis*** and *Acacia retinervis* tall open shrubland over ***Sorghum timorense*** annual grassland over *Gomphrena parviflora* open herbland. Note: this vegetation unit was too small in area to be displayed on Figure 3-48.	–	x	–	–	–	–
CpcTASt	***Corymbia polycarpa*** and ***Corymbia clavigera*** (or with ***Terminalia petiolaris***) low woodland over ***Acacia retinervis***, ***Acacia stigmatophylla***, *Pittosporum moluccanum* (P4) and *Terminalia canescens* tall open shrubland over *Celtis philippensis*, *Croton habrophyllus*, *Flueggea virosa* subsp. *melanthesoides*, *Pavetta muelleri*, *Pouteria sericea* (= *Sersalisia sericea*) and *Premna acuminata* open shrubland over *Triumfetta aquila*, *Vitex glabrata* and *Galactia tenuiflora* low open shrubland over ***Sorghum timorense*** and *Cenchrus elymoides* var. *brevisetosus* (= *C. brevisetosus*) (closed) annual grassland.	x	x	–	–	–	–
CpcTcAr	***Corymbia polycarpa*** (or with ***Corymbia clavigera***) low woodland over ***Terminalia canescens*** (or with *Grevillea pyramidalis* subsp. *pyramidalis*) (tall open) shrubland over ***Acacia retinervis*** and *Premna acuminata* (low) open shrubland over *Triodia bynoei* (open) hummock grassland and *Cenchrus elymoides* var. *brevisetosus* (= *C. brevisetosus*) (very open) annual grassland.	x	–	–	–	–	–

Table 3-13: Vegetation unit codes and descriptions for each of the islands surveyed (continued)

Vegetation unit code	Description	Island					
		NMI	SMI	BER	EMI	WMI	LAM
CpTcAs	***Corymbia polycarpa*** low woodland over ***Terminalia canescens*** tall open shrubland over *Pavetta muelleri*, *Premna acuminata*, *Croton habrophyllus*, *Pittosporum moluccanum* (P4), *Flueggea virosa* subsp. *melanthesoides* and ***Acacia stigmatophylla*** (open) shrubland over *Distichostemon hispidulus* var. *phyllopterus* (= *Dodonaea hispidula* var. *phylloptera*) and *Galactia tenuiflora* scattered low shrubs over *Cenchrus elymoides* var. *brevisetosus* (= *C. brevisetosus*) and *Sorghum timorense* annual grassland.	x	–	–	–	–	–
CpTp	***Corymbia polycarpa***, ***Terminalia petiolaris***, *Garuga floribunda* var. *floribunda* and *Mimusops elengi* low closed forest over *Pavetta muelleri*, *Pittosporum moluccanum* (P4), *Sterculia quadrifida*, *Diospyros maritima* and *Vitex acuminata* tall (open) shrubland with lianas of *Abrus precatorius*, *Asparagus racemosus*, *Capparis sepiaria*, *Luvunga monophylla* and *Sarcostemma viminale* subsp. *brunonianum* (= *Cynanchum viminale* subsp. *brunonianum*).	x	–	–	–	–	–
CpTSt	***Corymbia polycarpa*** low open woodland over *Pavetta muelleri*, ***Trophis scandens*** (= *Malaisia scandens*), *Premna acuminata* and *Celtis philippensis* shrubland over ***Sorghum timorense*** and *Cenchrus elymoides* var. *brevisetosus* (= *C. brevisetosus*) closed tussock grassland over *Galactia tenuiflora* low open shrubland over *Indigofera linifolia*, *Spermacoce* sp. “Blue” (NM31-13) and *Gomphrena canescens* subsp. *canescens* open herbland. Where vegetation unit CpTSt occurs in gullies, its vine-thicket elements may become markedly denser. Although in some ways such a gully community may appear to be a discrete vegetation unit, in fact its species composition is essentially the same as that of the main extent of the CpTSt unit. In Figure 3-47 the gully community is the southernmost portion of the CpTSt unit in the vicinity of the latitude–longitude coordinates 14°24´25˝S, 124°58´35˝E.	x	–	–	–	–	–
FaGtSt	***Ficus aculeata* var. *aculeata*** open shrubland over ***Galactia tenuiflora*** and *Melhania oblongifolia* low open shrubland over ***Sorghum timorense*** annual grassland over *Gomphrena canescens* subsp. *canescens* and *Ptilotus conicus* very open herbland with lianas of *Tinospora smilacina*.	–	–	x	–	–	–
GfVT	***Garuga floribunda* var. *floribunda*** low open woodland over *Diospyros maritima*, *Celtis philippensis*, *Drypetes deplanchei*, *Sterculia quadrifida*, *Flueggea virosa* subsp. *melanthesoides* and *Pavetta muelleri* closed tall scrub with lianas of *Luvunga monophylla*, *Secamone timoriensis*, *Capparis sepiaria* and *Abrus precatorius*.	–	x	–	–	–	–
GfZC	***Garuga floribunda* var. *floribunda***, ***Zanthoxylum parviflorum***, *Mimusops elengi*, *Ganophyllum falcatum* and *Terminalia petiolaris* low (open) woodland over ***Celtis philippensis***, *Pavetta muelleri* and *Sterculia quadrifida* tall open shrubland over *Acacia gonocarpa* and *Diospyros maritima* low open shrubland over *Cenchrus elymoides* var. *brevisetosus* (= *C. brevisetosus*) annual grassland, and *Triodia microstachya* open hummock grassland with *Tinospora smilacina* lianas.	–	–	–	–	–	x
GGMd	***Ganophyllum falcatum***, ***Garuga floribunda* var. *floribunda***, *Diospyros rugosula* and *Diospyros maritima* low woodland over *Vitex glabrata*, *Sterculia quadrifida*, *Capparis sepiaria* and *Trophis scandens* (= *Malaisia scandens*) tall open scrub with closed lianas of ***Mucuna diabolica* subsp. *kenneallyi***, *Jasminum didymum* subsp. *didymum*, *Flagellaria indica*, *Pisonia aculeata* and *Pachygone ovata*.	–	–	–	x	–	–

Table 3-13: Vegetation unit codes and descriptions for each of the islands surveyed (continued)

Vegetation unit code	Description	Island					
		NMI	SMI	BER	EMI	WMI	LAM
GGVT	***Ganophyllum falcatum***, ***Garuga floribunda* var. *floribunda***, *Gyrocarpus americanus* subsp. *americanus* and *Glycosmis trifoliata* low open forest over *Diospyros maritima*, *Grewia breviflora*, ***Vitex glabrata***, *Diospyros rugosula*, *Mimusops elengi*, ***Trophis scandens*** (= *Malaisia scandens*), *Drypetes deplanchei* and *Pouteria sericea* (= *Sersalisia sericea*) tall open scrub over *Capparis sepiaria*, *Luvunga monophylla* shrubland over *Hypoestes floribunda* var. *suaveolens* low open shrubland with lianas of *Mucuna diabolica* subsp. *kenneallyi*, *Pisonia aculeata*, *Ipomoea trichosperma*, *Flagellaria indica* and *Adenia heterophylla.*	–	–	–	x	–	–
Gmi	***Gomphrena* sp. Maret Islands (A.A. Mitchell 5414)** open grassland with scattered grasses and herbs, often at low densities, usually at the edge of cliffs and ridges on the margins of the island.	x	x	x	–	x	–
GpPGS	***Grevillea pyramidalis* subsp. *pyramidalis*** (tall) open shrubland over ***Pavetta muelleri*** and *Mimusops elengi* (tall to low) open shrubland over ***Gomphrena canescens* subsp. *canescens***, *Ptilotus conicus* and ***Spermacoce* sp. "Blue"** (NM31-13) very open herbland over *Sorghum timorense* open annual grassland.	–	x	–	–	–	–
Lr	***Lumnitzera racemosa*** scattered low trees over *Sorghum timorense* open annual grassland, and *Spinifex longifolius* (open) grassland over *Ipomoea pes-caprae* subsp. *brasiliensis*, *Canavalia rosea* and *Ipomoea macrantha* open herbland.	–	x	–	–	–	–
MdAi	***Mucuna diabolica* subsp. *kenneallyi*** and *Flagellaria indica* closed lianas over *Morinda citrifolia* scattered tall shrubs over ***Abutilon indicum*** (low) open shrubland over *Xenostegia tridentata* very open herbland.	x	–	–	–	–	–
MlFi	***Melaleuca leucadendra*** open forest over *Mimusops elengi*, *Terminalia petiolaris*, *Exocarpos latifolius*, *Drypetes deplanchei* and *Canarium australianum* var. *velutinum* low woodland over *Acacia deltoidea* subsp. *deltoidea* and *Acacia gonocarpa* tall open shrubland over *Sorghum timorense* open annual grassland, and *Triodia microstachya* very open hummock grassland with *Passiflora foetida*, *Capparis sepiaria* and ***Flagellaria indica*** lianas.	–	–	–	–	–	x
PmCSt	***Pavetta muelleri***, *Mimusops elengi* and *Premna acuminata* open shrubland over ***Cenchrus elymoides* var. *brevisetosus*** (= *C. brevisetosus*) and ***Sorghum timorense*** (closed) annual grassland.	–	x	–	–	–	–
PmPa	***Pavetta muelleri***, ***Premna acuminata*** and *Mimusops elengi* tall shrubland over *Sterculia quadrifida*, *Grewia breviflora*, *Grewia glabra*, *Drypetes deplanchei* and *Celtis philippensis* (open) shrubland with lianas of *Abrus precatorius* and *Jacquemontia paniculata.*	–	x	–	–	–	–
PmSpCSt	***Pavetta muelleri***, *Mimusops elengi* and *Premna acuminata* open shrubland over ***Spinifex longifolius*** grassland, and ***Cenchrus elymoides* var. *brevisetosus*** (= *C. brevisetosus*) and ***Sorghum timorense*** (very) open grassland.	–	x	–	–	–	–
PsS	***Pandanus spiralis*** screw pine stands over ***Sorghum timorense*** annual grassland.	x	–	–	–	–	–
PsTbSt	***Pandanus spiralis*** screw pine stands with *Premna acuminata*, *Flueggea virosa* subsp. *melanthesoides*, *Grewia oxyphylla*, *Mimusops elengi*, *Pouteria sericea* (= *Sersalisia sericea*) and *Garuga floribunda* var. *floribunda* (tall) shrubland over *Capparis spinosa* var. *nummularia* and *Fioria vitifolia* (= *Hibiscus vitifolius*) over ***Triodia bynoei*** hummock grassland, ***Sorghum timorense*** annual grassland with lianas of *Tinospora smilacina* and *Ampelocissus acetosa.*	x	–	–	–	–	–

Table 3-13: Vegetation unit codes and descriptions for each of the islands surveyed (continued)

Vegetation unit code	Description	Island					
		NMI	SMI	BER	EMI	WMI	LAM
SqTp	***Sterculia quadrifida***, ***Terminalia petiolaris***, *Exocarpos latifolius*, *Ganophyllum falcatum* and *Mimusops elengi* (closed tall scrub) to closed low forest over *Drypetes deplanchei*, *Celtis philippensis*, *Pavetta muelleri*, *Croton habrophyllus*, *Flueggea virosa* subsp. *melanthesoides* and *Premna acuminata* (tall) shrubland over *Abutilon indicum*, *Hibiscus peralbus* and *Luvunga monophylla* scattered shrubs or open shrubland over *Commelina ensifolia*, *Boerhavia dominii* and *Achyranthes aspera* (very) open herbland with lianas of *Adenia heterophylla*, *Asparagus racemosus*, *Jacquemontia paniculata*, *Pachygone ovata* and *Cissus reniformis*.	x	–	–	–	–	–
SVCe	***Sterculia quadrifida***, ***Vitex glabrata***, *Garuga floribunda* var. *floribunda*, *Ganophyllum falcatum* and *Drypetes deplanchei* tall open scrub over ***Cenchrus elymoides* var. *brevisetosus*** (= *C. brevisetosus*) very open annual grassland.	–	–	–	–	–	x
TbEc	***Triodia bynoei*** (closed) hummock grassland, ***Eriachne ciliata*** very open annual grassland over *Synaptantha scleranthoides*, *Gomphrena parviflora*, *Spermacoce* sp. “White” (NM21-01) and *Buchnera asperata* very open herbland.	–	–	–	x	–	–
TbG	***Triodia bynoei*** (open) hummock grassland over ***Gomphrena canescens* subsp. *canescens***, ***Gomphrena flaccida***, ***Gomphrena parviflora***, *Ptilotus conicus* and *Calandrinia uniflora* open herbland over *Bulbostylis barbata* very open sedgeland.	x	x	–	–	–	–
TcAr	***Terminalia canescens*** tall open shrubland over ***Acacia retinervis*** scattered shrubs over open shrubland over *Triodia bynoei* (open) hummock grassland and *Sorghum timorense* open annual grassland over *Gomphrena flaccida* open herbland.	x	–	–	–	–	–
TcAsTbS	***Terminalia canescens*** tall open shrubland over ***Acacia stigmatophylla***, *Wrightia saligna*, *Breynia cernua*, *Flueggea virosa* subsp. *melanthesoides* open shrubland over ***Triodia bynoei*** hummock grassland and ***Sorghum timorense*** very open annual grassland.	–	x	–	–	–	–
TcF	***Terminalia canescens*** and ***Flueggea virosa* subsp. *melanthesoides*** scattered shrubs over *Buchanania oblongifolia*, *Melhania oblongifolia* and *Tephrosia rosea* var. *rosea* low open shrubland over *Gomphrena canescens* subsp. *canescens* and *Hibiscus geranioides* herbland over *Heteropogon contortus*, *Enneapogon pallidus* and *Sorghum timorense* closed annual grassland over *Fimbristylis cymosa* very open sedgeland.	x	–	–	–	–	–
TcG	***Terminalia canescens***, ***Grevillea pyramidalis* subsp. *pyramidalis***, *Pavetta muelleri* and *Ficus aculeata* var. *aculeata* open shrubland over *Acacia stigmatophylla*, *Flueggea virosa* subsp. *melanthesoides*, *Hibiscus leptocladus*, *Pouteria sericea* (= *Sersalisia sericea*) and *Triumfetta aquila* open low heath over *Sorghum timorense* closed annual grassland and *Triodia bynoei* scattered hummock grasses.	x	–	–	–	–	–
TdGff	***Tarenna dallachiana***, ***Garuga floribunda* var. *floribunda*** and *Terminalia petiolaris* scattered low trees over *Grewia breviflora*, *Premna acuminata*, *Pouteria sericea* (= *Sersalisia sericea*) and *Diospyros maritima* open heath or tall open scrub over *Flueggea virosa* subsp. *melanthesoides* and *Hibiscus peralbus* low shrubland over *Xenostegia tridentata* and *Indigofera linifolia* open herbland with lianas of *Jacquemontia paniculata*, *Luvunga monophylla*, *Abrus precatorius* and *Capparis sepiaria.*	–	–	–	–	x	–
TmG	***Triodia microstachya*** grassland on coastal dunes.	–	–	–	–	–	x
TpArTb	***Corymbia clavigera*** and ***Terminalia petiolaris*** low open woodland over ***Acacia retinervis*** tall open shrubland over *Flueggea virosa* subsp. *melanthesoides*, *Garuga floribunda* var. *floribunda* and *Pavetta muelleri* open shrubland over *Gomphrena parviflora* and *Gonocarpus leptothecus* very open herbland over ***Triodia bynoei*** hummock grassland.	–	x	–	–	–	–

Table 3-13: Vegetation unit codes and descriptions for each of the islands surveyed (continued)

Vegetation unit code	Description	Island					
		NMI	SMI	BER	EMI	WMI	LAM
TpGf	***Diospyros maritima***, *Mimusops elengi*, ***Terminalia petiolaris***, ***Garuga floribunda* var. *floribunda*** and *Ganophyllum falcatum* low closed forest over *Celtis philippensis*, *Trophis scandens* (= *Malaisia scandens*), *Glycosmis trifoliata*, *Premna acuminata* and *Pouteria sericea* (= *Sersalisia sericea*) (open) shrubland with lianas of *Mucuna diabolica* subsp. *kenneallyi*, *Pachygone ovata*, *Pisonia aculeata* and *Adenia heterophylla.*	x	–	–	–	–	–
TpGffMe	***Terminalia petiolaris***, *Ganophyllum falcatum*, ***Garuga floribunda* var. *floribunda*** and *Glycosmis trifoliata* low woodland over *Croton habrophyllus*, *Sterculia quadrifida*, ***Mimusops elengi***, *Flueggea virosa* subsp. *melanthesoides*, *Diospyros maritima*, *Celtis philippensis*, *Strychnos lucida* and *Exocarpos latifolius* tall open scrub over *Tarenna pentamera* and *Grewia glabra* shrubland over *Hibiscus peralbus* low shrubland over *Sorghum timorense* very open grassland over *Achyranthes aspera* and *Commelina ensifolia* very open herbland with lianas of *Jacquemontia paniculata*, *Luvunga monophylla*, *Capparis sepiaria*, *Abrus precatorius* and *Rhynchosia minima* var. *australis.*	–	x	–	–	–	–
TpPM	***Terminalia petiolaris***, ***Pittosporum moluccanum*** (P4) and ***Mimusops elengi*** scattered low trees over *Pavetta muelleri*, *Premna acuminata*, *Buchanania oblongifolia* and *Celtis philippensis* shrubland over *Acacia stigmatophylla* low open shrubland over *Triodia bynoei* open hummock grassland and *Sorghum timorense* open annual grassland with lianas of *Jacquemontia paniculata.*	x	–	–	–	–	–
TpSq	***Terminalia petiolaris*** low open woodland over ***Sterculia quadrifida*** closed tall scrub over *Pittosporum moluccanum* (P4), *Drypetes deplanchei*, *Pouteria sericea* (= *Sersalisia sericea*), *Flueggea virosa* subsp. *melanthesoides*, *Pavetta muelleri* and *Celtis philippensis* open shrubland with lianas of *Adenia heterophylla*, *Ipomoea macrantha* and *Flagellaria indica*.	x	–	–	–	–	–
UVU	Undescribed vegetation unit.	–	–	–	–	–	x


Figure 3-44: Vegetation unit ArTb—South Maret Island (SM01)


Figure 3-45: Vegetation unit TbG—North Maret Island (SM13)


Figure 3-46: Vegetation unit CpcTASt—South Maret Island (SM12)

Vegetation distributions by island

North Maret Island

A total of 162 taxa from 54 families were collected or recorded on North Maret Island (see tables 3-10 and 3-14).

Table 3-14: Numbers of taxa per family recorded on North Maret Island

Family	No. of taxa	Family	No. of taxa	Family	No. of taxa
Amaranthaceae	8	Amaryllidaceae	1	Anacardiaceae	1
Apocynaceae	3	Araliaceae	1	Asparagaceae	1
Asteraceae	1	Boraginaceae	3	Burseraceae	1
Cannabaceae	1	Capparaceae	3	Caryophyllaceae	1
Chenopodiaceae	1	Cleomaceae	1	Combretaceae	2
Commelinaceae	1	Convolvulaceae	9	Cucurbitaceae	1
Cyperaceae	3	Dioscoreaceae	1	Ebenaceae	2
Euphorbiaceae	4	Fabaceae (subfamily Caesalpinioideae)	1	Fabaceae (subfamily Faboideae)	14
Fabaceae (subfamily Mimosoideae)	2	Flagellariaceae	1	Goodeniaceae	2
Lamiaceae	3	Lauraceae	3	Loganiaceae	1
Loranthaceae	2	Malvaceae	15	Menispermaceae	2
Moraceae	3	Myrtaceae	3	Nyctaginaceae	3
Oleaceae	1	Orobanchaceae	2	Pandanaceae	1
Passifloraceae	1	Phyllanthaceae	6	Pittosporaceae	1
Poaceae	13	Polygalaceae	2	Portulacaceae	5
Proteaceae	1	Putranjivaceae	1	Rubiaceae	7
Rutaceae	2	Santalaceae	1	Sapindaceae	4
Sapotaceae	2	Stylidiaceae	1	Taccaceae	1
Vitaceae	3	Zygophyllaceae	2		

Declared Rare Flora, Priority Flora and significant flora

- Conservation significance 1: no Declared Rare Flora species as listed in the *Wildlife Conservation (Rare Flora) Notice 2006(2)* (Government of Western Australia 2006) were found on North Maret Island.
- Conservation significance 2: two Priority Flora species were collected during this survey:
  - *Pittosporum moluccanum* (P4): this species is widely distributed across North Maret Island on slopes, in vine thicket and on the plateau, in a variety of vegetation units but not including grassland units such as TbG, ArTb and AsTb.
  - *Brachychiton xanthophyllus* (P4): this species occurs intermittently in woodland, specifically in the CpTSt, CpcTcAr and CpTcAs vegetation units.
- Conservation significance 3: a summary list of the 14 taxa in this category found on North Maret Island is provided in Table 3-15.

Table 3-15: North Maret Island: taxa of "conservation significance 3" and their distribution ranges

Name	Notes
Carissa lanceolata – C. ovata intergrade (NM10-15)	This plant is possibly more of taxonomic interest than of conservation significance. It is widely distributed in most vegetation units.
Cayratia maritima	Prior to this survey, there was only one other record from Western Australia from a nearby island (held in a Queensland herbarium and therefore not registered on the Western Australian plant census). It appears locally common but is of unknown wider distribution. It was recorded in the vegetation units CpTcAs, CptSt and MdAi. It was also found during this survey on Berthier Island, East Montalivet Island and Lamarck Island.
Cleome sp. Bonaparte Archipelago (A.A. Mitchell 4774)	This is a new taxon, previously confused with *Cleome viscosa*, found on several Kimberley islands. Further work is required to determine how widespread it is. It was recorded from a variety of vegetation units: ArTb, ArTcTb, TbG, AsTb, AsTm, TcF, CpTcAs, CpTSt and CpcTcAr.
Commicarpus chinensis subsp. *chinensis*	This subspecies is also known from two nearby islands, but was not previously recognised as this species. This was an opportunistic collection at 713235mE, 8405336mN[9] (WGS84), in a gully behind Speargrass Beach (see Figure 3-1).
Corymbia clavigera	Prior to this survey, this species was only known from five records. It is very poorly known and is potentially of restricted distribution. It was recorded on the plateau in the vegetation units CpcTASt and CpcTcAr but it is not widely distributed on North Maret Island.
Evolvulus sp. "White Flower" (NM14-05)	Recorded once in the TbG vegetation unit, at the time of the survey this taxon was thought to be possibly "new". It has since been confirmed to be *Evolvulus alsinoides* var. *alsinoides*.
Gomphrena sp. Maret Islands (A.A. Mitchell 5414)	This taxon was first found on South Maret Island prior to this survey, and also later on West Montalivet Island. It was recorded in the Gmi vegetation unit.
Goodenia sp. aff. *microptera* (NM27-19)	This is possibly a new taxon. It is currently known only from North Maret Island and Berthier Island and was recorded in the vegetation units ArTb, ArsTbs, CpcTcAr and TcF.
Heliotropium sp. aff. *dichotomum*	This is possibly a new taxon. It was recognised late in the survey program as being related to *Heliotropium dichotomum*, a species from the east Kimberley. Further taxonomic studies are required to determine its identity. It was found scattered in open grasslands on North Maret Island and South Maret Island.
Hibiscus peralbus	Of restricted distribution and probably a good indicator species for rainforest health, this species was recorded or observed in the vegetation units CpTp, SqTp and TpGf.
Mucuna diabolica subsp. *kenneallyi*	This subspecies has only four previous records in the Western Australian Herbarium. It is possibly widespread but its extent is not known. It was recorded in the vegetation unit MdAi.
Portulaca sp. "River Mud" (R.L. Barrett 3285)	This is a recently recognised species that is still poorly known, but probably widespread. It was an opportunistic collection from 713310mE, 8406986mN, on the edge of Brunei Bay Beach (see Figure 3-1), but it was also observed on the North Maret Island plateau.
Spermacoce sp. "Blue" (NM31-13)	The taxonomy of this plant has still to be resolved, but it is possibly new. It was recorded in the CpTSt and AsTb vegetation units, and opportunistically in the TbG vegetation unit.
Spermacoce sp. "White" (NM21-01)	The taxonomy of this plant has still to be resolved, but it is possibly new. It was recorded in the AsTb, ArsTbS, ArTb and CpcTASt vegetation units.

[9] Coordinates provided relative to the World Geodetic System 1984 (WGS84), utilised by the global positioning system (GPS), have been referenced in this text as relative to the Geocentric Datum of Australia 1994 (GDA94) to provide a consistent coordinate reference system (CRS) throughout this book. For all practical purposes, GDA94 coordinates can be considered to be coincident with those of WGS84.

Vegetation

Twenty-four vegetation units were described for North Maret Island from data collected in the quadrats and vine-thicket transects (Figure 3-47). In total, North Maret Island has 26.40 ha of vine thicket (vegetation units SqTp, TpGf, TpPM, and TpSq).

It should be noted that one example of the vegetation unit AiTSpC, from behind Brunei Bay Beach (see Figure 3-1), has been largely extrapolated from aerial photography and has not been ground-truthed. This is because this area could not be accessed for Aboriginal cultural heritage reasons by the survey team. This AiTSpC unit was confirmed at the northern part of this area where it is adjacent to the CpTp unit.

The following 12 vegetation units were considered to be significant:

ArsTbS: a shrubland–grassland unit represented by one community on the northern tip of North Maret Island covering 2.03 ha.

AsSt: a shrubland–grassland unit represented by one community towards the southern tip of North Maret Island covering 8.1 ha.

AsTm: a shrubland–grassland unit represented by one community above the south-western beach; this is the major representation of *Triodia microstachya* on the Maret Islands and covers 4.48 ha.

CcVTSt: a *Corymbia* low open forest unit with vine-thicket elements occurring in an incised drainage line above the cliffs on the north-western side of the island; it covers 2.36 ha.

Gmi: a shrubland unit which includes the new taxon *Gomphrena* sp. Maret Islands (A.A. Mitchell 5414); it is restricted to small patches on cliffs above beaches.

MdAi: a unit with vine-thicket elements, restricted to a deeply incised gully on the south-east side of the island covering only 0.36 ha. It is the only representation of the vine *Mucuna diabolica* subsp. *kenneallyi* on the Maret Islands, the nearest populations being found on Berthier Island and East Montalivet Island.

PsS: a shrubland community consisting of a dense pure stand of *Pandanus spiralis* (all other examples of *P. spiralis* communities on North Maret Island are mixed); it covers 0.16 ha on the north-west coast.

TcAr: a single community of shrubland vegetation on the plateau above Queenfish Beach (see Figure 3-1) covering 2.2 ha.

TcF: a shrubland unit represented by one community on the south-west side of the island covering 3.3 ha.

TcG: a shrubland unit represented by one community covering 1.5 ha in a shallow drainage line on the western side of the island.

TpPM: a unit with vine-thicket elements represented by a single community on the north-eastern side of North Maret Island that appears to receive extra drainage from surrounding slopes; it covers 2.9 ha.

TpSq: a unit with vine-thicket elements; although occurring at a number of sites around the island, it covers only 2.75 ha.

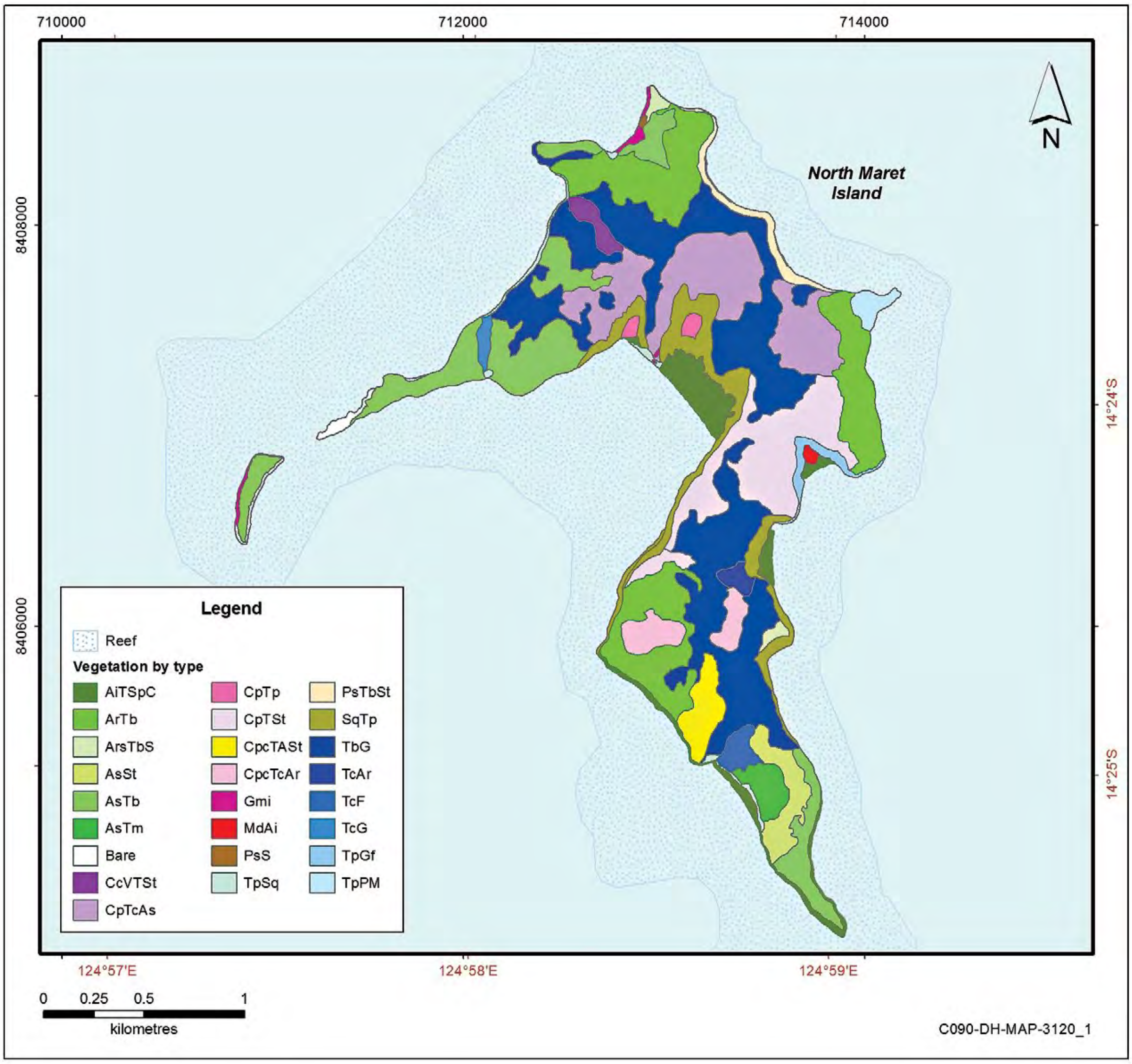


Figure 3-47: Vegetation units of North Maret Island (refer to Table 3-13 for vegetation unit descriptions)

South Maret Island

A total of 185 taxa from 56 families were collected or otherwise recorded on South Maret Island (see tables 3-10 and 3-16).

Table 3-16: Numbers of taxa per family recorded on South Maret Island

Family	No. of taxa	Family	No. of taxa	Family	No. of taxa
Acanthaceae	1	Amaranthaceae	9	Amaryllidaceae	1
Anacardiaceae	1	Apocynaceae	11	Araliaceae	1
Asparagaceae	1	Asteraceae	2	Boraginaceae	4
Burseraceae	1	Cannabaceae	1	Capparaceae	3
Caryophyllaceae	1	Chenopodiaceae	1	Cleomaceae	2
Combretaceae	3	Commelinaceae	1	Convolvulaceae	9
Cucurbitaceae	1	Cyperaceae	3	Dioscoreaceae	2
Ebenaceae	3	Euphorbiaceae	3	Fabaceae (subfamily Caesalpinioideae)	1
Fabaceae (subfamily Faboideae)	17	Fabaceae (subfamily Mimosoideae)	4	Flagellariaceae	1
Goodeniaceae	2	Haloragaceae	1	Lamiaceae	3
Lauraceae	3	Loganiaceae	1	Loranthaceae	2
Malvaceae	14	Menispermaceae	2	Moraceae	3
Myrtaceae	3	Nyctaginaceae	4	Oleaceae	1
Orobanchaceae	3	Pandanaceae	1	Passifloraceae	1
Phyllanthaceae	6	Pittosporaceae	1	Poaceae	16
Polygalaceae	2	Portulacaceae	4	Proteaceae	1
Putranjivaceae	1	Rubiaceae	6	Rutaceae	3
Santalaceae	1	Sapindaceae	4	Sapotaceae	2
Stylidiaceae	1	Taccaceae	1	Vitaceae	2
Zygophyllaceae	2				

Declared Rare Flora, Priority Flora and significant flora

- Conservation significance 1: no Declared Rare Flora species as listed in the *Wildlife Conservation (Rare Flora) Notice 2006(2)* (Government of Western Australia 2006) were found on South Maret Island.
- Conservation significance 2: one Priority Flora species was recorded during this survey:
  - *Pittosporum moluccanum* (P4): this species is widespread in a variety of habitats and was recorded at 14 sites in five vegetation units, CpcTASt, CcpVTSt, GpPGS, CcpAr and TpGffMe.
- Conservation significance 3: sixteen taxa were collected on South Maret Island that are considered to be significant although they do not currently have a conservation code (Table 3-17).

Table 3-17: South Maret Island: taxa of "conservation significance 3" and their distribution ranges

Name	Notes
Carissa lanceolata – C. ovata intergrade (NM10-15)	This plant is possibly more of taxonomic interest than of conservation significance. It was found in a wide variety of habitats in the vegetation units ArTb, ArTcTb, TcAsTbS, CcpVTSt, CpcTASt, CcpAr, PmPa and TpArTb.
Cathormion umbellatum subsp. *moniliforme*	This collection (together with another on Berthier Island) represents a significant range extension westwards for this taxon in Western Australia. It was recorded in vegetation unit TpGffMe and opportunistically at 714670mE, 8403150mN above the beach on the north-east coast of South Maret Island.
Cleome sp. Bonaparte Archipelago (A.A. Mitchell 4774)	This is a new taxon, previously confused with *Cleome viscosa*, found on several Kimberley region islands. Further work is required to determine how widespread it is. It was recorded in vegetation units TbG, CpcTASt and GpPGS.
Commicarpus chinensis subsp. *chinensis*	This subspecies is also known from two nearby islands, but was not previously recognised as this species. It was recorded in vegetation unit TpGffMe and opportunistically at 713750mE, 8401662mN above South Beach (see Figure 3-2) and at 714633mE, 8513120mN in the thicket above the beach on the north-east coast of South Maret Island.
Cordia subcordata	This species is known from only 12 other collections, ten in the Kimberley and two in the Pilbara. It was recorded opportunistically at South Beach on South Maret Island at 714158mE, 8401772mN (see Figure 3-2).
Corymbia bleeseri	This species is known from a number of collections in the far north Kimberley. Recorded as a few plants on the plateau on South Maret Island, this population represents a significant disjunction from mainland populations.
Corymbia clavigera	Prior to this study, this species had only been recorded on five previous occasions. It is very poorly known and potentially of restricted distribution. It was recorded in vegetation units CcpAr, CcpVTSt, CpcTASt and TpArTb.
Diospyros rugosula	Along with the collections from Berthier Island and East Montalivet Island this was considered to be a new record of *D. hebecarpa* for Western Australia. It was found in vine thicket. Following a review of the taxonomy of this group, it has been determined that the correct name for these collections is *D. rugosula*.
Eriachne sulcata	This collection was an unusually hairy form. The species is possibly widespread in the Kimberley region but has been poorly collected. It was collected in vegetation unit TbG.
Evolvulus sp. "White Flower" (NM14-05)	Recorded twice in the ArTcTb vegetation unit, at the time of the survey this taxon was thought to be possibly "new". It has since been confirmed to be *Evolvulus alsinoides* var. *alsinoides*.
Gomphrena sp. Maret Islands (A.A. Mitchell 5414)	This taxon was first found on South Maret Island prior to this survey, and also later on West Montalivet Island. It was collected opportunistically at 713907mE, 8403937mN near the isthmus between the two islands, at 714348mE, 8402269mN, and at 714816mE, 8403107mN on the east coast by Cormorant Beach (see Figure 3-2).
Heliotropium sp. aff. *dichotomum*	This is possibly a new taxon. It was recognised late in the survey program as being related to *Heliotropium dichotomum*, a species from the east Kimberley. Further taxonomic studies are required to determine its identity. It was found scattered in open grasslands on North Maret Island and South Maret Island.
Hibiscus peralbus	Of restricted distribution and probably a good indicator species for rainforest health, this species was recorded in the vegetation units CcpAr, CpcTASt and TpGffMe.
Portulaca sp. "River Mud" (R.L. Barrett 3285)	This is a recently recognised species that is still poorly known, but probably widespread. It was recorded in the vegetation units ArTcTb, TcAsTbS and TpArTb.
**Pupalia micrantha*	This plant has been treated as an introduced species as it has weedy characteristics. However it is possibly native but poorly collected in Western Australia. It was recorded in the TpGffMe vegetation unit.
Spermacoce sp. "Blue" (NM31-13)	The taxonomy of this plant has still to be resolved, but it is possibly new. It was recorded in the GpPGS vegetation unit.

Vegetation

Sixteen vegetation units were described for South Maret Island from data collected in the quadrats and vine-thicket transects (Figure 3-48). In total, South Maret Island has 74.76 ha of vine thicket (vegetation units GfVT, PmPa, TpGffMe).

The following seven vegetation units were considered to be significant:

ArTb: a shrubland–grassland unit represented by one community on South Maret Island covering approximately 7.3 ha. It is also represented on North Maret Island where it covers approximately 46.7 ha.

GfVT: a vegetation unit with vine-thicket elements represented by one community covering approximately 3.16 ha. It is restricted to a shallow drainage line above the western coast.

Gmi: a shrubland unit represented by three small communities with a total area of just over 1 ha. The *Gomphrena* species that this vegetation unit is named after is a new taxon, *Gomphrena* sp. Maret Islands (A.A. Mitchell 5414), possibly with a restricted distribution.

PmPa: a vegetation unit with vine-thicket elements represented by two communities on the north-east coast of the island which cover just over 1 ha.

PmCSt: a shrubland–grassland unit with vine-thicket elements represented by one community on the east coast covering approximately 2.5 ha.

PmSpCSt: a shrubland–grassland unit represented by three communities behind beaches, covering approximately 4.8 ha.

Lr: the white-flowered black mangrove *Lumnitzera racemosa* is the only mangrove species occurring on the Maret Islands. Although widespread in the Kimberley, it is represented on the Maret Islands in only one small patch in a non-tidal location at the northern end of Sparrowhawk Beach (see Figure 3-2) on the east coast of South Maret Island.

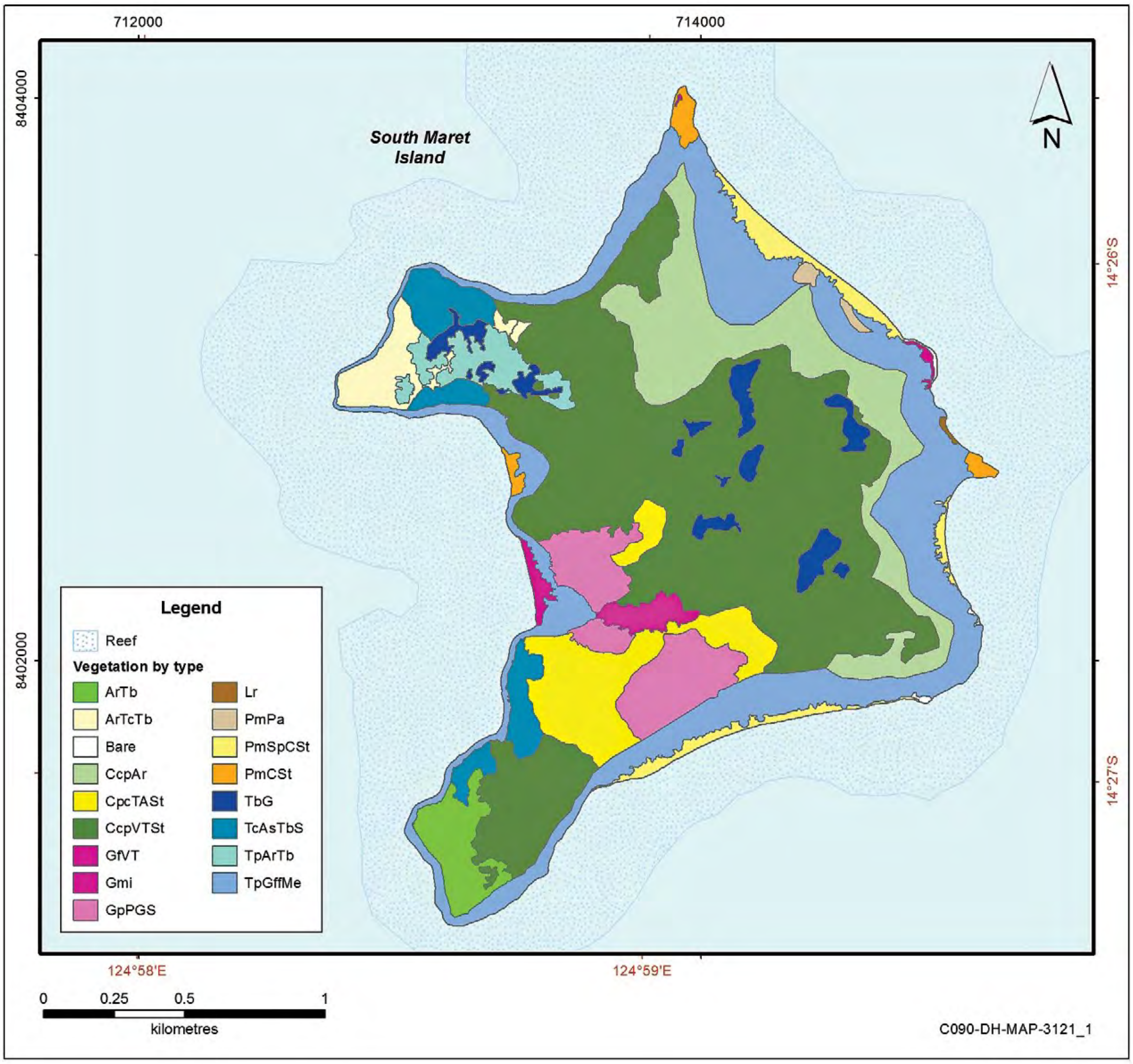


Figure 3-48: Vegetation units of South Maret Island (refer to Table 3-13 for vegetation unit descriptions)

3 TERRESTRIAL FLORA

Berthier Island

A total of 209 taxa from 58 families were collected or recorded on Berthier Island (see tables 3-10 and 3-18).

Table 3-18: Numbers of taxa per family recorded on Berthier Island

Family	No. of taxa	Family	No. of taxa	Family	No. of taxa
Acanthaceae	3	Amaranthaceae	9	Amaryllidaceae	1
Anacardiaceae	1	Apocynaceae	10	Araliaceae	1
Asparagaceae	1	Asteraceae	4	Bixaceae	1
Burseraceae	1	Cannabaceae	2	Boraginaceae	1
Caryophyllaceae	1	Chenopodiaceae	1	Capparaceae	5
Combretaceae	3	Commelinaceae	1	Cleomaceae	1
Cucurbitaceae	3	Cyperaceae	1	Convolvulaceae	11
Ebenaceae	3	Euphorbiaceae	3	Dioscoreaceae	2
Fabaceae (subfamily Faboideae)	26	Fabaceae (subfamily Mimosoideae)	5	Fabaceae (subfamily Caesalpinioideae)	2
Goodeniaceae	3	Lamiaceae	6	Flagellariaceae	1
Loganiaceae	1	Loranthaceae	2	Lauraceae	2
Meliaceae	1	Menispermaceae	2	Malvaceae	17
Myrtaceae	3	Nyctaginaceae	3	Moraceae	4
Orobanchaceae	4	Pandanaceae	1	Oleaceae	2
Phyllanthaceae	7	Pittosporaceae	1	Passifloraceae	2
Polygalaceae	1	Portulacaceae	3	Poaceae	15
Pteridaceae	2	Putranjivaceae	1	Proteaceae	2
Rutaceae	3	Santalaceae	1	Rubiaceae	3
Sapotaceae	2	Stylidiaceae	1	Sapindaceae	5
Vitaceae	3	Zygophyllaceae	1	Taccaceae	1

Declared Rare Flora, Priority Flora and significant flora

- Conservation significance 1: no Declared Rare Flora species as listed in the *Wildlife Conservation (Rare Flora) Notice 2006(2)* (Government of Western Australia 2006) were found on Berthier Island.
- Conservation significance 2: one Priority Flora species was recorded during this survey:
  - *Pittosporum moluccanum* (P4): this species is widespread in a variety of habitats, was recorded at 18 sites, and occurs in seven of the nine vegetation units described for Berthier Island, ArGS, BcBd, BdGff, CcAr, CcPmVg, CpArG and CPAr.
- Conservation significance 3: a summary list of the 12 taxa in this category found on Berthier Island is provided in Table 3-19.

Table 3-19: Berthier Island: taxa of "conservation significance 3" and their distribution ranges

Name	Notes
Carissa lanceolata – C. ovata intergrade (NM10-15)	This plant is possibly more of taxonomic interest than of conservation significance. It was found in the vegetation units ArGS, BcBd, BdGff, CpAr, CcPmVg and CpArG.
Cathormion umbellatum subsp. *moniliforme*	This record (together with another on South Maret Island) represents a significant range extension westwards for this taxon in Western Australia. It was collected opportunistically in vine thicket above the south-east beach at 714863mE, 8393804mN.
Cayratia maritima	Prior to this survey, there was only one other record from Western Australia from a nearby island (held in a Queensland herbarium and therefore not registered on the Western Australian plant census). It appears locally common but is of unknown wider distribution. It was recorded in the vegetation units BcBd, CcPmVg and CpAr. It was also found during this survey on North Maret Island, East Montalivet Island and Lamarck Island.
Cleome sp. Bonaparte Archipelago (A.A. Mitchell 4774)	This is a new taxon, previously confused with *Cleome viscosa*, found on several Kimberley region islands. Further work is required to determine how widespread it is. It was recorded in vegetation units BdGff and FaGtSt.
Commicarpus chinensis subsp. *chinensis*	This subspecies is also known from two nearby islands, but was not previously recognised as this species. It was recorded in vegetation units CpArG and CcPmVg.
Corymbia clavigera	Prior to this survey, this species was only known from five records. It is very poorly known and is potentially of restricted distribution. It was recorded in vegetation units CcAr and CcPmVg.
Diospyros rugosula	Along with the collections from South Maret Island and East Montalivet Island this was considered to be a new record of *D. hebecarpa* for Western Australia. It was found in vine thicket. Following a review of the taxonomy of this group, it has been determined that the correct name for these collections is *D. rugosula*. It was recorded in vegetation units CcPmVg and CpArG.
Evolvolus sp. "White Flower" (NM14-05)	Recorded in the vegetation unit BdGff, at the time of the survey this taxon was thought to be possibly "new". It has since been confirmed to be *Evolvulus alsinoides* var. *alsinoides*.
Gomphrena sp. Maret Islands (A.A. Mitchell 5414)	This taxon was first found on South Maret Island prior to this survey, and also later on West Montalivet Island. It was recorded at numerous locations on Berthier Island and coded as vegetation unit Gmi.
Hibiscus peralbus	Of restricted distribution and probably a good indicator species for rainforest health, this species was recorded in the vegetation units BcBd, BdGff, CcPmVg, CpArG and CpAr.
Secamone timoriensis	This species is known from six other collections in Western Australia, only one of which is held in the Western Australian Herbarium. It was recorded in vegetation units BdGff, CcAr, CcPmVg and CpArG.
Spermacoce sp. Berthier Dunes (R.L. Barrett RLB 5753) (P3)	This record was an opportunistic collection from dunes by the beach at 714661mE, 8396668mN. This a new species.

Vegetation

Nine vegetation units were described for Berthier Island from the areas surveyed. This is not a definitive list of the vegetation units of Berthier Island, however, as survey sites were chosen selectively for comparison with the Maret Islands. These units are displayed in the vegetation map provided in Figure 3-49. The map includes a tenth vegetation unit marked as "Unsurveyed vine thicket". This unit was not surveyed on the ground but was identified from the aerial survey as a vine-thicket association; its constituent taxa are as yet unknown.

Berthier Island was not surveyed in sufficient detail to provide information as to which vegetation units might be considered to be significant. However, the unit Gmi is significant as it contains the new taxon *Gomphrena* sp. Maret Islands (A.A. Mitchell 5414), the distribution of which is possibly restricted.

The vegetation map for Berthier Island is incomplete, as the entire island was not surveyed. The focus when surveying the island was on vegetation that resembled communities on the Maret Islands. Units have been extrapolated from quadrat and transect data on aerial photography for those areas mapped, but their exact extent has not been adequately ground-truthed.

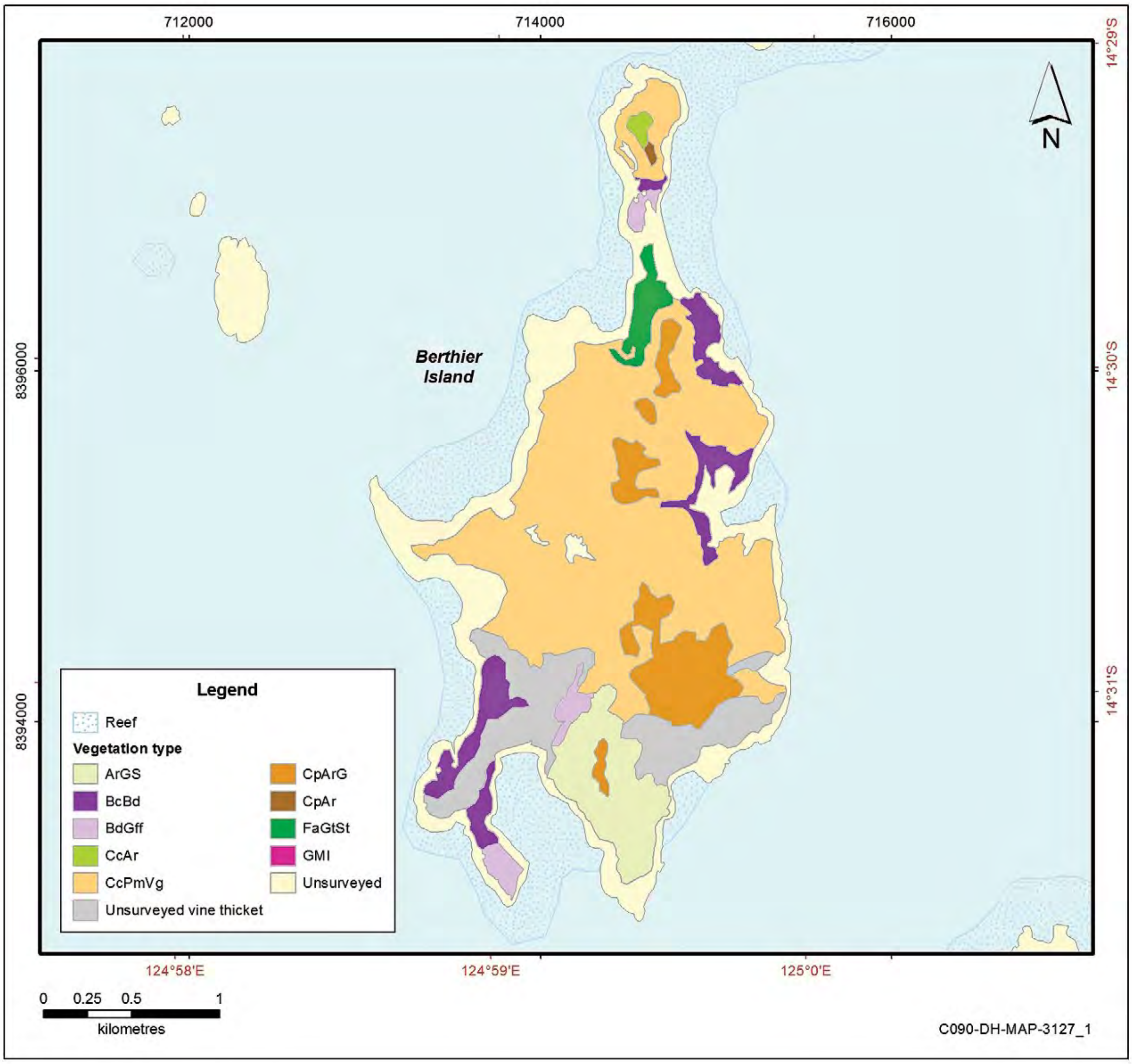


Figure 3-49: Vegetation units of Berthier Island (provisional) (refer to Table 3-13 for vegetation unit descriptions)

East Montalivet Island

A total of 142 taxa from 48 families were collected or otherwise recorded from East Montalivet Island (see tables 3-10 and 3-20).

Table 3-20: Numbers of taxa per family recorded on East Montalivet Island

Family	No. of taxa	Family	No. of taxa	Family	No. of taxa
Acanthaceae	1	Amaranthaceae	7	Amaryllidaceae	1
Apocynaceae	7	Asparagaceae	1	Asteraceae	1
Bignoniaceae	1	Burseraceae	1	Cannabaceae	1
Capparaceae	2	Celastraceae	1	Cleomaceae	1
Combretaceae	2	Commelinaceae	1	Convolvulaceae	7
Cucurbitaceae	1	Cyperaceae	1	Dioscoreaceae	1
Ebenaceae	3	Euphorbiaceae	4	Fabaceae (subfamily Caesalpinioideae)	2
Fabaceae (subfamily Faboideae)	22	Fabaceae (subfamily Mimosoideae)	2	Flagellariaceae	1
Hernandiaceae	1	Lamiaceae	2	Lauraceae	3
Loganiaceae	2	Malvaceae	12	Menispermaceae	2
Moraceae	1	Myrtaceae	1	Nyctaginaceae	1
Oleaceae	1	Orobanchaceae	1	Passifloraceae	1
Phyllanthaceae	6	Poaceae	12	Polygalaceae	2
Portulacaceae	1	Proteaceae	1	Pteridaceae	1
Putranjivaceae	1	Rubiaceae	5	Rutaceae	2
Santalaceae	1	Sapindaceae	3	Sapotaceae	2
Taccaceae	2	Vitaceae	3		

Declared Rare Flora, Priority Flora and significant flora

- Conservation significance 1: no Declared Rare Flora species as listed in the *Wildlife Conservation (Rare Flora) Notice 2006(2)* (Government of Western Australia 2006) were found on East Montalivet Island.
- Conservation significance 2: one Priority Flora species was recorded during this survey:
  - *Brachychiton xanthophyllus* (P4) was recorded in vegetation units CcArTb and BtTpTcS.
- Conservation significance 3: eight taxa were collected on East Montalivet Island that, while not currently having a conservation code, are considered to be significant for various reasons (Table 3-21).

Table 3-21: East Montalivet Island: taxa of "conservation significance 3" and their distribution ranges

Name	Notes
Carissa lanceolata – C. ovata intergrade (NM10-15)	This intergrade is possibly more of taxonomic interest than of conservation significance.
**Chamaecrista nigricans*	This species is widespread in the Northern Territory but known in Western Australia from only one collection. This is the first record of this species in the state for over a century. It was recorded from the unit BtTpTcS.
Cleome sp. Bonaparte Archipelago (A.A. Mitchell 4774)	This is a new taxon, previously confused with *Cleome viscosa*, found on several Kimberley region islands. Further work is required to determine how widespread it is. It was recorded in vegetation unit BtTpTcS.
Corymbia clavigera	Prior to this survey, this species was only known from five records. It is very poorly known and is potentially of restricted distribution. It was recorded in vegetation unit CcArTb.
Cullen leucanthum	The record represents a range extension for this species, which was only recorded once previously in the north of the Kimberley region although it is widespread and relatively common in the Pilbara region. It was recorded in vegetation unit BtTpTcS.
Diospyros rugosula	Along with the collections from South Maret Island and Berthier Island this was considered to be a new record of *D. hebecarpa* for Western Australia. It was found in vine thicket. Following a review of the taxonomy of this group, it has been determined that the correct name for these collections is *D. rugosula*. It was recorded in vegetation units GGMd and GGVT.

Table 3-21: East Montalivet Island: taxa of "conservation significance 3" and their distribution ranges (continued)

Name	Notes
Hibiscus peralbus	Of restricted distribution and probably a good indicator species for rainforest health, this species was recorded in vegetation units BtTpTcS and GGVT.
Mucuna diabolica subsp. *kenneallyi*	This subspecies has only four previous records in the Western Australian Herbarium. It is possibly widespread but its extent is not known. It was recorded in vegetation unit GGMd.

Vegetation

Five vegetation units were described for East Montalivet Island. This is not a definitive list of vegetation types for the island as sites were chosen selectively for comparison with the Maret Islands. The units are displayed in the vegetation map (Figure 3-50).

No vegetation units defined for East Montalivet Island were present on the other islands surveyed.

East Montalivet Island was not surveyed in sufficient detail to provide information as to which vegetation units might be significant.

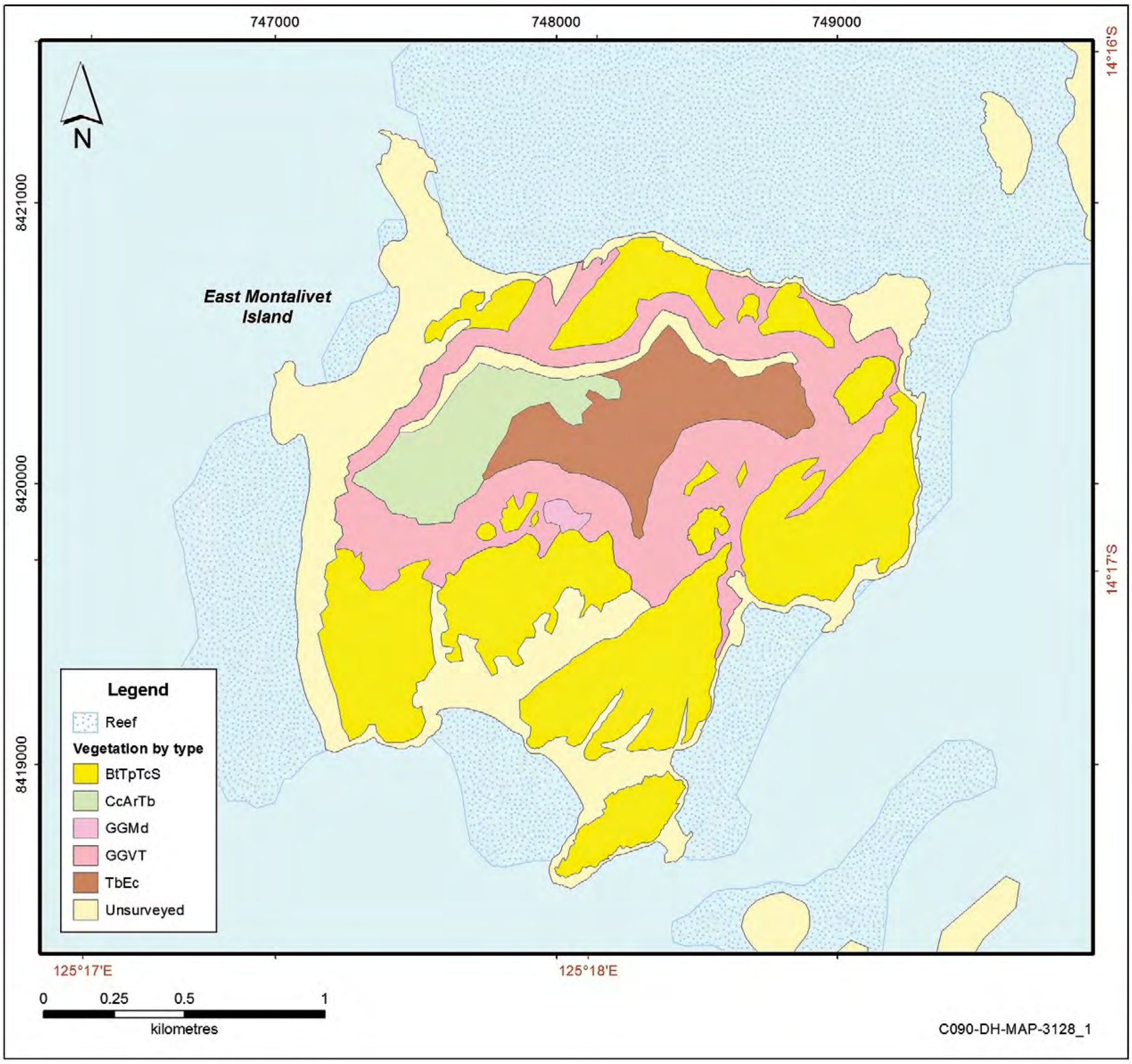


Figure 3-50: Vegetation units of East Montalivet Island (provisional) (refer to Table 3-13 for vegetation unit descriptions)

The vegetation map for East Montalivet Island is incomplete as the entire island was not surveyed. Units have been extrapolated from quadrat and transect data on aerial photography for those areas mapped, but their exact extent has not been ground-truthed.

West Montalivet Island

A total of 121 species from 46 families were collected or recorded on West Montalivet Island (see tables 3-10 and 3-22).

Table 3-22: Numbers of taxa per family recorded on West Montalivet Island

Family	No. of taxa	Family	No. of taxa	Family	No. of taxa
Acanthaceae	1	Amaranthaceae	4	Anacardiaceae	1
Annonaceae	1	Apocynaceae	6	Araliaceae	1
Asparagaceae	1	Asteraceae	1	Boraginaceae	2
Burseraceae	1	Cannabaceae	1	Capparaceae	3
Caryophyllaceae	1	Celastraceae	1	Combretaceae	2
Commelinaceae	1	Convolvulaceae	12	Cyperaceae	3
Ebenaceae	2	Euphorbiaceae	3	Fabaceae (subfamily Faboideae)	11
Fabaceae (subfamily Mimosoideae)	2	Flagellariaceae	1	Goodeniaceae	1
Haloragaceae	1	Lamiaceae	2	Lauraceae	2
Loganiaceae	1	Loranthaceae	1	Malvaceae	11
Meliaceae	1	Menispermaceae	1	Moraceae	1
Myrtaceae	2	Oleaceae	1	Orobanchaceae	2
Passifloraceae	1	Phyllanthaceae	6	Poaceae	9
Proteaceae	2	Putranjivaceae	1	Rubiaceae	3
Rutaceae	2	Santalaceae	1	Sapindaceae	4
Sapotaceae	2	Vitaceae	1		

Declared Rare Flora, Priority Flora and significant flora

- Conservation significance 1: no Declared Rare Flora species as listed in the *Wildlife Conservation (Rare Flora) Notice 2006(2)* (Government of Western Australia 2006) were found on West Montalivet Island.
- Conservation significance 2: two Priority Flora taxa were collected during this survey:
  - *Acacia deltoidea* subsp. *ampla* (P2): this taxon is poorly collected, with only five specimen records in the Western Australian Herbarium. It was recorded on the plateau of the island in vegetation units CcGAr and CcTpV.
  - *Brachychiton xanthophyllus* (P4): this species was recorded in vegetation units ArVT, CcTpV, CgTp and TdGff.
- Conservation significance 3: eight taxa were collected on West Montalivet Island that are considered to be significant for various reasons (Table 3-23).

Table 3-23: West Montalivet Island: taxa of "conservation significance 3" and their distribution ranges

Name	Notes
Acalypha pubiflora subsp. *australica*	This is the fourth record of this subspecies for Western Australia. It was recorded in vegetation unit TdGff.
Carissa lanceolata – C. ovata intergrade (NM10-15)	This intergrade is possibly more of taxonomic interest than of conservation significance.
Cleome sp. Bonaparte Archipelago (A.A. Mitchell 4774)	This is a new taxon, previously confused with *Cleome viscosa*, found on several Kimberley region islands. Further work is required to determine how widespread it is. It was collected opportunistically.
Corymbia clavigera	Prior to this survey, this species was only known from five records. It is very poorly known and is potentially of restricted distribution. It was recorded in vegetation units CcGAr and CcTpV.
Gomphrena sp. Maret Islands (A.A. Mitchell 5414)	This taxon was first found on South Maret Island prior to this survey, and also later on West Montalivet Island. Approximately 1250 mature plants were counted along the coast between 739368mE, 8419008mN and 739253mE, 8418448mN.

Table 3-23: West Montalivet Island: taxa of "conservation significance 3" and their distribution ranges (continued)

Name	Notes
Hibiscus peralbus	Of restricted distribution and probably a good indicator species for rainforest health, this species was recorded in vegetation units CcTpV and TdGff.
Marsdenia velutina	This species is known from only five previous collections in Western Australia. It was recorded in vegetation unit CcTpV.
Secamone timoriensis	This species is known from six other collections in Western Australia, only one of which is held in the Western Australian Herbarium. It was recorded in vegetation unit CgTp.

Vegetation

Seven vegetation units were defined for the areas surveyed on West Montalivet Island. These units are displayed on the vegetation map in Figure 3-51. This mapping should be regarded as provisional as the sites were not surveyed with the same intensity as sites on other islands.

No vegetation units defined for West Montalivet Island occur on the other islands surveyed except for small areas of unit Gmi.

West Montalivet Island was not surveyed in sufficient detail to provide information on which vegetation units might be significant. However, the unit Gmi is significant as it contains the new taxon *Gomphrena* sp. Maret Islands (A.A. Mitchell 5414), the distribution of which is possibly restricted.

The vegetation map for West Montalivet Island is incomplete, as the entire island was not surveyed. Units have been extrapolated from quadrat and transect data on aerial photography for those areas mapped, but their exact extent has not been ground-truthed.

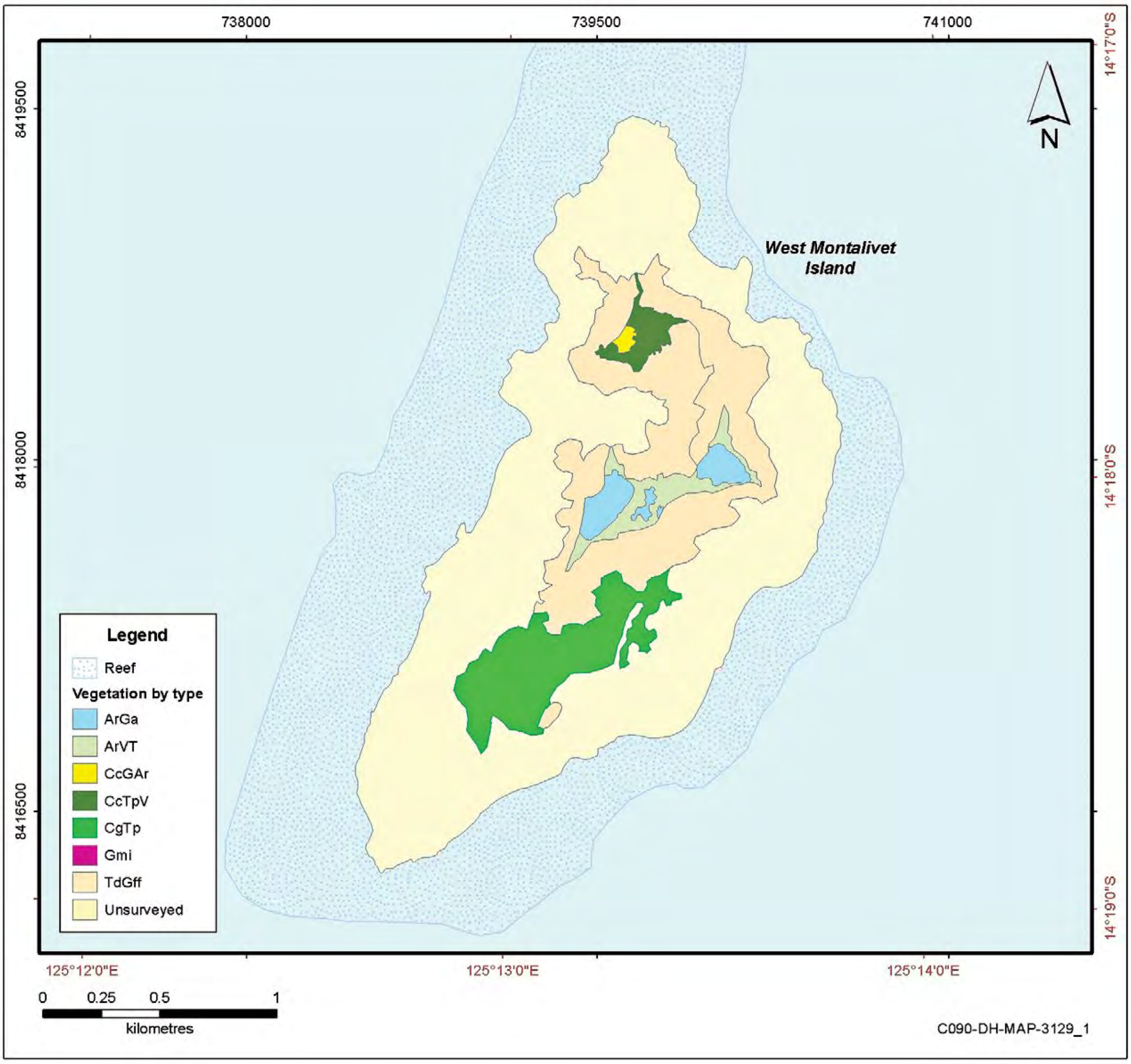


Figure 3-51: Vegetation units of West Montalivet Island (provisional) (refer to Table 3-13 for vegetation unit descriptions)

Lamarck Island

A total of 141 taxa from 53 families were recorded from Lamarck Island (see tables 3-10 and 3-24). The family Malvaceae was represented by 14 taxa, followed by Fabaceae and Poaceae (11), Phyllanthaceae (7), Lamiaceae and Moraceae (6), Rubiaceae and Rutaceae (4). Those families with the greatest representation largely correspond to those with the highest representation in Phase 1 of this survey, that is, for the surveys of the Maret Islands and the three reference islands with lateritic geology. The number of taxa per family recorded on Lamarck Island is presented in Table 3-24.

Table 3-24: Numbers of taxa per family recorded on Lamarck Island

Family	No. of taxa	Family	No. of taxa	Family	No. of taxa
Acanthaceae	1	Amaranthaceae	4	Anacardiaceae	3
Apocynaceae	5	Araliaceae	1	Asparagaceae	1
Boraginaceae	1	Burseraceae	3	Cannabaceae	1
Capparaceae	3	Celastraceae	1	Chenopodiaceae	1
Cleomaceae	1	Combretaceae	2	Commelinaceae	2
Convolvulaceae	5	Cucurbitaceae	1	Cyperaceae	2
Ebenaceae	2	Euphorbiaceae	2	Fabaceae (subfamily Caesalpinioideae)	1
Fabaceae (subfamily Faboideae)	7	Fabaceae (subfamily Mimosoideae)	3	Flagellariaceae	1
Haloragaceae	1	Hernandiaceae	1	Lamiaceae	6
Lauraceae	2	Loranthaceae	3	Malvaceae	14
Meliaceae	1	Menispermaceae	1	Moraceae	6
Myrtaceae	3	Nyctaginaceae	1	Oleaceae	2
Onagraceae	1	Opiliaceae	1	Pandanaceae	1
Passifloraceae	2	Phyllanthaceae	7	Plantaginaceae	1
Plumbaginaceae	1	Poaceae	11	Proteaceae	1
Putranjivaceae	1	Rubiaceae	4	Rutaceae	4
Santalaceae	1	Sapindaceae	2	Sapotaceae	2
Solanaceae	1	Taccaceae	1	Vitaceae	3
Zygophyllaceae	1				

Declared Rare Flora, Priority Flora and significant flora

- Conservation significance 1: no Declared Rare Flora species as listed in the *Wildlife Conservation (Rare Flora) Notice 2006(2)* (Government of Western Australia 2006) were recorded on Lamarck Island.
- Conservation significance 2: one Priority Flora species, as listed on the Declared Rare and Priority Flora List for Western Australia (Atkins 2008), was recorded during the survey of Lamarck Island:
  - *Brachychiton tridentatus* (P3).
- Conservation significance 3: the three taxa listed below were recorded during the survey of Lamarck Island and are considered to be significant for various reasons (RPS 2008):
  - *Cleome* sp. Bonaparte Archipelago (A.A. Mitchell 4774)
  - *Glochidion perakense* var. *supra-axillare*
  - *Spermacoce* sp. Berthier Dunes (R.L. Barrett RLB 5753) (P3).

Vegetation

Eleven provisional vegetation units were described for Lamarck Island and one unit remains undescribed. The structure and dominant species of the units are described in Appendix 6 of RPS (2008). The condition of the vegetation in all surveyed quadrats was found to be "Pristine" under the scale developed by Keighery (1994).

The identified units are extrapolated from data collected during the field part of the survey and from examination of aerial photography, and will require further ground-truthing to confirm the accuracy of the boundaries. These units are displayed on the provisional vegetation map in Figure 3-52.

While the islands of the archipelago share floral elements, none of the vegetation units described for Lamarck Island were found on the small limestone islands in the archipelago to the east of Berthier Island during the Phase 1 surveys.

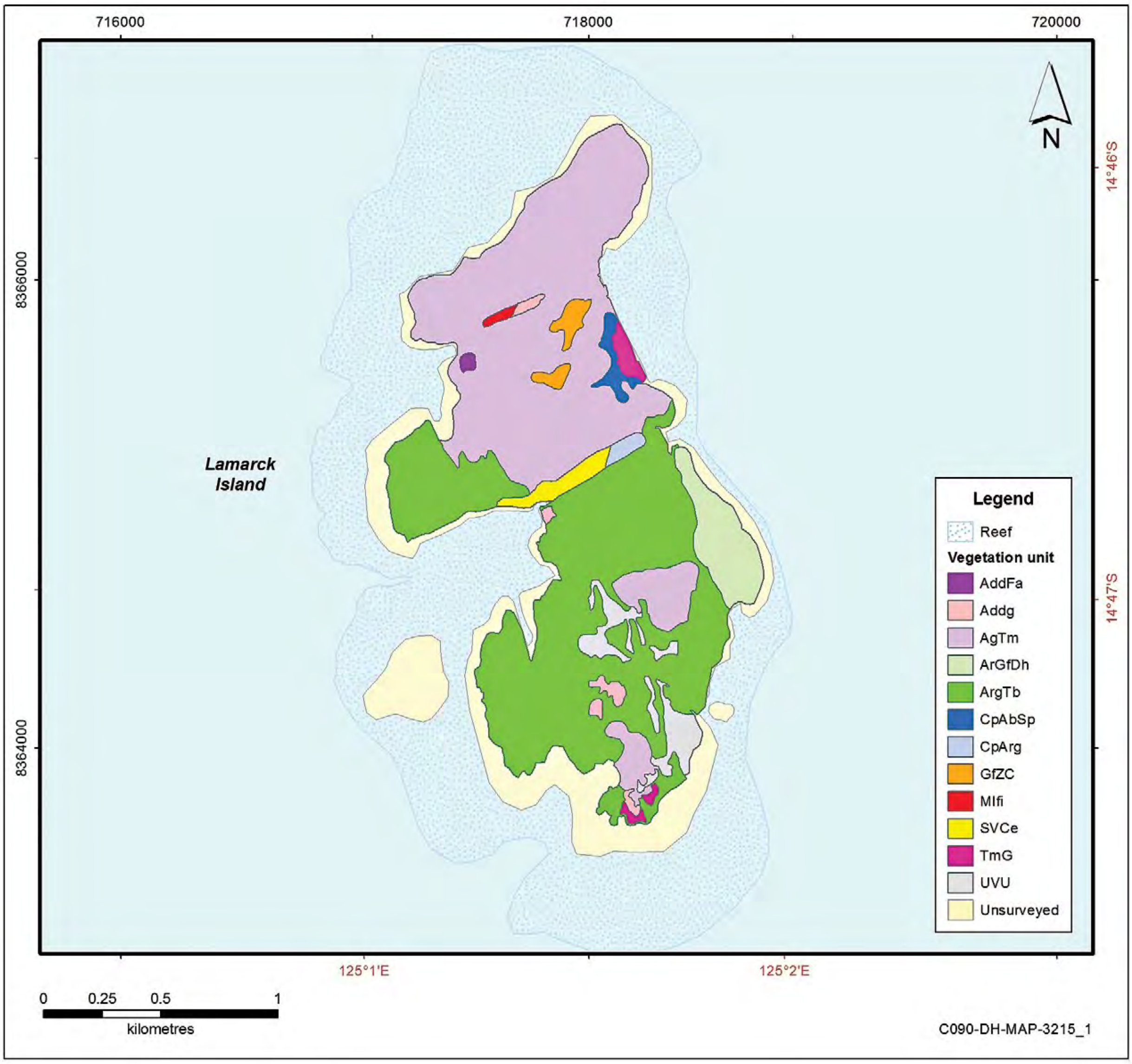


Figure 3-52: Vegetation units of Lamarck Island (provisional) (refer to Table 3-13 for vegetation unit descriptions)

PATN analysis

Dendrogram

PATN analysis was undertaken for North Maret Island, South Maret Island, Berthier Island, East Montalivet Island and West Montalivet Island. Lamarck Island was not included in this analysis.

The dendrogram analysis grouped the sites into 10, 20 and 40 groups (Group 10, Group 20 and Group 40 respectively) based on the presence or absence of species at each site. Comparison of the three groupings shows that a level of grouping slightly larger than the Group 20 level would be a more accurate representation of the vegetation associations. At the Group 40 level there were 16 (40%) singletons (associations defined by a single site) compared with four at Group 20 (10%) and two at Group 10 (5%) levels (Table 3-25). While this suggests that at the Group 40 level some of the groupings are defined in too much detail, other groupings at this level appear to be well-defined vegetation associations.

The ASO (calculation of similarity) matrix indicated that the singletons do have high dissimilarity coefficients in comparison with other sites, suggesting that the singletons at Group 40 may accurately reflect distinct vegetation assemblages. The majority of these singletons have relatively lower species numbers and appear to be missing some of the common dominant species. Most of these sites are in very bare parts of the islands and the low species numbers are therefore expected. Therefore, most of the singletons (and therefore groupings at the Group 40 level) appear to reflect real variation in the vegetation sampled. This level of variation is not reflected in the vegetation mapping as the mapped vegetation units combine structural and floristic elements and rare taxa (<2%) are not included.

Floristic communities are usually defined at a dissimilarity coefficient of 0.6, as a boundary below which groupings approximate distinct plant communities (E.A. Griffin and Associates, Perth, Western Australia, pers. comm. 2008). The Group 20 sites in the current analysis were separated at a dissimilarity coefficient of 0.635. This is only just above the nominal level of 0.6 and indicates that some confidence can be placed in defining associations on the basis of the Group 20 grouping.

Table 3-25 shows the number of sites on each island that fell into each group at the Group 20 level.

Table 3-25: Number of sites on each surveyed island within groups derived from a dendrogram split at the Group 20 level

Group 20	North Maret Island	South Maret Island	Berthier Island	East Montalivet Island	West Montalivet Island
1	–	–	11	–	–
2	1	4	7	–	2
3	10	11	–	–	–
4	–	–	1	1	–
5	–	–	–	3	–
6	3	–	1	–	–
7	–	3	–	–	–
8	2	10	2	3	–
9	–	–	–	–	4
10	1	–	–	–	–
11	–	2	–	–	–
12	–	–	1	–	–
13	1	–	–	2	–
14	–	4	–	–	–
15	10	1	–	–	–
16	2	–	–	–	–
17	2	–	–	–	–
18	–	–	–	–	1
19	–	–	–	–	1
20	1	–	–	–	–

Groups with sites on more than one island show that there is some overlap in vegetation communities between the islands. Other groups (communities) were only represented on one island or at a few sites on two or more islands. This suggests that these communities are not common on the islands surveyed, or were sampled from only a few survey sites.

Semi-strong hybrid multidimensional scaling analysis

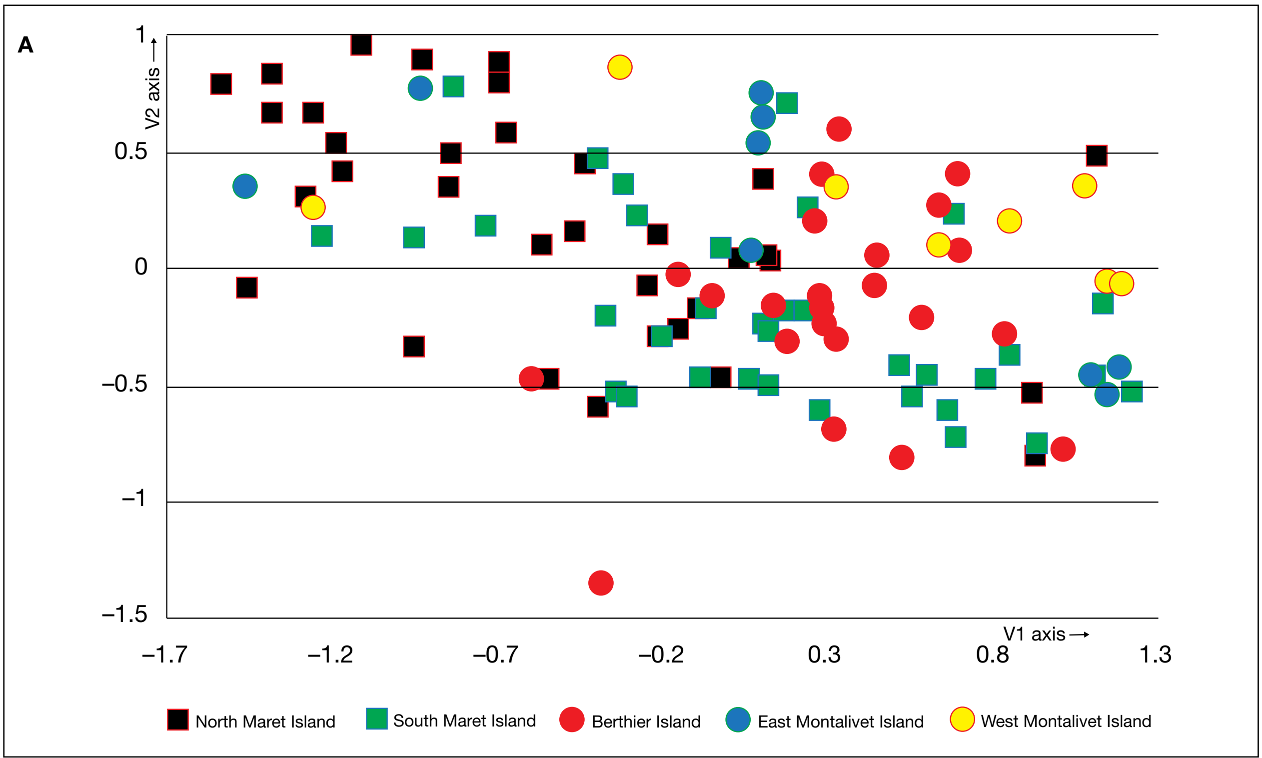
The ordination plots shown in Figure 3-53 are two-dimensional representations of a three-dimensional figure produced by the SSH MDS analysis. The plots show the survey sites (quadrats and transects) identified by island. The distances between them, based on their floristic composition, reflect the ecological distance between the plant communities at each site. These distances, however, are relative to the rest of the data set and are not an absolute measure of dissimilarity. The more unusual sites tend to the extremities of the axes while the other data, being ordinated relative to these sites, are more centralised.

Plot A represents the data against the V1 and V2 relative axes. Plot B represents the data against the V1 and V3 relative axes.

The plots demonstrate the overlap in floristic composition between the islands, indicating that sites in comparable vegetation formations on different islands are floristically similar.

The ordination tended to separate the sites according to the major formations. The grassland quadrats tend to lie to the left of the plots, the woodland quadrats lie to their right, woodland sites with vine-thicket species lie in the middle around the V2 and V3 axes, and the vine-thicket transects tend to the right.

The overlap of the sites from different islands within each formation cluster highlights the similarities in floristic composition among the islands. For example, the presence of sites from each of the five islands at the far right of the plots indicates that the vine-thicket communities are floristically similar across the islands.



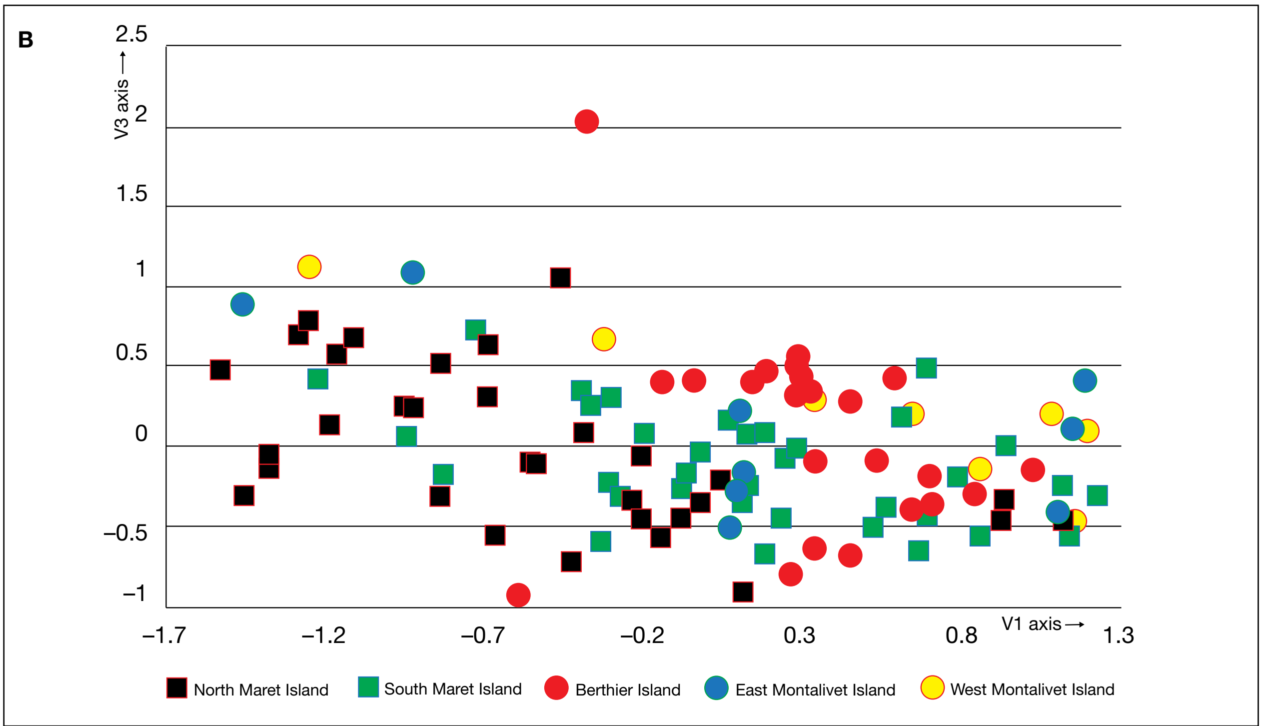


Figure 3-53: SSH MDS two-dimensional representations of a three-dimensional ordination plot of floristic data from all quadrats and transects on North Maret, South Maret, Berthier, East Montalivet and West Montalivet islands

DISCUSSION

Floristically, the Maret Islands and other islands in the region have two main components: the savannah-woodland component and the vine-thicket component. Differences in the vagility of their respective species may provide an indication of how these components originated on the Kimberley islands. Vine thickets, for example, may be more recent colonisers of the islands. The majority of species from hummock grasslands, *Corymbia* woodlands and heathlands have limited capacity for dispersal over ocean barriers whereas many of the vine-thicket species, which are fruit-bearing and utilised by migratory birds, have greater dispersal potential. It is likely that the savannah vegetation on the plateaux of the surveyed islands has been there since the islands were separated from the mainland. It may have occupied much of the land area of the islands at the time of their separation from the mainland and probably makes up a subset of the current mainland flora.

Mobile frugivorous birds are abundant on the Maret Islands and surrounding islands and are likely to transfer propagules between islands and from the mainland. They may have been a critical factor in establishing the diverse vine thickets on these islands and they may be necessary for their persistence.

Lateritic islands

Of the approximately 2600 islands scattered along the Kimberley coast, only a small proportion are more than 20 ha in area and a subset of these are basaltic rather than composed of sandstone. The Maret Islands are composed of basalt, overlain with laterite, and are considerably larger than 20 ha in area, totalling approximately 654 ha of vegetated ground. This size is likely to make them regionally important in terms of both landform and biodiversity. The current combined species list of 220 taxa for the Maret Islands makes up 7.6% of the known Kimberley flora or 11.1% of the known flora of the Northern Kimberley Bioregion.

Regional vine thickets

Vine thickets are a subcategory of the rainforest vegetation type. While the term “rainforest” brings to mind the jungles of the Amazon or Africa (that have high rainfall throughout the year), or the seasonally dry but evergreen forests of the east coast of Australia, vine thicket (sometimes called “monsoon forest”) is semi-deciduous and characterised as being “more or less leafless during the dry season, … tropophilous in character, usually less lofty than the rain-forest, rich in woody lianes, rich in herbaceous but poor in woody epiphytes” (Schimper 1903). The term “vine thicket” is used here for consistency.

Vine thickets, as found in northern Australia, occur as “small, seasonally sparse, ‘raingreen’ patches confined to gullies and scree-slopes in rugged terrain” (McKenzie 1991). While their closest floristic relationships are with rainforests, their structural features differ and annual herbs may be present. Vine thickets are known to occur in the far north of Western Australia and the Northern Territory, and in inland areas of Queensland.

The vine thickets surveyed and described as part of this survey fall into the category of “semi-deciduous notophyll vine thicket” (Russell-Smith 1991; Webb, Tracey & Williams 1984). This floristic group occurs on a variety of well to excessively drained coastal and subcoastal sites through the Northern Territory (Russell-Smith 1991) and apparently through Western Australia as well. Many of Russell-Smith’s sites were located on lateritic substrates, especially on “actively slumping coastal cliffs”.

The vine thickets display high taxonomic diversity at family and genus level, but low diversity at species level (Kenneally, Keighery & Hyland 1991). This means that a large number of families and genera are represented in the patches, but each may be represented by only one or two species. This is a contributing factor in the high level of diversity found in this vegetation type.

Kenneally, Keighery and Hyland (1991) found 453 species from 339 genera in mainland Kimberley vine thickets. The methods used during this survey differed from the INPEX 2006–2007 studies in that 10 m × 10 m quadrats (in contrast to 50 m × 50 m) were used during the “detailed” phase of the survey, and the “rapid phase” of the survey relied on relevé work. However, this highlights the taxonomic diversity of the mainland vine thickets. Stands of vine thicket are rarely dominated by one or two taxa in each structural unit (tree, shrub, etc.).

Beard, Clayton-Greene and Kenneally (1984) report that larger extensive areas on the Bougainville Peninsula are vegetated by a mosaic of savannah and vine thicket and that some areas, proposed as transitional, have scattered emergent eucalypts (now placed in the genus *Corymbia*). The southernmost part of the peninsula shows similarities to the Mitchell Plateau, with well-defined patches of vine thicket merging with the *Corymbia* savannah. All three structures are present on South Maret Island, the northern and eastern sides of which have extensive tracts of vine-thicket species growing among the *Corymbia* savannah on the central plateau. It would appear that on South Maret Island the savannah vegetation is receding and being replaced by vine thicket, a process aided by the lack of burning on the island for, probably, a considerable period of time. It has been observed that “relaxation of fire frequency” over a period of only 20–30 years will result in rainforest elements beginning to colonise adjacent sclerophyll vegetation (Webb & Tracey 1981).

South Maret Island has 76 ha of vine thicket in one continuous band, possibly one of the largest expanses of this vegetation type in the Kimberley region. It has been noted that the thickets on the basaltic substrate have different species assemblages and structures from thickets on sandstone islands (Dr R.L. Barrett, School of Plant Biology, University of Western Australia, pers. comm. July 2007). At this point no quantitative data have been collected from surrounding sandstone island vine thickets.

When the vegetation with vine-thicket elements on the South Maret Island plateau is taken into consideration, the total area of communities with vine-thicket species is nearly 277 ha. However, the plateau vegetation is clearly colonised woodland and is not made up of "pure" stands of vine-thicket species. It is unlikely that "pure" vine thicket will ever be a seral stage on the plateaux of Maret Islands because of the lack of year-round moisture, even if the islands remain fire-free.

Significance of the Maret Islands vine thickets

The Maret Islands form part of the wider "rainforest archipelago" that encompasses northern Australia. It is estimated that there are 16 500 rainforest patches over the entire region, including 1500 in Western Australia (Kay, Hick & Houghton 1991).

The Maret Islands vine thickets are relatively undisturbed and isolated from similar patches on the mainland. They have not been subjected to fire or to disturbance by feral animals as has happened on the adjoining mainland. They include aspects of both coastal sand-dune thickets (characterised by the occurrence of *Pittosporum moluccanum* (P4)) and thickets on lateritic scree.

Regionally, vine-thicket patches are mostly less than a few hectares in size, ranging from the cover of a few tree canopies, to riparian strips and coastal tracts covering thousands of hectares (McKenzie & Belbin 1991; Russell-Smith 1991). The largest patch in the Kimberley is approximately 100 ha in area, with a median of between 2 and 3 ha (Russell-Smith, McKenzie & Woinarski 1992). The small size of these patches makes them particularly vulnerable to disturbance (Kenneally & McKenzie 1991).

Ecological significance of vine thickets

The term "rainforest" was coined in 1898 by Schimper (1903) to describe forests of the ever-wet tropics. Tropical rainforests are among the most complex and species-rich ecosystems to have existed on this planet (Whitmore 1984). They include at least half of the world's species richness although they occupy only 5% of its land surface (Grainger 1980). In current usage "rainforest" includes monsoon forest (also classified as semi-evergreen vine thicket).

In Australia, there is a sharp ecological segregation between closed forests containing species with Indo-Malesian (tropical) affinities and the Australian autochthonous flora. This autochthonous element is characterised by a tendency to sclerophylly, many species having developed thickened leaves resistant to water loss such as the typical eucalyptus leaf or acacia phyllode (although the term sclerophylly includes other adaptations).

Australian rainforests have very few species in common with the adjacent sclerophyll vegetation, and are distinguished from other closed forests by the prominence of epiphytes, lianas, aerial roots, buttress tree trunks and the absence of annual herbs (Webb 1959). These dry rainforests are characterised by their relatively high proportion of vagile, cosmopolitan genera, their raingreen canopy during the wet season and the fact that they are generally deciduous during the dry season. The emergent trees tend to be liberally festooned with creepers. There is little or no ground vegetation and the rubble surface is covered with fallen leaves (Beard 1976).

Table 3-26 summarises information concerning vine thickets from other studies in Western Australia and the Northern Territory.

Table 3-26: Vine-thicket references from other studies in northern Australia

Location	Vegetation type	Area	Mean	Comments	Source
Mitchell Plateau					
General	Monsoon forest	25 ha (average)	1–2 ha	38 patches mapped.	Beard 1976
Admiralty Gulf					
On King Leopold sandstone – dolerite intrusion. On a ridge 6 km east-north-east of Mt Anderdon	Monsoon forest	3 km length (along the ridge)			Beard 1976
Slopes of Savage Hill, at south-east corner of Bigge Island	Monsoon forest	Substantial occurrence		On dolerite intrusion.	Beard 1976
Bougainville Peninsula					
General. On 50 m scarp bordering the plateau	Monsoon forest	Almost completely covered		Covers a greater area than on the Mitchell Plateau, extending continuously along the scarps instead of in small patches.	Beard 1976
General	Vine thicket	Continuous communities		Where the terrain is narrow, very steep or otherwise inaccessible (e.g. on the narrow arms of the peninsula).	Beard, Clayton-Greene and Kenneally 1984
General	Vine thicket	Larger extensive areas (mosaic of vine thicket and savannah)		Especially south of Parry Harbour.	Beard, Clayton-Greene and Kenneally 1984
Southernmost part of the peninsula	Vine thicket	Scattered, well-defined patches		As on the Mitchell Plateau.	Beard, Clayton-Greene and Kenneally 1984
Osborn Islands: the group comprises Steep Head, South West Osborn, Kidney, Middle Osborn and Borda islands and an unnamed basalt promontory and unnamed island					
Steep Head Island on the extremity of the mainland promontory	Vine thicket	Present		A section isolated by a sandy isthmus.	Beard, Clayton-Greene and Kenneally 1984
Unnamed island on the south-west basalt portion	Vine thicket	Present			Beard, Clayton-Greene and Kenneally 1984
South West Osborn Island on basalt slopes	Vine thicket	Present		In a mix of eucalypt savannah and vine thicket; the most dense vine thicket on south-east side; mixed patches on the north-west side.	Beard, Clayton-Greene and Kenneally 1984
Kidney and Middle Osborn islands	Vine thicket	Limited patches		On fire-protected sides.	Beard, Clayton-Greene and Kenneally 1984
Middle Osborn Island	Vine thicket	Occasional distinct patches		One larger patch occurs at the foot of the headland at the western end of the island.	Beard, Clayton-Greene and Kenneally 1984

Table 3-26: Vine-thicket references from other studies in northern Australia (continued)

Location	Vegetation type	Area	Mean	Comments	Source
Institut Islands					
Fenelon Island	Vine thicket	Dense patch		On a basalt slope below the plateau rim. The landing was made on the southern side of the island.	Beard, Clayton-Greene and Kenneally 1984
Northern Territory					
General	Rainforest	Median 3.6 ha		In scattered patches; described as wet and dry rainforest and riparian corridor patches.	Price 2004
General	Rainforest	Average 5 ha			Russell-Smith 1991; Shapcott 1999
Gunn Point region, near Darwin	Dry rainforest	11 ha and 140 ha	75.5 ha	Sites DRY1 and DRY2.	Price 2004
	Wet rainforest	27.7 ha, 5.8 ha, 23 ha, 63 ha, 22 ha and 23 ha	27.4 ha	Sites SPR1, SPR2, SPR3, CAR1, CAR2 and CAR3.	Price 2004
	Riparian rainforest	1.4 ha and 3.2 ha	2.3 ha	Sites RIP1 and RIP2.	Price 2004
General	Monsoon rainforest	Most <5 ha		Occurring as small scattered patches.	Bach 2002
Gunn Point peninsula, 40 km north-east of Darwin	Dry monsoon rainforest	5 ha, 30 ha, 40 ha and 10 ha	21.25 ha	Sites DMF 1, DMF 7, DMF 10 and DMF 11.	Bach 2002
	Wet monsoon rainforest	20 ha, 10 ha, 2.3 ha, 26 ha, 32 ha, 2.3 ha, 12.3 ha, 2 ha, 20 ha, 30 ha, 40 ha and 6.5 ha	16.95 ha	Sites WMF 2–6, WMF 8, WMF 9, WMF 12, WMF 13, WMF 17, WMF 18 and WMF 20.	Bach 2002

In the Kimberley, the most species-rich and extensive patches of vine thickets occur along the north-western coastline, the area of highest rainfall. They form closed-canopy communities that differ significantly from the open-canopied savannah woodlands that otherwise dominate the Kimberley. Only three closed-canopy vegetation types are found in the wet–dry tropics of Western Australia: rain (monsoon) forests, mangroves and riverine forests. Rainforest patches in the Kimberley are concentrated in rugged terrain between the Prince Regent River and the Bougainville Peninsula. Beard, Clayton-Greene and Kenneally (1984) suggest that there is much more vine thicket on the Bougainville Peninsula than anywhere else in the area. One consequence of such restricted distribution patterns is that rainforest patches occupying similar ecological settings, even when adjacent, commonly support different species assemblages (Russell-Smith, McKenzie & Woinarski 1992).

Vine thickets are highly productive, with most species producing fleshy fruits at the outset of the wet season. They provide shade and shelter for many species and this is particularly important at the end of the dry season. The fleshy fruits of many rainforest plants are attractive to a rich guild of frugivores including fruit pigeons, flying-foxes (fruit-bats) and more facultative species such as trillers, orioles, honeyeaters, cuckoos, etc. Rainforests contain more fleshy-fruited plants than the surrounding open forests and savannah that dominate much of the Kimberley. Frugivores and nectarivores are forced to be reliant upon the isolated patches of monsoon rainforest for most of the year. Frugivores can persist only if fruit is available all year round. They need high floristic diversity within and between patches with different species fruiting at different times of the year, or separately in different patches. Keystone species such as figs bear fruit throughout the year and provide a continuous food source.

Many rainforest plants are readily dispersed by birds, bats, wind or water. On a landscape scale, frugivores will persist only where the distance between patches is not too prohibitive. The monsoon forest system is not only home to obligate rainforest species but is also used as a seasonal, daily or occasional refuge by many animal species from the surrounding vegetation associations.

The rainforests of the Kimberley are part of a great corridor of monsoon forests extending through South-East Asia and into Australia that is important for the seasonal migration of birds such as koels and channel-billed cuckoos.

Vine-thicket and semi-vine-thicket vegetation units

Although there are a number of areas on the plateaux of the islands that contain a variety of vine-thicket species, few vegetation units can be described as purely vine thicket. While the thickets are diverse at family and genus level, the same suite of species tends to be present throughout; it is mainly the relative abundance of the species and the structure of the units that vary.

The species recorded in the vine thickets appear to be regionally common, except for those few noted as being of "conservation significance 3".

Plant species of conservation significance

Conservation significance 1

No Declared Rare Flora taxa or designated "threatened ecological communities" were recorded from the six islands surveyed or are known from adjacent areas.

Conservation significance 2

Four Priority Flora taxa were collected from the islands surveyed: *Acacia deltoidea* subsp. *ampla* (P2), *Pittosporum moluccanum* (P4), *Brachychiton tridentatus* (P3) and *Brachychiton xanthophyllus* (P4). Priority Flora species are species which are considered to be possibly rare and threatened but which have not been sufficiently well surveyed to justify a Declared Rare Flora ranking (see Table 3-1).

Of the four Priority Flora taxa recorded, *Acacia deltoidea* subsp. *ampla* (P2), was found only on West Montalivet Island and *Brachychiton tridentatus* (P4) was found only on Lamarck Island.

Prior to this survey, *Pittosporum moluccanum* (P4) was known in Western Australia from nine collections (DEC 2007), three of which were from the Maret Islands. This survey has shown the species to be widespread in a variety of habitats (on plateaux, beaches and in vine thicket) on both North Maret Island and South Maret Island. It was also recorded at 18 sites in various habitats on Berthier Island. Of the collections lodged with the Western Australian Herbarium, the majority are from collections on sand dunes, with one collection from coastal vine thicket at Broome, one from basalt scree and one from the plateau of "Maret Island" (*sic*) collected in 1972. This indicates the relatively wide range of habitats that this species can occur in, and which has been confirmed by this survey. In summary, *P. moluccanum* appears to be locally common on the Maret Islands and also on Berthier Island, although it was not recorded in areas surveyed on either East Montalivet Island or West Montalivet Island.

Prior to this survey, *Brachychiton tridentatus* (P3) was known in Western Australia from 18 collections (DEC 2007), one of which was taken on West Montalivet Island. The majority of the records are from sandstone or sand with only one record from lateritic gravel. It was only collected from sandstone on Lamarck Island during this survey.

During the survey *Brachychiton xanthophyllus* was recorded from three islands: North Maret Island, East Montalivet Island and West Montalivet Island. Individuals are scattered in woodland and vine thicket on the plateaux and slopes of these islands and the species appears to be regionally widespread.

Conservation significance 3

A number of taxa were collected during this survey that for various reasons may be considered significant, and for the purposes of this report these are classified as being of "conservation significance 3". The significance of each may be because it represents the first collection in Western Australia, or is one of only a few records for a particular taxon, or represents a range extension, or is an unusual variant of something already known.

Carissa lanceolata – *C. ovata* intergrade (NM10-15): This taxon is currently of taxonomic interest because it possesses features of both *C. lanceolata* and *C. ovata*. If it is actually a discrete taxon, it is widespread through vegetation units on the Maret Islands and on the three reference islands.

Cathormion umbellatum subsp. *moniliforme*: This subspecies was recorded from vegetation unit TpGffme on South Maret Island and opportunistically from a beach on Berthier Island; these records represent a significant range extension from its current known distribution in the east Kimberley mainland.

Cayratia maritima: This species appears to be locally common but its full distribution range in Western Australia is unknown; this is only the second record of this species in Western Australia. It was recorded on North Maret Island, Berthier Island, East Montalivet Island and Lamarck Island from several vegetation units.

Cleome sp. Bonaparte Archipelago (A.A. Mitchell 4774): This is a new taxon and was recorded in a variety of vegetation units. It is widespread on North Maret Island, South Maret Island, Berthier Island, East Montalivet Island and Lamarck Island.

Commicarpus chinensis subsp. *chinensis*: This is the first record of this taxon in Western Australia, although it has possibly been collected on nearby islands with some confusion regarding the name. In either case, it is not well known in Western Australia. It was recorded from South Maret Island and Berthier Island from opportunistic collections in vine-thicket units.

Cordia subcordata: Known in Western Australia from ten collections scattered along the Kimberley coast and two from the Pilbara, this taxon occurs on beaches. In this survey it was recorded only from a small area on South Maret Island.

Corymbia clavigera: Prior to this survey this species was known from six collections held at the Western Australian Herbarium and is thus potentially of restricted distribution. It was, however, found on the Maret Islands and on all three of the lateritic reference islands. It appears to be locally common.

Evolvulus sp. "White Flower" (NM14-05): At the time of the survey this taxon was thought to be possibly "new", but it has since been confirmed to be *Evolvulus alsinoides* var. *alsinoides*. Recorded once on North Maret Island in a widespread grassland unit and twice on South Maret Island in a more restricted unit, this taxon was also recorded on Berthier Island and West Montalivet Island.

Eriachne sulcata: An unusually hairy form of a common species, this may be of more taxonomic interest than conservation significance, but its status is unknown at the present time. It was collected on South Maret Island and Lamarck Island.

Gomphrena sp. Maret Islands (A.A. Mitchell 5414): This is a new taxon, originally collected on South Maret Island in 1998 but with insufficient material for taxonomic resolution. It is regarded as a possible Declared Rare Flora or Priority Flora species. In this survey it was collected from North Maret Island, South Maret Island, Berthier Island and West Montalivet Island and it was observed opportunistically on Albert Island and Turbin Island. This taxon has been surveyed thoroughly on the Maret Islands and the surrounding islands (except for Bigge Island). In July 2007 botanists also searched for it on the Osborn Islands and on part of the Bougainville Peninsula, but although these areas have similar habitats to those in which the new *Gomphrena* species occurs on the Maret Islands no specimens were found.

Goodenia sp. aff. *microptera* (NM27-19): This is possibly another new taxon. It bears similarities to *G. microptera* and its status is as yet unknown. It was recorded from North Maret Island, South Maret Island and Berthier Island in grassland and woodland vegetation units. Its wider distribution is unknown.

Hibiscus peralbus: Known previously in the Western Australian Herbarium from 15 collections from the Mitchell Plateau and the Bonaparte Archipelago, this species appears to have a restricted distribution. During this survey it was recorded at 29 sites over all of the islands surveyed, except for Lamarck Island, in vegetation units with vine-thicket species. It is relatively common on the Maret Islands and also on Berthier Island (12 records). There was one record from East Montalivet Island and there were two from West Montalivet Island.

Mucuna diabolica subsp. *kenneallyi*: This subspecies was previously known from four records in the Western Australian Herbarium. It was collected during this survey at one location on North Maret Island and it was also found on East Montalivet Island.

Portulaca sp. "River Mud" (R.L. Barrett 3285): Recently recognised as a new taxon, the status of this species is as yet unknown. One opportunistic collection was made from North Maret Island, three collections from South Maret Island and one from Berthier Island. It is also known from the mainland in the north Kimberley.

Spermacoce sp. "Blue" (NM31-13): Possibly a new taxon, this species was only recorded from the plateaux of North Maret Island and South Maret Island, and its wider distribution is unknown. It is a potential Declared Rare Flora or Priority Flora species.

Spermacoce sp. "White" (NM21-01): Possibly a new taxon, this species was recorded from the plateaux of North Maret Island, South Maret Island, Berthier Island and East Montalivet Island. It appears to have a wide distribution.

**Pupalia micrantha*: This herb was collected in dense undisturbed vine thicket on South Maret Island, Berthier Island, East Montalivet Island and Lamarck Island. It has been poorly collected in Western Australia.

Glochidion perakense var. *supra-axillare*: This taxon was found on Lamarck Island and had only been collected in the eastern Kimberley prior to these surveys. This collection, therefore, represents a significant range extension for this plant.

The local and regional abundance and distribution of these taxa, especially the potentially new ones, is largely unknown. It is possible that they could be relatively common or well distributed, but such an assessment is hampered by the lack of detailed survey work in the area.

Vegetation

The dendrogram analysis and the SSH MDS analysis (Figure 3-53) indicated that the floristic composition of the vegetation communities is similar between islands, with sites of the same formation, but from different islands, generally grouping together. For example, the composition of vine thickets was similar on the Maret Islands, Berthier Island and East Montalivet Island, although there were minor differences in the species present and also in their relative abundances. The same patterns were true of grassland–herbland and woodland formations and probably reflect the regional distributions of many of the species.

Within the vegetation formations there was a secondary grouping by island. This indicates that sites in the same formation type on an island are more similar to each other than to sites on other islands.

The SSH MDS analysis indicated that the woodland units on North Maret Island were floristically similar to those on South Maret Island. However, the North Maret Island sites tended towards the upper left-hand corner of the plot whereas the majority of the South Maret Island sites tended to the right. This reflects a difference in this formation between the two islands. The dominant grassland and light woodland (with some vine-thicket species) associations on the North Maret Island plateau differ from the denser woodland (often colonised by vine thicket) association on the plateau of South Maret Island.

While most of the Berthier Island sites grouped with the South Maret Island sites to the right of the scatter plots, four sites were well to the left and one of these is an outlier from all other site groupings. This outlier is a beach site and the separation from the other sites reflects the different floristic composition in this habitat. The three other sites represent a grassland quadrat, a shrubland quadrat and a shrubland transect close to the shrubland quadrat. These sites are all towards the northern tip of Berthier Island and are similar to shrubland or low woodland sites on both North Maret Island and South Maret Island.

Sites on East Montalivet Island formed three clusters. The first, in the top left of the scatter plot, comprises two plateau woodland sites. The second, comprising four grassland–shrubland quadrats, is in the centre, and the three vine-thicket transects are grouped close together in the lower right. All are grouped with similar sites from both North Maret Island and South Maret Island, indicating similarity in vegetation unit composition.

The West Montalivet Island sites tended to group with the more densely vegetated sites on Berthier Island and the Maret Islands. However, the survey effort was lower on this island than it was on the other islands, so the results should be interpreted with caution.

It is evident from the ordination analyses that the major vegetation types on North Maret Island and South Maret Island are widely represented within the study area in the archipelago. Minor differences in floristics and structure appear to be outweighed by the similarity in community composition among the islands. The similarities in the grassland and woodland units probably reflect the common origin of the island floras, and similarities in the vine-thicket units across islands probably reflect connectivity through frugivorous birds transporting seeds between the islands.

The 11 provisional vegetation units used to map Lamarck Island (Figure 3-52) show that three species of acacia, *Acacia deltoidea* subsp. *deltoidea*, *A. gonocarpa* and *A. retinervis*, are present in, or dominate, many of the units. Vine thickets are almost absent from Lamarck Island (Figure 3-52), apart from one area on the eastern side of the island. The vine-thicket species present generally occur in small sparse stands associated with rocky outcrops. While these species are well represented in this association on the island, the stands often contain only a few species and are not vine thickets in themselves.

On the basis of the vegetation survey, the vegetation of Lamarck Island differs from that on the Maret Islands as described below:

- Lamarck Island is dominated by *Acacia* communities of varying densities and structures, whereas the Maret Islands support a greater variety of species and communities and are not dominated over the greater part of their land area by any single genus.
- Unlike the Maret Islands, Lamarck Island does not support large areas of fringing vine thicket despite supporting vine-thicket species which are scattered in small stands over most of the island.
- Grassland is not well represented on Lamarck Island, whereas it is a dominant vegetation type on the Maret Islands.

Condition of the vegetation

The condition of the vegetation on all of the islands visited during the current study was "Pristine" under the scale developed by Keighery (1994) and used in the "Bush Forever" plan published by Western Australia's Department of Environmental Protection (DEP 2000). This assessment considers both understorey and overstorey strata. All of the vegetation maps produced in this report display vegetation units in "Pristine" condition.

Vegetation mapping units

While analyses such as the SSH MDS rely solely on presence–absence data, vegetation mapping units are described with reference to structure and cover values, as well as floristics. This is why vegetation map units vary and are rarely repeated between islands, despite floristic similarities. Structural differences may be attributable to such variables as soil development, shelter or shading, seral stage, or moisture availability.

Restricted vegetation units

Some of the mapped vegetation units on the Maret Islands were regarded as restricted in distribution because they are poorly represented on the islands of the study area.

On North Maret Island these units were ArsTbS, AsTm, AsSt, TcAr, TcF, TcG, MdAi, Gmi and CcVTSt. These units are mainly separated from otherwise similar units by the presence of taxa that are not represented in the other units. The vegetation units TcF and TcG are small shrubland units with *Terminalia canescens* in common; however, TcG also features *Grevillea pyramidalis* subsp. *pyramidalis*. Vegetation unit MdAi contains the only example of *Mucuna diabolica* subsp. *kenneallyi* found on the Maret Islands, and Gmi contains the new and possibly restricted *Gomphrena* sp. Maret Islands (A.A. Mitchell 5414). The unit CcVTSt appears unique for both North Island and South Maret Island in that it is composed only of *Corymbia clavigera* and vine-thicket species, whereas other similar units also contain *Corymbia polycarpa*.

Vegetation units considered restricted on South Maret Island are TpArTb, PmCSt, PmSpCSt, Gmi, PmPa, Lr, GfVT. The vegetation unit Gmi contains the new *Gomphrena* species. The unit TpArTb is a combination of *Terminalia petiolaris* and *Acacia retinervis* over *Triodia bynoei*, an unusual combination on the Maret Islands. PmPa and GfVT are both vine-thicket units. The unit PmPa is floristically dominated by *Pavetta muelleri* and *Premna acuminata* and GfVT by *Garuga floribunda* var. *floribunda*, structural combinations not found elsewhere on either island. PmCSt and PmSpCSt are similar units, except that the latter also contains *Spinifex longifolius* because of its location behind the beach and a different substrate.

The vegetation unit Lr is of particular interest as it shows the only occurrence of mangroves on the Maret Islands. *Lumnitzera racemosa* forms an open stand on the foredune, spread over a distance of approximately 50 m.

With the exceptions of the taxa classified in this chapter as being of "conservation significance 3", the floristic components of the vegetation units are generally widespread and well collected through the Kimberley region.

Introduced taxa

Only three introduced species were recorded for the Maret Islands: **Pupalia micrantha* and **Bidens pilosa* were both recorded for South Maret Island, while **Vigna radiata* var. *setulosa* was recorded for both islands.

**Pupalia micrantha* is found in dense undisturbed vine thicket. It was recorded on South Maret Island from two sites, both of which are in the TpGffMe vegetation unit, although it is possible that it occurs elsewhere on the island in other units.

**Vigna radiata* var. *setulosa* has a scattered distribution in the Kimberley region, often in near-coastal areas, and it is likely to have been a pre-European introduction to the region. It was found in a few locations on North Maret Island and South Maret Island.

**Bidens pilosa* is an introduced weed of the Kimberley and Pilbara regions and of south-west Western Australia around Perth. It was recorded on the north-western edge of the South Maret Island plateau in the vegetation unit CcpVTSt. Although there is only one record of this species, it is possible that it occurs elsewhere on the island and in other vegetation units.

The method of seed dispersal for *B. pilosa* is by the pronged seed being transported by attachment to animal fur, bird feathers or human clothing (or less easily by wind). It is possible that it was introduced to South Maret Island by a bird, but as there are no mammalian vectors on the island its spread may have been restricted.

Environmental weeds

One species listed as an environmental weed, **Passiflora foetida*, was recorded on Berthier Island and Lamarck Island. It was not recorded on the Maret Islands, but may be present. This species is an invasive weed with the potential to cause environmental disturbance (Hussey et al. 2007). The potential for introduction from neighbouring islands is a risk. This species is readily spread by birds which eat the flesh-covered seeds.

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Botanical assistants: Angela Mercier and Paul Tod (RPS); Vicki Levien (Astron Environmental Services); and Ellen Poole.

Fungus and slime mould specialist: Dr Matt Barrett (Botanic Gardens and Parks Authority, Perth, Western Australia).

Statistician: Edward Arnold Griffin (E.A. Griffin & Associates).

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GLOSSARY

autochthonous	(Of plant species) native or endemic, having originated where they are presently found.
Declared Rare Flora	The term "Declared Rare Flora" is defined in Western Australia's *Wildlife Conservation Act 1950* as follows: "Plants which have been adequately searched for and are deemed in the wild to be plants either rare, in danger of extinction, or otherwise in need of special protection, and have been gazetted as such."
edaphic	Produced or influenced by the soil.
flora	The traditional definitions of "flora" are as follows: 1. the plants of a particular region, geological period, or environment, listed by species 2. a treatise or work systematically describing such plants. In environmental biology, however, the definition of the term "flora" is sometimes broadened to include individual species, vegetation groupings or, simply, "plants".
IBRA	Interim Biogeographic Regionalisation for Australia. This Commonwealth Government scheme classifies Australia's landscapes into a number of geographically distinct "bioregions" and provides the national and regional planning framework for the systematic development of a comprehensive and representative Australian national reserve system.
mangal	A mangal is the name used for a mangrove forest (or swamp) community and was created by W. McNae in 1968 (*Advances in Marine Biology* 6: 75–270) to distinguish between mangrove plants and the community in which they live.
mesic	(In plant ecology) having moderate growing conditions, with medium or balanced moisture supplies.
notophyll	(In forest ecology) referring to a community of trees, the majority of which have leaves 75–125 mm in length or 2025–4500 mm^2 in area.
Priority Flora	In Western Australia, "Priority Flora" species are those that are considered potentially rare but about which insufficient is currently known to declare them as such. Western Australia's Department of Environment and Conservation lists five Priority ratings, the definitions of which are reproduced in Table 3-1.
quadrat	A quadrat is a sampling site of a defined size and shape that is usually recorded in a homogeneous area of vegetation. In the case of this survey, quadrats were set as a square 50 m × 50 m (2500 m^2), although the size or shape was occasionally varied to fit stands of vegetation. Quadrats or plots are used to give a higher level of replicability than is achievable from a relevé. See **relevé** and **transect** below.
relevé	A relevé is a vegetation field sampling site that does not have a fixed size or marked-out shape. The relevé technique is a simple quantitative sampling technique in which a visual description is made of the vegetation of an area, including characteristics such as species found, cover, density, etc. It allows large areas to be classified and mapped in a limited amount of time. Unlike quadrats, relevés are not replicable for scientific purposes and were used during this survey as a method of gaining initial data for the definition of vegetation units. See **quadrat** above and **transect** below.
riparian	Relating to the banks of a natural watercourse. "Riparian vegetation" is the vegetation fringing such a watercourse.
sclerophylly	(Of plant species) the condition of having tough leathery leaves resistant to water loss.

subspecies	In botanical nomenclature a subspecies is an infraspecific rank immediately below that of species. Subspecies differ in distinct morphological (but heritable) ways from other subspecies of the same species. They will normally be capable of interbreeding with them, but will be prevented from doing so by geographical or other form of isolation.
taxon	A taxon is any taxonomic unit, of any rank in the taxonomic hierarchy. A taxon encompasses all included taxa of lower rank. In botany the expression is widely used as a catch-all term in a plant list for any species-group name, from species down through the infraspecific levels of subspecies, variety, subvariety, form and subform.
transect	In botanical surveying, a transect is a fixed line through a vegetation association or landscape etc. along which systematic sampling takes place. Transects are used to measure changes in vegetation patterns or as a sampling method when quadrats or relevés are not suitable, as in the case of the vine thickets studied during this survey. See **quadrat** and **relevé** above.
vagile	(Of plant species) having the ability to adapt to new situations and to colonise new locations.
variety	In botanical nomenclature a variety is an infraspecific rank immediately below that of subspecies. Varieties differ in minor morphological (but heritable) ways from other varieties of the same species and may be geographically separated from them. Varieties regularly intergrade and may be difficult to define in some populations.
vegetation association	A climax community of which the dominant stratum has a qualitatively uniform floristic composition and which exhibits uniform structure as a whole. A maximum of three strata are allowed. For each stratum, the association description of the vegetation type typically includes floristic information for the dominant and/or diagnostic species together with the structural formation (dominant growth form, cover, height) (DEH 2003).
vegetation community	An assemblage of plant species which are structurally and floristically similar and form a repeating “unit” across the landscape (DEH 2003).
vegetation formation	The synthetic structural unit to which are referred all climax communities exhibiting the same structural form, regardless of floristic composition (DEH 2003).
vegetation type	A community that has a floristically uniform structure and composition, often described by its dominant species (DEH 2003).
vegetation (or map) unit	A spatial category which contains a vegetation type or group of co-occurring vegetation types (DEH 2003). It is, in effect, a structurally and floristically repeatable vegetation stand defined for mapping purposes.
vine thicket	A closed-canopy community of vegetation similar to rainforest but with strongly seasonal rainfall. It may be deciduous or semi-deciduous, is structurally lower than rainforest, and is rich in woody lianas. Vine thickets grow in patches where soil moisture is available year-round.

Terrestrial fauna 4

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ABSTRACT

This chapter describes studies carried out on the terrestrial fauna of the Maret Islands and adjacent islands in the Bonaparte Archipelago and, on a broader scale, in the Mitchell Subregion of the Northern Kimberley Bioregion as delineated in the Interim Biogeographic Regionalisation for Australia. It is based on unpublished studies carried out in 2006 and 2007 by a team of zoologists and environmental consultants.

An initial reconnaissance survey was carried out in July and August 2006, followed by a more intensive survey program in November 2006 which continued into September 2007. The survey program was concentrated on North Maret Island and South Maret Island (both with laterite geology), Berthier Island and East Montalivet Island (two laterite "reference" islands), and Prudhoe Island and Lamarck Island (two sandstone reference islands), but brief visits were also paid to other islands, including Bigge, West Montalivet, Albert and Walker islands. The surveys were designed to record the occurrence of mammals, birds (including shorebirds and seabirds), reptiles, amphibians and invertebrates.

The study team gathered visual and acoustic records, employed a range of live-trapping techniques (using funnel, Elliott, cage and pitfall traps), and hand-searched along transect lines through all representative vegetation units. Mist nets and head torches were used to capture and identify bats and nocturnal birds. Although a specialised ultrasonic detector was used to identify bat calls, no analysable calls were detected by this means.

Surveys were undertaken for selected invertebrate groups, including land snails, earthworms, spiders, pseudoscorpions, schizomids, scorpions and millipedes. The intention was to identify potential short-range endemic species on the Maret Islands and the Montalivet Islands, as well as on other nearby islands including Berthier Island, Prudhoe Island and Lamarck Island.

During the surveys, 141 vertebrate species were recorded: 4 amphibians, 33 reptiles, 51 landbirds, 47 shorebirds and seabirds (including records south to Pender Bay), and 6 mammals (5 bats and the Kimberley rock-rat). Resident colonies of bats were found only on West Montalivet Island (two species).

Approximately 43 species of invertebrates were recorded: 15 land snails, 2 earthworms, 3 spiders, 13 pseudoscorpions, possibly 4 species of schizomid (3 of them troglobitic), 2 scorpions, 1 centipede, 2 millipedes (1 possibly troglobitic) and 1 troglobitic thysanuran (silverfish).

Over the whole terrestrial fauna survey program, 31 species thought to be new to science were discovered: 1 gecko (the only vertebrate), 6 land snails, 2 earthworms, 3 spiders, 10 pseudoscorpions, 4 schizomids, 2 scorpions, 2 millipedes and 1 thysanuran (silverfish). Most if not all of these species are short-range endemics.

INTRODUCTION

This chapter summarises the findings of the terrestrial fauna studies carried out in 2006 and 2007 on several groups of islands in the Bonaparte Archipelago in the Kimberley region of Western Australia. It is based on unpublished reports by RPS (2007). The studies were carried out to provide baseline environmental data for an environmental impact statement for a proposal by INPEX Browse, Ltd. to establish an onshore natural-gas processing plant on the Maret Islands as part of its Ichthys Gas Field Development Project. In 2008, however, INPEX selected Darwin in the Northern Territory as the preferred site for the plant and the company now has no plans to develop the Maret Islands for industrial purposes.

Background information

The islands of the Bonaparte Archipelago lie along a 150 km stretch of the Kimberley coastline between Kuri Bay in the south and Admiralty Gulf in the north. Although the archipelago consists of several hundred islands, most of these are small and many have areas of less than a square kilometre and are best described as small islets or emergent rocks. The Maret Islands and their neighbours, including the Montalivet Islands, Berthier Island, Prudhoe Island and Lamarck Island, lie in the heart of the archipelago.

The islands of the group are composed either of dissected laterite or of Proterozoic siliceous sandstone and are remnants of the Mitchell Plateau. The laterite is tentatively regarded as Tertiary and consists of bauxitic and ferruginous components. The complete laterite profile is 3–15 m thick over volcanics (basalt) but forms only a thin ferruginous layer on sandstone.

The islands are largely uninhabited and free of destructive introduced species such as goats, cats, rabbits, foxes, house mice and black rats. Consequently, the archipelago's "continental stress class", a means of describing the landscape health of biogeographic regions in Australia (Gethin 2001), is 6 on a scale of 1 to 6 (near-pristine) (Graham 2003; May & McKenzie 2003). However, little is known about the conservation status of many individual species and ecosystems as there has been a general lack of research in the area. A major gap in existing data is the lack of region-wide vegetation and soil maps at scales larger than 1:250 000 and quantitative fauna and flora surveys to assess condition and status.

The long period of physical isolation of the Maret Islands and other islands in the region from the mainland (around 6500 years) is likely to have resulted in genetic and morphological divergence within certain animal groups (such as earthworms and land snails of the family Camaenidae). Island populations tend to divergence genetically and morphologically as a result of natural selection, genetic drift and the geographic barriers to gene flow among the island populations and between the various island populations and those on mainland Australia. Such genetic and morphological divergence from mainland populations is expected in isolated island populations (Johnson, Adler & Cherry 2000; Mills, Moro & Spencer 2004) to the point that speciation may occur. However, where islands are connected periodically, for example North Maret Island and South Island are connected at low tide by an isthmus, there is potential for gene flow between populations which may offset the divergent trend. It is also noteworthy that ancient patterns in biogeography, formed during previous sea level fluctuations and glacial periods, may persist in island populations whereby historical geographic connections are reflected in genetic patterns amongst islands. This can lead to genetic connections among particular islands and divergence among groups of islands, despite effective isolation of gene flow among all islands.

Terrestrial vertebrates

The Kimberley region has a rich herpetofauna and shows biogeographic affinities with the Northern Territory and north Queensland (Kendrick & Rolfe 1991). In the mainland west Kimberley, 24 amphibian species have been recorded by other surveys. Few amphibian species, however, have been recorded on islands of the Bonaparte Archipelago, partly because many have not been adequately surveyed and partly because most islands lack permanent fresh water or suitable mesic refugia. Bigge Island is an exception, with four species from this island in the Western Australian Museum collection.

Eighty-eight terrestrial reptile species and 3 species of freshwater turtle have previously been recorded from or are likely to occur in the west Kimberley. From islands within the Bonaparte Archipelago for which detailed data are available, including the six islands subject to intensive surveys for this study in 2007 (the Maret Islands, Berthier Island, East Montalivet Island, Prudhoe Island and Lamarck Island), 35 terrestrial reptile species have been recorded. In comparison, 49 species were recorded during a 1987–1989 survey of mainland Kimberley vine-thicket patches (Kendrick & Rolfe 1991) and 29 species were recorded between 2002 and 2005 from 35 islands in the Bonaparte Archipelago (How et al. 2006).

The avifauna of the west Kimberley includes over 200 species, of which at least 152 have been recorded on islands in the Bonaparte Archipelago. In all, 89 land- and shorebird species, comprising 63 landbird species and 26 shorebird species, have been recorded from the Maret Islands, Berthier Island, the Montalivet Islands, Prudhoe Island, Lamarck Island, Albert Island[1] and Bigge Island (Burbidge & McKenzie 1978; RPS 2007).

The Kimberley vine thickets support an avifauna similar to that found in thickets in the Northern Territory and far north Queensland (Johnstone & Burbidge 1991). The distribution of birds within vine thickets is largely determined by rainfall, floristic structure and, to a lesser extent, substrate. Coastal vine-thicket patches are generally rich in trees and shrubs which produce succulent fruits and they also possess a thick layer of leaf litter rich in invertebrates. These food resources attract many frugivorous and other vine-thicket specialist birds, mangrove specialist birds, and other species not normally associated with vine thickets. However, many of the Kimberley mainland vine-thicket patches support fewer frugivores than tropical vine thickets elsewhere in the Australasian region (Johnstone & Burbidge 1991).

The Maret Islands and their neighbouring islands represent a potential stopover point for migratory shorebirds along the East Asian – Australasian Flyway. Many of these migratory species and their associated habitats are protected under international agreements.

[1] Albert Island is the unofficial name used during this study for the largest island of the Albert Islands group.

A number of species of seabirds nest on offshore islands and during the breeding period feed in offshore waters close to their nesting locations. They are often long-lived and as they commonly display fidelity to nesting sites year after year, they are vulnerable to disturbance. The numbers of nesting seabirds on any given island are controlled by the availability of suitable nesting space, so displacement of a breeding colony could be critical for that colony and that species. It would be unlikely that there would be any breeding populations of burrowing seabirds on the islands of the Bonaparte Archipelago because of a lack of suitable habitat. However, species known to nest on rocky outcrops, such as boobies and terns, are likely to nest on islands within the region.

Only a small subset of the rich mammal fauna of the West Kimberley was expected to occur on the Maret Islands because of the small size of the islands and the lack of permanent fresh water. Expeditions by staff of the Western Australian Museum between 2002 and 2005 failed to record mammals on the Maret Islands and Berthier Island (How et al. 2006).

Bigge Island is the exception, however, as it is the second-largest island in the Bonaparte Archipelago with an area of 17 000 ha. Mammals recorded from Bigge Island by museums or pre-existing in museum collections are the northern quoll (*Dasyurus hallucatus*), the warabi or monjon (*Petrogale burbidgei*), the sugar glider (*Petaurus breviceps*), the delicate mouse (*Pseudomys delicatulus*), the short-beaked echidna (*Tachyglossus aculeatus*), the black flying-fox (*Pteropus alecto*), the common sheathtail-bat (*Taphozous georgianus*), the scaly-tailed possum (*Wyulda squamicaudata*) and the Kimberley rock-rat (*Zyzomys woodwardi*).

No amphibians, reptiles or mammals listed under the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC Act) as "threatened" are known from the Maret Islands.

In contrast, landbirds appear to exist as metapopulations[2] across the islands, with at least some gene flow occurring between islands and from the mainland, thus reducing the opportunities for genetic divergence to occur. Some of these species of landbirds are probably seasonal visitors from the mainland, taking advantage of fruit in the vine thickets and not having to compete with terrestrial mammals for the food resource on the islands.

[2] In population dynamics, a metapopulation is a regional group of connected populations of a species. For a given species, each metapopulation is continually being modified by increases (from births and immigration) and decreases (from deaths and emigration) of individuals, as well as by the emergence and extinction of local populations contained within it. The term is usually applied to species living in fragmented habitats.

Invertebrate short-range endemics

Terrestrial invertebrates include species known as narrow-range endemics (Ponder 1999, not seen, cited in Harvey 2002) or short-range endemics (Harvey 2002) that have naturally small distribution ranges, often much smaller than 10 000 km^2 in extent. These species have ecological and life-history traits that can lead to reproductive isolation of adjacent populations, for example low dispersal ability, confinement to discontinuous habitats, slow growth and low fecundity. High levels of short-range endemism have been found in Australian invertebrates, including land snails, earthworms, arachnids (mygalomorph spiders, pseudoscorpions, schizomids and scorpions) and millipedes.

There are many habitats that lend themselves to the evolution of short-range endemics. These include mountainous terrain, inselbergs, islands and isolated freshwater habitats, but also areas that have been subject to habitat fragmentation caused by aridification or a rise in sea level. The islands of the Bonaparte Archipelago present such an example of fragmented habitat. As they are thought to have been separated from the Kimberley mainland for approximately 6500 years they are likely to contain a number of island-specific short-range endemics.

Previous investigations into selected groups of the invertebrate fauna of the Kimberley region, in particular earthworms, spiders, pseudoscorpions, schizomids and scorpions, have been limited. Land snails, however, are an exception and have been the subject of extensive work on the Kimberley mainland since the late 19th century (Solem 1991).

Land snails

Although the land snails of certain mainland areas of the Kimberley region have been surveyed in some detail, there have been no such surveys of the snails of the islands of the Bonaparte Archipelago.

Among the early descriptions of land snails of the western and north-western areas of the Kimberley were those of European malacologists, principally E.A. Smith (1893, 1894). There are few records of any further snails having been collected in the area until the middle to late 20th century, although the Western Australian Wildlife Research Centre, then part of Western Australia's Department of Fisheries and Wildlife, surveyed snails on islands north-eastwards of Kuri Island and on areas of the mainland between 1971 and 1974 (Miles & Burbidge 1975).

It was considered likely that the land snails found on the different islands of the Bonaparte Archipelago would include genetically distinct populations at species level because of the long period of geographic isolation of the islands from each other and from the mainland. As it is known that genetic isolation in land snails can occur even over a few kilometres (Johnson, Hamilton & Fitzpatrick 2006), they were seen as suitable candidates for genetic studies investigating short-range endemism.

Earthworms

Terrestrial oligochaetes (earthworms) were identified by Harvey (2002) as potential short-range endemics. They rely on seasonally moist soil, but as seasonal soil-moisture regimes are patchy and uneven at local and landscape scales, this can result in a similarly patchy distribution of earthworm species (Wills & Abbott 2003).

Little is known of earthworm species in the islands of the Bonaparte Archipelago and in the Kimberley region in general. Worms collected from widely dispersed patches of vine thicket on the Kimberley mainland in 1988 and 1989 showed that there was a remarkable lack of earthworm diversity within vine-thicket patches. Only 15 out of the approximately 1500 patches in the Kimberley were surveyed. Earthworms of the genus *Diplotrema* were recorded at 10 of the 15 sites sampled and each patch had its own apparently unique species. Only one patch yielded two species (McKenzie & Dyne 1991).

As with land snails, the approximately 6500 years of separation of the Bonaparte islands from each other and from the mainland rendered it likely that any discrete earthworm populations located by the survey would be found to be short-range endemics.

Arthropods

Certain arthropod groups such as mygalomorph spiders, pseudoscorpions, schizomids, scorpions, and millipedes are also known to include taxa that have poor dispersal capabilities, are confined to disjunct habitats and have low fecundity; these are therefore likely to include short-range endemic forms.

For example, spiders have been undersurveyed in the Kimberley region and the Kimberley Rainforest Survey in 1988 and 1989 contributed disproportionately to the scientific record. The collections in the Kimberley vine-thicket patches showed that there is a rich spider fauna and that many of the species are short-range endemics. Main (1991) noted that the eight vine-thicket patches sampled yielded 207 species from 33 families (Main 1991). Seventy-nine of the species collected (38%) were "patch-unique" and all but one of the patches had at least some unique species.

Prior to 1991, only eight scorpion species, no schizomid species and five pseudoscorpion species had been reported from the Kimberley region (Harvey 1991a; Koch 1977; Smith, G.T. 1991). However, Harvey noted that in the survey work carried out in 1988 and 1989 in mainland Kimberley vine-thicket patches as part of the Kimberley Rainforest Survey, an unidentified epigean schizomid was collected (the first record of the order from the Kimberley) along with 26 previously undescribed short-range endemic pseudoscorpion species collected from 16 patches.

Although only a few specimens of pseudoscorpions have been recorded from islands of the Bonaparte Archipelago, a rich fauna would be expected because the islands support a wide range of habitats, including extensive vine thickets which have been found to be rich in short-range endemic species of this group on the Kimberley mainland.

In 2002 the order Schizomida was thought to consist of 200 species in 37 genera worldwide (Harvey 2002). The number of species and genera has been reviewed since then and new species are being discovered relatively frequently. The vast majority of Australian schizomids are short-range endemic species and many are known from only single locations (Harvey 1992, 2000a, 2000b, 2001, 2002; Harvey & Humphreys 1995).

Assessment of conservation significance

The conservation status of animal species in Australia is addressed under both Commonwealth and state legislation. Threatened species requiring special protection in Western Australia are listed under the EPBC Act and the *Wildlife Conservation Act 1950* (WA).

However, populations that are at the limit of a species' distribution, that have a very restricted range, or that are likely to constitute a distinct genetic race are also considered to be of conservation significance, although this level of significance has not been accorded legislative recognition.

There is some uncertainty as to how the conservation significance of reproductively isolated populations should be interpreted and it is widely recognised that there is difficulty in addressing protection of biodiversity at the genetic level (EPA 2002). In the context of the surveys described here, reproductively isolated island populations are considered to have intrinsic conservation value, below that of potentially new or Priority species[3], but above that of species thought to be able to move freely between islands.

[3] In Western Australia, "Priority Fauna" are species that are believed to be possibly rare but about which insufficient is currently known to satisfy the criteria for listing as threatened fauna under Schedule 1 of the *Wildlife Conservation Act 1950* (WA).

Three levels of conservation significance[4] are recognised in this report.

- Conservation significance 1: this category includes species which are listed as "threatened" or "migratory" under the EPBC Act and/or the *Wildlife Conservation Act 1950* (WA).
- Conservation significance 2: this category includes species which are not listed under state or Commonwealth Acts, but which are listed as Priority species by Western Australia's Department of Environment and Conservation[5]; new species that are currently unnamed; and species found outside their previously known distribution ranges.
- Conservation significance 3: this category includes those species which do not fall under categories "1" and "2" above, but which are considered to be of conservation significance because of the scarcity of information on their broader distribution, or because of their contribution to biodiversity at the genetic variation level (EPA 2002). Animals contributing to biodiversity at the genetic variation level would include, for example, short-range endemics or isolated populations (e.g. island-based flightless birds) of widespread species that are likely to have unique genetic characteristics. Populations on the edge of the known range of a species (EPA 2004) or that are particularly sensitive to impacts such as habitat fragmentation are also classed as being of conservation significance 3 for the purposes of this study.

Objectives

The studies were designed to determine the composition and distribution of the faunal assemblages and habitats on the Maret Islands, as well as on several nearby islands for comparative purposes. The main objectives of the studies were to identify significant or sensitive animal habitats, the ecological processes upon which animals may depend, and general patterns of biodiversity.

The objectives of the field surveys were as follows:

- to determine the diversity and distribution of terrestrial vertebrate fauna (including birds) on the Maret Islands and selected reference islands
- to investigate whether listed threatened fauna and potential short-range endemics such as land snails, earthworms, scorpions and spiders, occur on the islands
- to assess the geographic scale of endemism in representative groups that are known to produce short-range endemics when their species distribution ranges are restricted and disjunct
- to quantify the use of the Maret Islands and surrounding islands by migratory shorebirds and seabirds, particularly those protected by the JAMBA (DoFA 1981), CAMBA (DFAT 1988) and ROKAMBA (DFAT 2006) bilateral migratory-bird agreements with Japan, China and South Korea respectively, or protected under other Commonwealth or state legislation
- to compare the faunal habitats and fauna of the Maret Islands with those on nearby islands of similar and dissimilar geomorphology.

THE STUDY AREA

The islands which were the subject of the detailed terrestrial fauna investigations are listed below:

- North Maret Island (laterite geology)
- South Maret Island (laterite geology)
- Laterite reference islands
  - East Montalivet Island
  - Berthier Island
- Sandstone reference islands
  - Prudhoe Island
  - Lamarck Island.

The Maret Islands, Berthier Island and East Montalivet Island were visited on two occasions for the terrestrial vertebrate assessments in order to maintain scientific rigour and comply with the requirements of an Environmental Protection Authority (EPA) "Level 2" survey (EPA 2002). Prudhoe Island and Lamarck Island were subject to intensive trapping programs similar to those of the Maret Islands. Albert Island, Walker Island, Bigge Island and West Montalivet Island were visited but surveyed less intensively.

Shorebird and seabird surveys were conducted more broadly throughout the Bonaparte Archipelago. Locations visited included the Maret Islands, the Berthier Island group, Albert Island and its associated islets, the Montalivet Islands, Patricia Island, Don Island, Walker Island and its associated islets, Heritage Reef (north-west of West Montalivet Island), and selected rock outcrops.

[4] Note: the definitions of these three levels of conservation significance (for any possibly undescribed or genetically distinct species-group taxon collected on the survey) were developed by the RPS scientific team in recognition of the published conservation status of previously named species of plants and animals, the perceived ecological importance of the taxon, the rarity of the taxon in the study area and the likelihood of it being part of a genetically distinct and localised population.

[5] This was the name of the department at the time of the survey. It became the Department of Parks and Wildlife on 1 July 2013.

Terrestrial invertebrate surveys, targeting potential short-range endemics such as land snails, earthworms, scorpions and spiders, were conducted across the Maret Islands and Berthier Island. Land snail surveys were extended on to a small number of other regional islands, including the Montalivet Islands, Albert Island, Lamarck Island, Patricia Island and Don Island.

The locations of these islands are shown in Figure 4-1.

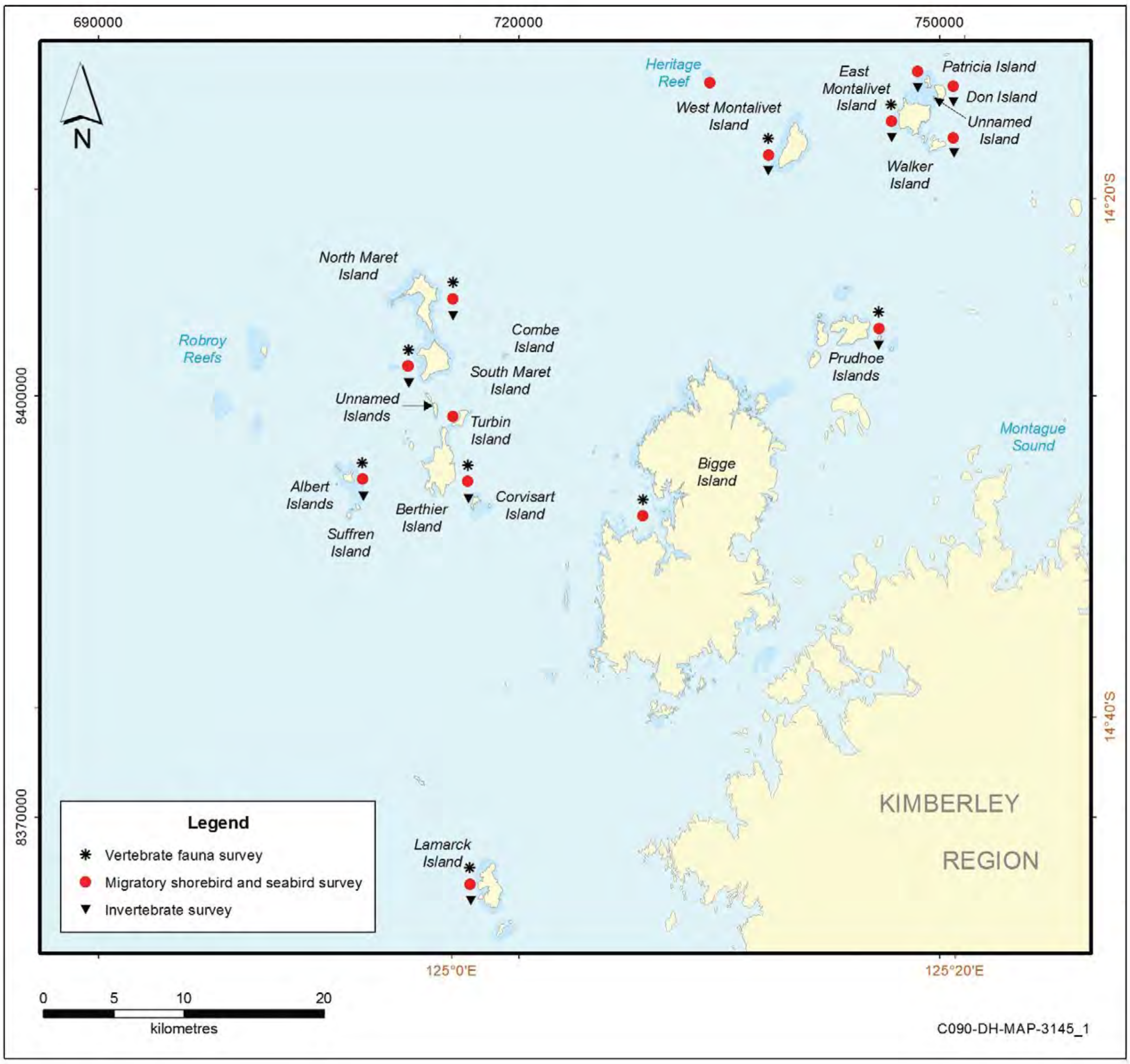

Figure 4-1: The study islands in the Bonaparte Archipelago

4 TERRESTRIAL FAUNA

METHODOLOGY

Little was known about the faunal assemblages of the Maret Islands and their neighbouring islands in the Bonaparte Archipelago prior to the study program described in this chapter. The program was conducted by scientists with expertise in surveys of terrestrial fauna from Bamford Consulting Ecologists, RPS Environment Pty Ltd, Aquila Wildlife Fieldwork, the Western Australian Museum, the University of Western Australia and the Department of Environment and Conservation.

Previous work in this region includes non-quantitative surveys by the Western Australian Museum (How et al. 2006) and the Department of Environment and Conservation. However, the current study represents the most thorough survey of the Maret Islands, Berthier Island, East Montalivet Island, Prudhoe Island and Lamarck Island completed to date.

The nomenclature and taxonomic order presented in this chapter are based on the Western Australian Museum's *Checklists of the vertebrates of Western Australia*. The authorities used for each vertebrate group were as follows:

- amphibians and reptiles—Aplin and Smith (2001)
- birds—Christidis and Boles (2008); Johnstone (2001)
- mammals—How, Cooper and Bannister (2001).

The common names for the vertebrate animals discussed in this chapter are based largely on the CSIRO's list of Australian vertebrates (Clayton et al. 2006).

Surveys of vertebrate animals (including migratory birds and shorebirds) and land snails were conducted in both the wet and the dry season in 2006. In 2007, these wet- and dry-season surveys were repeated and expanded to include earthworms and arthropods. A summary of the terrestrial fauna survey schedule is presented in Table 4-1.

Table 4-1: The field survey schedule for terrestrial fauna studies

Season	Month	Animals surveyed				
		Terrestrial vertebrates (excluding migratory birds and shorebirds)	Migratory birds and shorebirds	Land snails	Earthworms	Arthropods
Dry	July 2006	Maret Islands and regional islands	–	–	–	–
	August 2006		–	–	–	–
	September 2006	–	–	–	–	–
	October 2006	–	Maret Islands and regional islands	Maret Islands and regional islands	–	–
Wet	November 2006	–	Maret Islands and regional islands	Maret Islands and regional islands	–	–
	December 2006	–	–	Maret Islands and regional islands	–	–
	January 2007	–	–	Maret Islands and regional islands	–	–
	February 2007	North Maret Island	North Maret Island		Maret Islands	–
	March 2007	South Maret Island	South Maret Island	Maret Islands and regional islands		Maret Islands
	April 2007	Berthier Island	Berthier Island	Regional islands	Berthier Island	Berthier Island
	May 2007	East Montalivet Island	East Montalivet Island	–	East Montalivet Island	East Montalivet Island
Dry	June 2007	–	–	–	–	–
	July 2007	Prudhoe Island	Prudhoe Island	Prudhoe Island	Prudhoe Island	Prudhoe Island
	August 2007	–	–	–	–	–
	September 2007	Lamarck Island	Lamarck Island	Lamarck Island	Lamarck Island	Lamarck Island

Vertebrate fauna surveys

All of the reptiles that were caught in the traps or caught by hand (except for dangerously venomous snakes) were measured (snout–vent length and tail length). The sex of each animal was recorded only if it could be confidently ascertained. Voucher specimens were taken for specialist identification only when the identity of the species was not certain.

Bats were identified from direct sightings and their locations and behaviour were recorded. Although an AnaBat II detector was deployed and signals were obtained at South Maret Island, Prudhoe Island and Lamarck Island, they did not yield usable recordings.

Landbirds were identified to species level and abundances were recorded using a point-census approach. Shorebirds were identified using binoculars and the abundances were recorded by location. Where many individuals were present, the flock size was estimated using standard techniques. Table 4-2 summarises the terrestrial vertebrate survey methods used on each of the islands visited.

Transects and sampling points

Transects were determined to be the best method for obtaining a representative sample across all vegetation and landform types and therefore all habitat types.

The use of transects, as opposed to discrete sites within vegetation assemblages, allowed the sampling to cover the occasional variations of the landscape, including a variety of ecotones (transition areas between adjacent, different ecological communities).

The transect lines varied in length from 50 m to several kilometres, depending on site access. Sampling points were generally set at 50 m intervals along each transect, a distance which allowed for gradual and abrupt changes in the landscape and vegetation to be recognised. Each sampling point contained either a pitfall or a funnel trap (or sometimes both), depending on the type of substrate encountered. Generally, pitfall and funnel traps were used in sandy substrates (common among the dunes and lower vine-thicket slopes of North Maret Island and South Maret Island) where penetration into the ground was possible. Funnel traps were used over basalt or sandstone substrates and on the impenetrable lateritic substrate found on the islands' plateaux. On most islands Elliott and cage traps were placed at every second or third sample point along each transect.

Trapping

Four different types of traps were used to sample fauna at each location: pitfall traps, funnel traps, Elliott traps and cage traps. Table 4-3 presents the number of traps used and the survey effort at each location.

Table 4-2: Summary of the terrestrial vertebrate survey methods used

Island	Survey date	Survey method								
		Opportunistic observation	Pitfall trap and drift fence	Funnel trap and drift fence	Elliott trap	Cage trap	Bird census (audio-visual)	Head torch	Mist net	Bat detector
North Maret Island	July 2006	✓	✓	✓	✓	–	–	✓	✓	✓
	February 2007	✓	✓	✓	✓	–	✓	✓	✓	✓
South Maret Island	July 2006	✓	✓	✓	✓	–	–	–	–	✓
	March 2007	✓	✓	✓	✓	✓	✓	✓	✓	–
Berthier Island	August 2006	✓	–	✓	–	–	–	–	–	✓
	April 2007	✓	✓	✓	✓	✓	✓	✓	✓	–
East Montalivet Island	August 2006	✓	✓	✓	✓	–	–	–	–	–
	April 2007	✓	✓	✓	✓	✓	✓	✓	✓	✓
West Montalivet Island	April 2007	✓	–	–	–	–	–	–	–	–
Prudhoe Island	July 2007	✓	✓	✓	✓	✓	✓	✓	–	✓
Lamarck Island	September 2007	✓	✓	✓	✓	✓	✓	✓	✓	✓
Walker Island	August 2006	✓	–	–	–	–	–	–	–	–
Bigge Island	August 2006	✓	–	–	–	–	–	✓	✓	–
Albert Island	July 2006	✓	✓	✓	✓	–	–	–	–	–

Table 4-3: Number of traps used and the survey effort (number of traps × number of trap nights) at each location

Trap type	North Maret Island		South Maret Island		Berthier Island		East Montalivet Island		Prudhoe Island		Lamarck Island	
	No. of traps	Survey effort	No. of traps	Survey effort	No. of traps	Survey effort	No. of traps	Survey effort	No. of traps	Survey effort	No. of traps	Survey effort
Pitfall	21	153	15	60	5	25	13	65	23	138	23	136
Funnel	54	372	59	288	44	212	66	330	60	360	50	281
Elliott	45	335	46	208	45	200	42	200	20	140	20	120
Cage	0	0	16	89	10	40	31	145	10	70	10	60
Total	**120**	**860**	**136**	**645**	**104**	**477**	**152**	**740**	**113**	**708**	**103**	**597**

Pitfall traps made from polyvinyl chloride (PVC) tubes (400 mm deep and 150 mm in diameter) were used in combination with drift fences (around 6 m long and 300 mm high) (Figure 4-2). They were used in sand dunes and vine thickets, generally around the shoreline and the bases of the vine-thicket slopes of the islands. They could not be installed in the very hard basalt or lateritic plateaux on the islands.

Figure 4-2: Pitfall trap and drift fence

Funnel traps 700 mm long and 150 mm high and wide were set at 50 m intervals along each transect. Drift fences (with total lengths of around 6 m) were placed at each end of the funnel trap to intercept and guide animals into the trap. The number of traps along each transect line varied according to total transect length.

Shadecloth was placed over each funnel trap to protect trapped animals from the sun (Figure 4-3).

Figure 4-3: Funnel trap with a Weigel's black snake (*Pseudechis weigeli*)

Baited Elliott traps were placed along transects at every second or third sampling point (approximately 100 m apart) (Figure 4-4). The bait used was a mixture of oatmeal, peanut paste and sardines. The traps were set in shade to reduce heat stress on trapped animals. They were also used in a more intensive sampling regime (placed every 20–50 m) in order to target small mammals in areas where they were known to occur, for example on East Montalivet Island and Prudhoe Island.

Figure 4-4: An Elliott trap

Cage traps 800 mm long, 400 mm wide and 400 mm high (Figure 4-5) were set along transects (between 100 and 150 m apart) and were baited with a mixture of oatmeal, peanut paste and sardines. Traps were placed across all known major habitats (see Figure 4-6, for example) and were concentrated in potential mammal or large reptile habitat.

Figure 4-5: Cage trap with a Kimberley rock-rat (*Zyzomys woodwardi*)

Opportunistic observations and hand-searching

Opportunistic animal sightings, habitat descriptions and other noteworthy pieces of information which could contribute to the knowledge of the vertebrate fauna of the islands were recorded during each survey. Hand-searching under rocks and bark for small reptiles was conducted during all of the surveys.

Night-time searches using head torches were undertaken on at least one occasion on each island during the wet-season surveys. Head-torching was undertaken for approximately two hours during and after dusk, and involved walking along existing transects and also in vine thickets and other habitats close to the beach.

Bird-censusing

Landbirds were intensively censused on North Maret Island, South Maret Island and on the four reference islands, Berthier Island, East Montalivet Island, Prudhoe Island and Lamarck Island. They were less intensively censused on West Montalivet Island, Albert Island and Bigge Island. The censuses were carried out by counting the birds observed or heard at each trapping point on each transect line. The number of landbirds within a 25 m radius of each sampling point was recorded. As the sampling points were 50 m apart this ensured that all visible or audible birds within a 50-metre-wide belt along each transect were logged. Bird-censusing was carried out on each day that traplines were checked, to ensure that the censusing was repeated by different observers.

Detectability between species inevitably varied, but comparisons were able to be made for the same species between islands and habitats, and more cautiously between species, particularly when these could be assumed to have similar levels of detectability (e.g. the different dove species). Each bird census point covered a circle with a radius of 25 m (that is, with an area of approximately 0.196 ha), which allowed density estimates to be made.

Bat-detecting

Bats were surveyed using an AnaBat II bat detector and Edirol digital recorder. The surveys were undertaken at dusk and during the early evening but although signals were obtained at South Maret Island, Prudhoe Island and Lamarck Island, they did not yield usable recordings.

Mist-netting

Fine-mesh (mist) nets were set up in likely bat habitat or bird flyways on the surveyed islands to target small bats and nocturnal landbirds. The nets were placed on extendable poles to a height of around 4 m and were in place for several hours after dusk. Mist nets were also used to catch some diurnal landbirds to confirm identification.

Fauna habitat assessments

Throughout the terrestrial fauna surveys, the fauna habitats were described at each sampling point along the transect lines. The dominant plant species were recorded, along with the associated substrate and soil type. This information was used in conjunction with the results from the detailed vegetation mapping (see Chapter 3 *Terrestrial flora*) and geological surveys to form the descriptions of the fauna habitats.

Data analysis

Microsoft Excel software was used to handle all data storage, descriptive statistics and graphs.

The total trapping survey effort for each island was calculated by multiplying the number of traps by the number of nights they were used. This allowed a comparison to be made of trapping effort between islands. Because of the unevenness of the survey effort between islands, species captures were standardised for each island by dividing the captures of each species by the trapping effort for that island and then multiplying by 50, which was taken as the average effort in any of the habitats. Any reptile–habitat associations were highlighted by examining abundance in relation to the habitat and to the soil and landform type in which each animal was recorded.

Landbird–habitat associations were highlighted by examining abundance in relation to the habitat in which each species was recorded. Species densities were then calculated per hectare of habitat and extrapolated over the whole island to gain estimates of population size for each island.

Any habitat or soil and landform associations for invertebrate species were examined by plotting specimen locations over vegetation maps and over soil and landform maps.

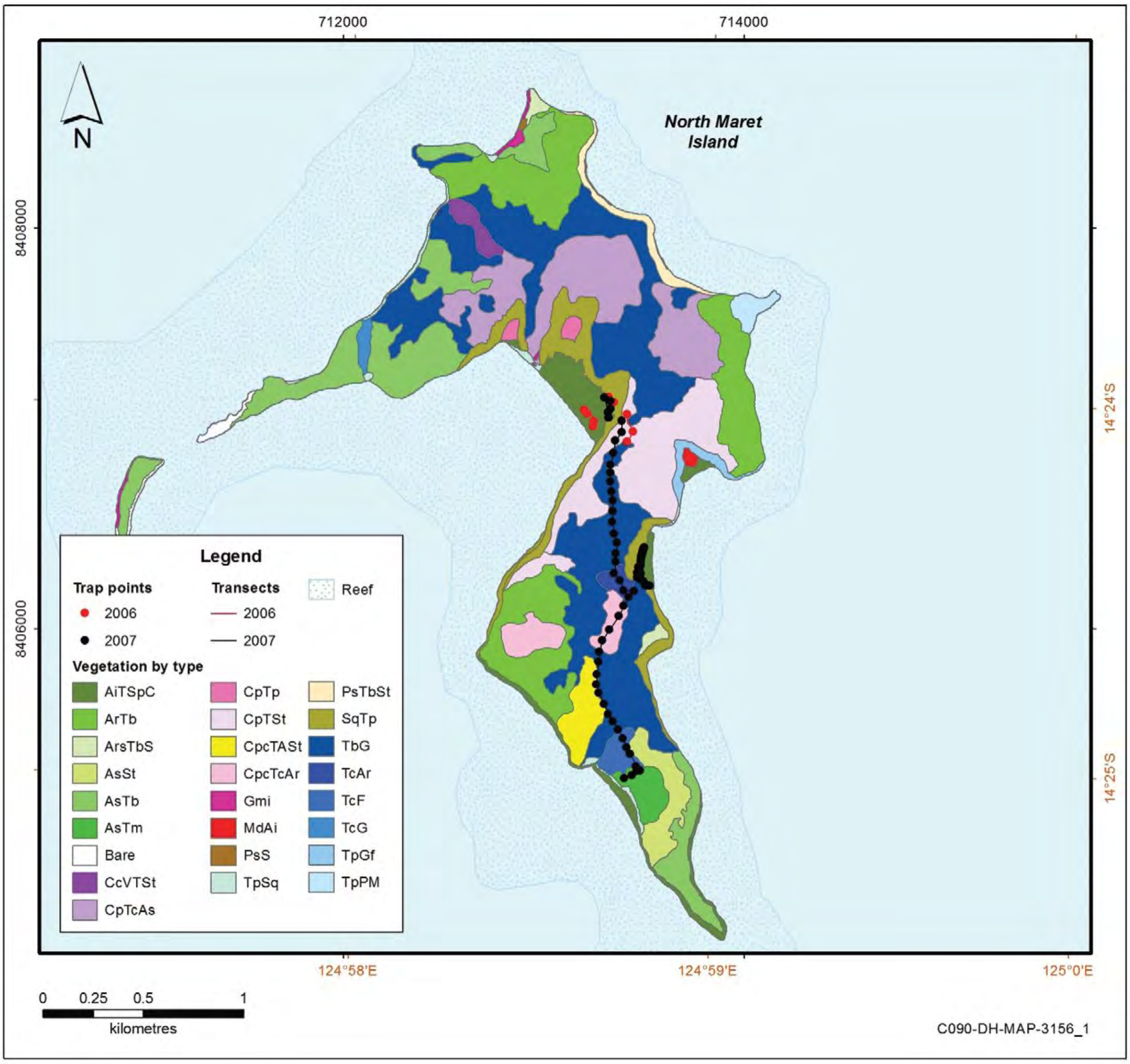

Figure 4-6: North Maret Island: vertebrate fauna trap sites and transect locations (see Table 3-13 for descriptions of the vegetation units)

Survey effort

North Maret Island

North Maret Island was sampled in July 2006 and February 2007. The July 2006 survey included opportunistic observations, head-torching and trapping along survey transects. Twenty-three funnel, 15 pitfall, and nine Elliott traps were used for between three and four nights depending on their location.

Survey transects and traps were established through the main vegetation units on the island in February 2007. The fauna survey in that month was undertaken over a nine-day period with between four and eight trap nights at each site. Bird-censusing was undertaken at every sample point on each day of monitoring. One night of head-torching, mist-netting and bat detection was undertaken during the study. The survey trap and transect locations are shown in Figure 4-6 over the vegetation units described in Chapter 3 *Terrestrial flora*.

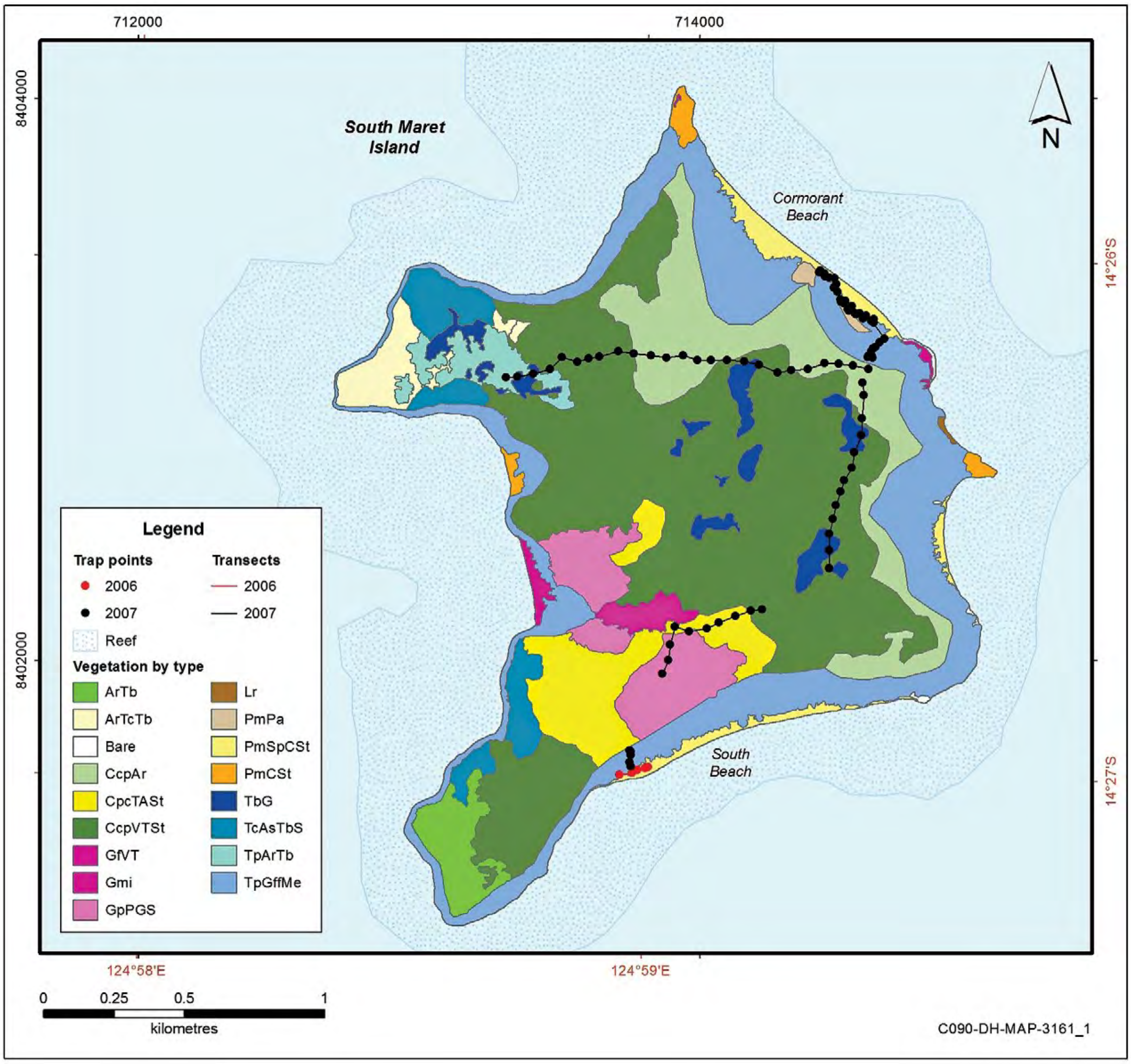

Figure 4-7: South Maret Island: vertebrate fauna trap sites and transect locations (see Table 3-13 for descriptions of the vegetation units)

South Maret Island

South Maret Island was sampled in July 2006 and March 2007. The July 2006 survey included opportunistic observations, head-torching and trapping. Five pitfall, five funnel and seven Elliott traps were used for two nights. These traps were deployed along South Beach.

Survey transects were established through the main vegetation units on the island in March 2007 and the fauna survey that month was undertaken over an eight-day period with either six or seven trap nights at each site.

Bird censusing was undertaken at every sample point on each day of monitoring. One night of head-torching (along the northern transect and Cormorant Beach) and of mist-netting (Cormorant Beach) was undertaken during the study. The survey trap and transect locations are shown in Figure 4-7 over the vegetation units described in Chapter 3 *Terrestrial flora*.

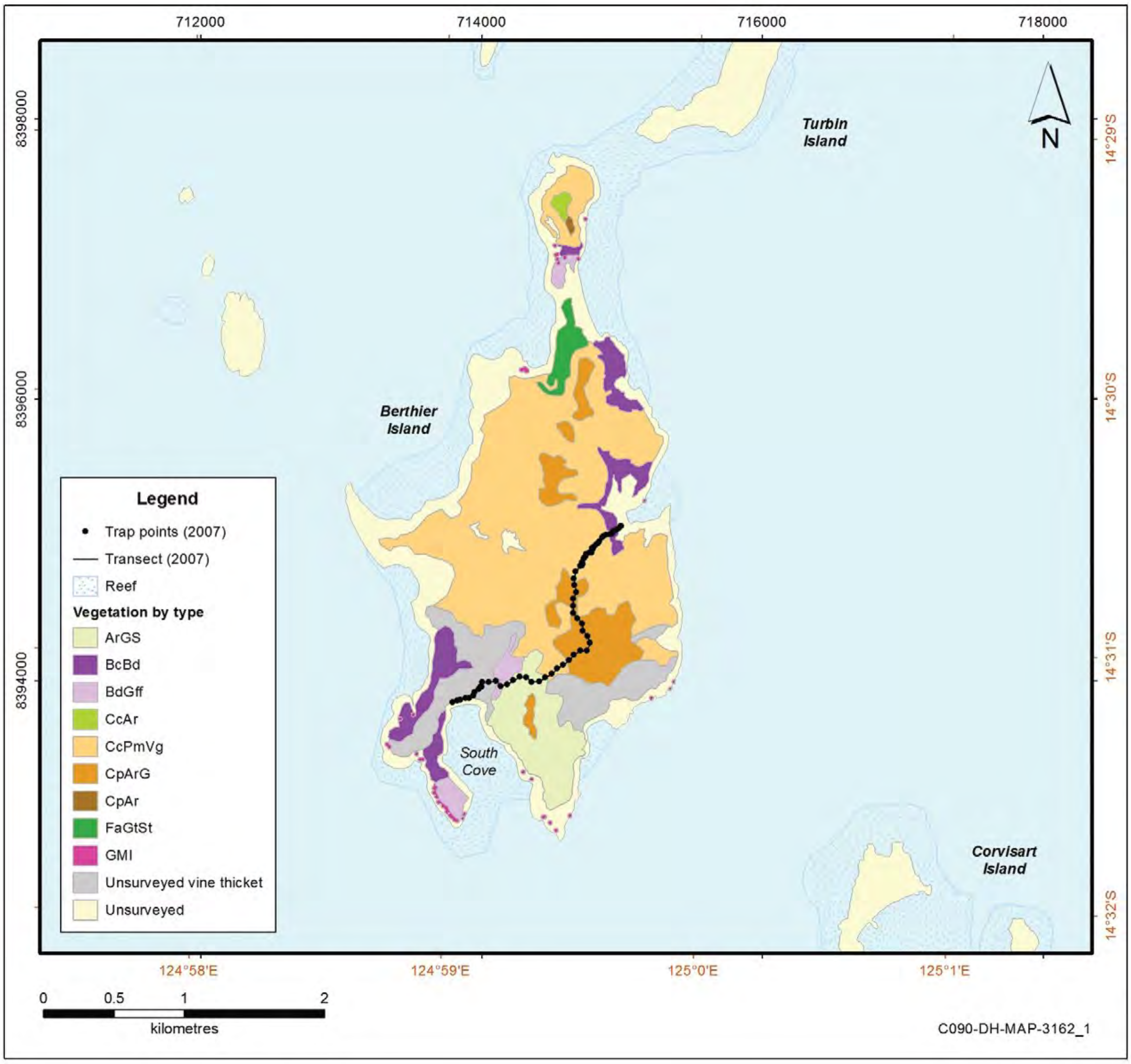

Figure 4-8: Berthier Island: vertebrate fauna trap sites and transect locations (see Table 3-13 for descriptions of the vegetation units)

Berthier Island

Berthier Island was sampled in August 2006 and April 2007. The August 2006 survey included opportunistic observations and trapping. Four funnel traps (two nights) and 11 Elliott traps (one night) were deployed near South Cove on the south coast of the island. Bat detection was also performed for one night from a boat anchored immediately offshore the island, also near South Cove.

Survey transects were established through the main vegetation groups on the island in April 2007 and the fauna survey that month was undertaken over an eight-day period with between four and six trap nights at each site. Bird-censusing was undertaken at every sample point on each day of monitoring. One night of head-torching, mist-netting and bat detection was undertaken during the study. The survey trap and transect locations are shown in Figure 4-8 over the provisional vegetation units described in Chapter 3 *Terrestrial flora*.

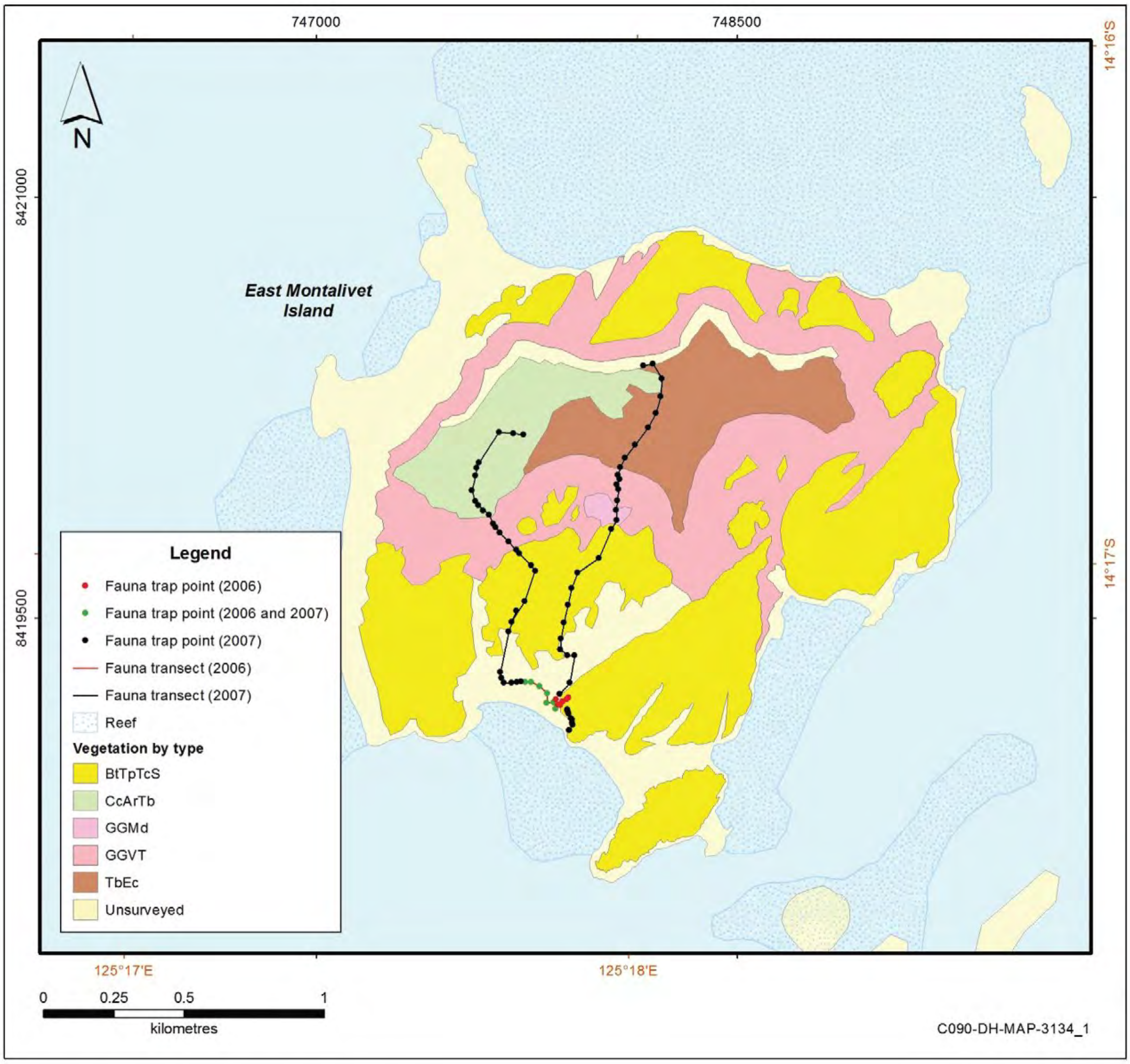

Figure 4-9: East Montalivet Island: vertebrate fauna trap sites and transect locations (see Table 3-13 for descriptions of the vegetation units)

East Montalivet Island

East Montalivet Island was sampled in August 2006 and May 2007. The August 2006 survey included opportunistic observations, head-torching and trapping. Seven pitfall, seven funnel and 16 Elliott traps were used for two nights. These traps were deployed in the dunes and vine thicket behind the beach at the south end of the island.

Survey transects were established through the main vegetation groups on the island in May 2007. The fauna survey that month was undertaken over a seven-day period with five or six trap nights at each site. Bird-censusing was undertaken at every sample point on each day of monitoring. One night of head-torching, mist-netting and bat detection was undertaken during the study. The survey trap and transect locations are shown in Figure 4-9 over the provisional vegetation units described in Chapter 3 *Terrestrial flora*.

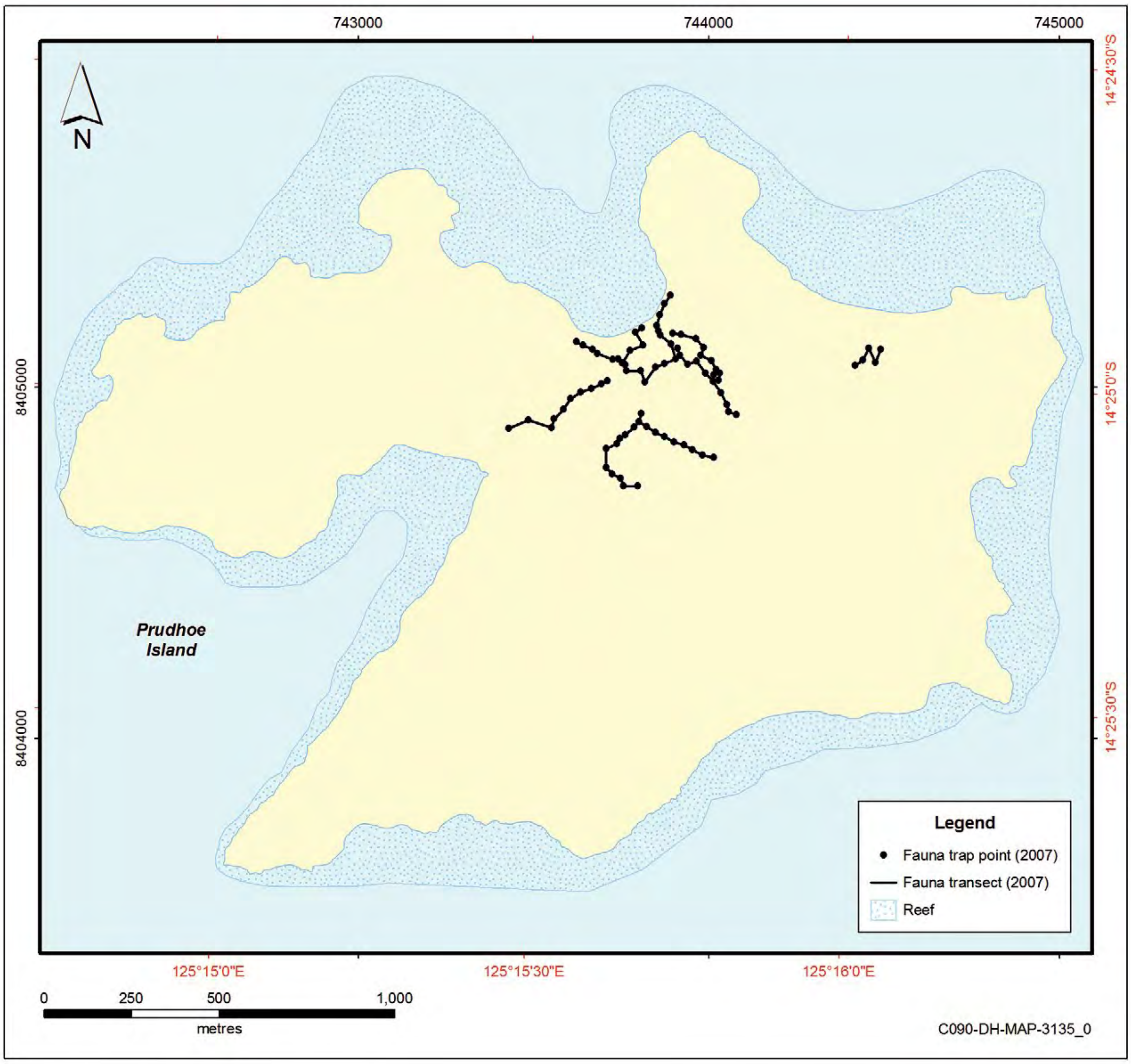

Figure 4-10: Prudhoe Island: vertebrate fauna trap sites and transect locations

Prudhoe Island

Prudhoe Island was surveyed once in July 2007 during the dry season. Survey transects were established through the habitats in the north-central part of the island. The survey was undertaken over a seven-day period with either five or six trap nights at each site. Bird-censusing was undertaken at every sample point on each day of monitoring. One night of head-torching and bat detection was undertaken during the study. The survey trap and transect locations are shown in Figure 4-10.

No detailed vegetation survey was conducted on Prudhoe Island.

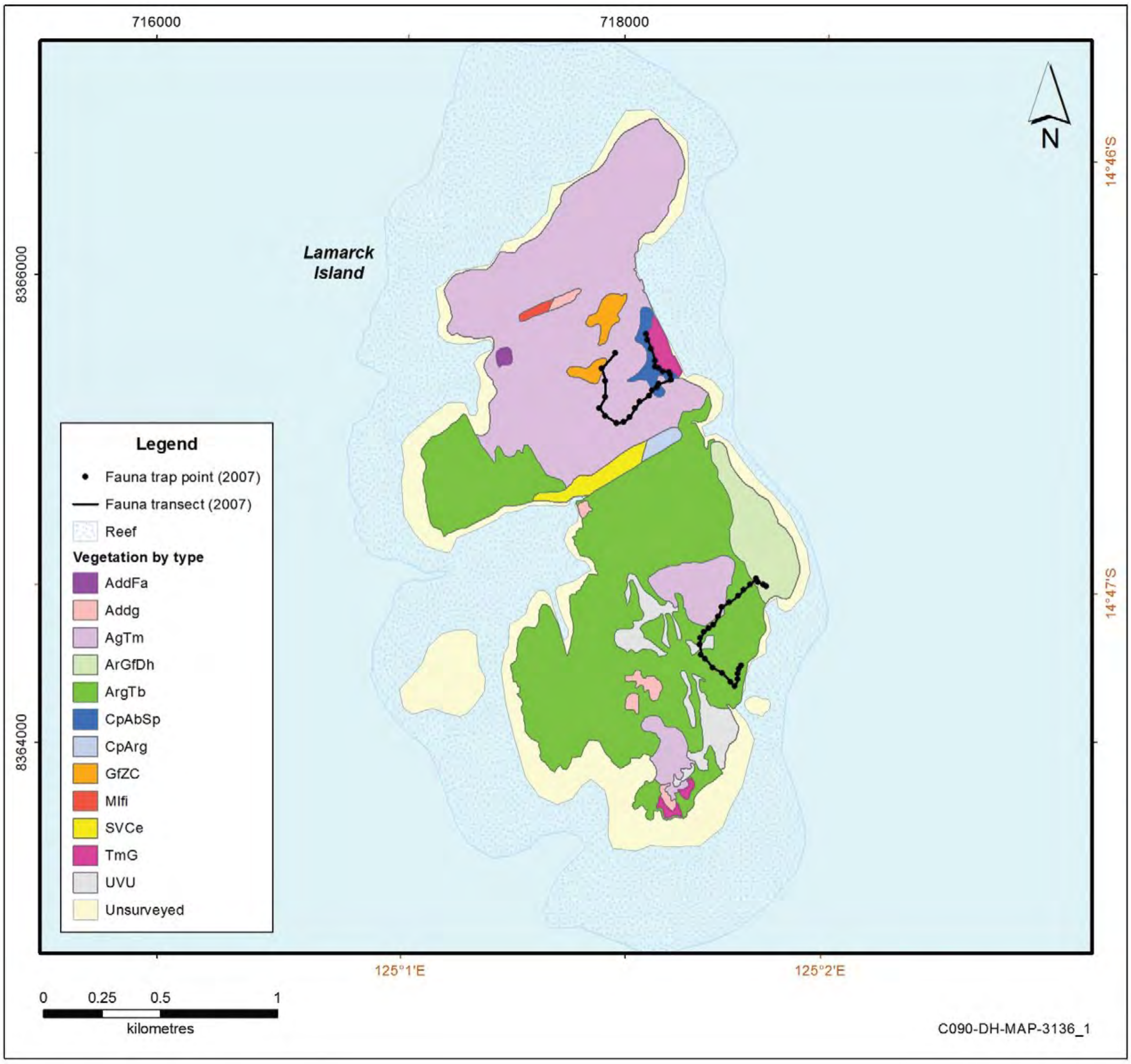

Figure 4-11: Lamarck Island: vertebrate fauna trap sites and transect locations (see Table 3-13 for descriptions of the vegetation units)

Lamarck Island

Lamarck Island was surveyed once in September 2007 during the dry season. Survey transects were established through some of the main habitats on the island and the survey was undertaken over a seven-day period (with either five or six trap nights at each site). Bird-censusing was undertaken at every sample point on each day of monitoring. One night of head-torching, mist-netting and bat detection was undertaken during the study. The survey trap and transect locations are shown in Figure 4-11 over the provisional vegetation units described in Chapter 3 *Terrestrial flora*.

Albert Island

Albert Island was surveyed in July 2006. The survey involved opportunistic observations and trapping using five pitfall, five funnel, and five Elliott traps over two nights on the south-east beach.

Bigge Island

Bigge Island was surveyed in August 2006. The survey included two days of opportunistic observations at Boomerang Bay (the large bay halfway down the west coast of the island) and at Wary Bay (a smaller bay on the north-west coast of the island), as well as one night of head-torching and mist-netting.

Walker Island

Walker Island was surveyed briefly in August 2006. The survey included opportunistic observations of birds and hand-searching for reptiles over one day.

West Montalivet Island

West Montalivet Island was visited briefly on 28 April 2007. The survey involved opportunistic observation of birds and hand-searching for reptiles for half a day, and allowed the team to become familiar with the environment of the island for comparison with East Montalivet Island.

Shorebirds and seabirds

Surveys were conducted across 36 islands and their associated reefs in October and November 2006 to record migratory shorebirds and seabirds (Table 4-4). The timing of these surveys was arranged to coincide with the southern migration of these bird species from east Asia.

Surveys were conducted by two experienced ornithologists from a dinghy travelling close to shore. The Maret Islands were surveyed repeatedly to assess daily variation in bird numbers. The other islands surveyed included the Berthier Island group, the Albert Islands, other associated rocks and unnamed islands, the Montalivet Islands, Patricia Island, Don Island, the Walker Islands and associated rocks, Heritage Reef and various rock outcrops.

Table 4-4: Shorebird and seabird survey dates and locations during the southern migration of birds from east Asia

Island, rock or reef	Date surveyed
North Maret Island	29-10-2006 to 30-10-2006 03-11-2006 to 04-11-2006
South Maret Island	29-10-2006 to 31-10-2006 03-11-2006 to 04-11-2006
Albert Islands Five small islands (one of which is Suffren Island) and two islets; the largest island was informally named “Albert Island” for the purposes of the survey.	31-10-2006
Berthier Island(s) A group of four islands—Berthier Island itself, together with three smaller unnamed islets off its north-west coast.	31-10-2006
“Unnamed Islands” Two unnamed islands between Berthier Island and South Maret Island, perhaps linked at low tide.	03-11-2006
Rocky islet west of the Maret Islands	30-10-2006
Combe Island	30-10-2006
Ripple Rock	30-10-2006
Trig Rock	30-10-2006
Turbin Island	30-10-2006 to 31-10-2006
Suffren Island This is the southernmost island of the Albert Islands group.	31-10-2006
Corvisart Island(s) A group of two islands south-east of Berthier Island—Corvisart Island itself, together with an unnamed islet off its east coast.	31-10-2006
Don Island A group of two islands—Don Island itself, together with a small islet off its south-west coast (“Unnamed Island”).	01-11-2006
Don Island and Patricia Island isthmus area	01-11-2006
Patricia Island	01-11-2006
Walker Island(s) A group of four islands—Walker Island itself, together with three smaller unnamed islets off its north-west coast between it and East Montalivet Island.	01-11-2006
Lamarck Island	02-11-2006
West Montalivet Island	01-11-2006 to 02-11-2006
East Montalivet Island	01-11-2006
Heritage Reef A submerged reef north-west of West Montalivet Island.	01-11-2006

Seabird observations were made in conjunction with cetacean surveys over 70 days between August and November 2006 (see Chapter 9 *Cetaceans*). The cetacean surveys covered the nearshore waters along the mainland coast and around the Maret Islands as well as the offshore waters of the Browse Basin.

Invertebrate short-range-endemic surveys

Land snails

Quantitative snail surveys were conducted on the plateau areas and the slopes with vine thickets on both North Maret Island and South Maret Island. Similar habitats were sampled on several other islands, including East Montalivet Island and West Montalivet Island, Don Island (and the small unnamed islet off its west coast), Patricia Island, Walker Island, Berthier Island and Lamarck Island. The approximate locations of land snail survey stations on the Maret Islands and the other islands surveyed are indicated on Figure 4-12. The exact locations of the total of 134 stations were recorded using a global positioning system (GPS) device (Table 4-5). They are listed in appendices 10 and 11 of the original RPS survey report (RPS 2007) as Western Australian Museum survey stations 1 to 107 and RPS survey stations W/F 1 to 27. At each survey station snails were collected by hand over an area of approximately 25 m^2.

Table 4-5: Number of sampling stations located on each island surveyed for land snails

Location	Number of snail sampling stations
North Maret Island	47
South Maret Island	38
East Montalivet Island	16
West Montalivet Island	14
Lamarck Island	2
Berthier Island	6
Patricia Island	2
Walker Island	3
Don Island	4
Albert Island	1
Unnamed Island*	1

* "Unnamed Island" is the unnamed islet off the south-west coast of Don Island as shown in Figure 4-1.

At each survey station a GPS reading was taken, together with notes on the time, locality, habitat and vegetation community. Snails were collected by hand over an area of approximately 25 m^2 at each station. Samples of soil and litter were collected from survey stations 1 to 92 and from some other survey stations. The collecting emphasis for stations 93–107 and W/F 1–27 was on hand-collecting live specimens of the larger, rock-dwelling *Amplirhagada* species for genetic analysis. The methodology and results of this genetic work have since been published by Johnson, O'Brien and Fitzpatrick (2010).

Soil and litter samples (approximately one litre in volume) were sieved in the field to remove large objects such as stones, leaves, twigs and dust. The sieved material, along with the specimens collected by hand within the station area, were then bagged, labelled and prepared for transport. The dead shells and the preserved live specimens were registered in the Western Australian Museum's database and stored in its research collections.

The soil and litter samples were sieved again in the laboratory and subsamples of each grade of litter and sand were examined under a dissecting microscope. Live and dead snails were identified and labelled.

When sufficient live specimens of a single species were available, some specimens were preserved in 100% ethanol and some were fixed in neutralised formalin and then preserved in 75% methylated ethanol to allow for subsequent anatomical work. Live specimens were frozen for DNA analysis.

The genus *Amplirhagada* was selected as a representative land snail group for a mitochondrial DNA study of potential short-range endemism. Live snails were collected from several potentially discrete populations on each island and were compared with outgroup samples taken from two adjacent mainland Kimberley sites. Further details are provided in the paper by Johnson, O'Brien and Fitzpatrick (2010).

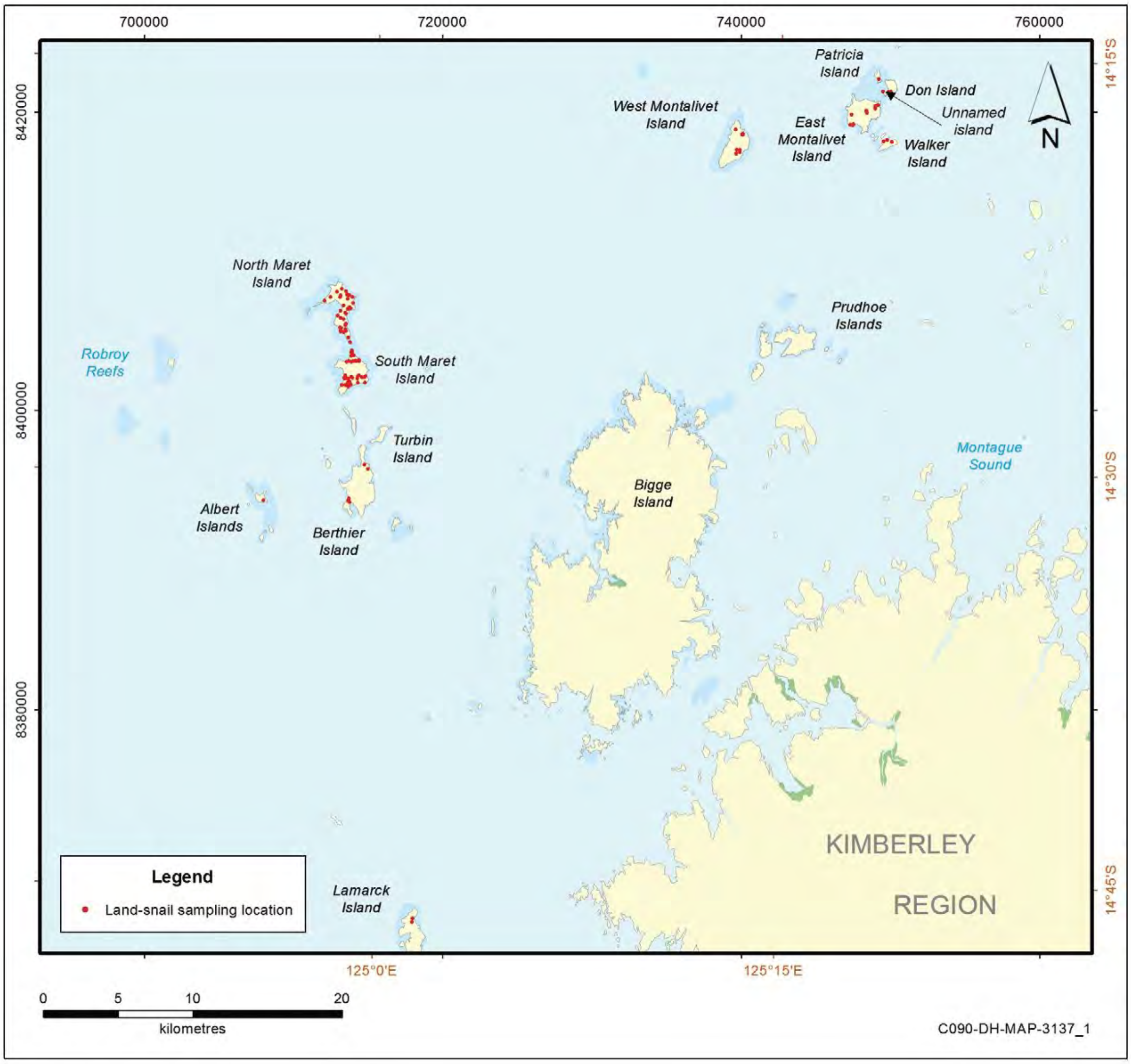

Figure 4-12: Regional overview showing land snail sampling sites in the study area

Earthworms

Systematic sampling for earthworms was conducted on North Maret Island and South Maret Island between 16 and 23 February 2007 using standard oligochaete sampling strategies (Abbott 1982, 1985a, 1985b; Abbott & Parker 1980; Abbott & Wills 2002; Wills & Abbott 2003).

Worm surveys were carried out across a range of landform and soil types (Table 4-6) and vegetation types (Table 4-7) over North Maret Island (12 sites) (Figure 4-13) and South Maret Island (21 sites) (Figure 4-14). At each site, a sample of soil was excavated from a hole approximately 190 mm × 190 mm square and 150 mm deep (or to the depth available if less than 150 mm).

Some earthworm species feed at the interface between moist litter and mineral soil. Where litter was present, it was scraped away to allow examination of the underlying soil surface. The exact geographic location of each sample was determined using GPS technology. The excavated block of soil was placed on a white surface and sorted in situ. The geomorphology, vegetation, litter depth and coverage, litter and soil moisture conditions, soil texture and colour, and the presence or absence of laterite pieces were recorded at each site. The details are recorded in appendices 14 and 15 of the original RPS survey report (RPS 2007).

Table 4-6: Geomorphic and soil units sampled during the Maret Islands earthworm survey

Geomorphic unit	General description of soils	Soil dryness	Litter dryness
Lateritic plateau	Massive laterite pavements. No spade penetration possible. Some soil associated with termite mounds.	No soil or dry	Scant litter
	Laterite with unlateritised surface “floaters” >5 cm in diameter. No spade penetration possible.	No soil	Dry
	Laterite with unlateritised surface floaters >5 cm in diameter and some interstitial soil. Limited spade penetration possible in interstices.	Dry	Dry
	Thin aeolian sand sheet over laterite.	Dry	Dry
Fringing cliffs and slopes	Cliffs of massive laterite. Not possible to sample.	n.a.	n.a.
	Slopes with red sandy soil with laterite pieces >1 cm in diameter. Surface boulders at some sites. Some spade penetration possible.	Dry	Dry
Swales between dunes and slopes	Red sands with laterite pieces >1 cm in diameter. Some spade penetration possible.	Dry	Dry
	Deep pale sands. Full spade penetration possible.	Dry	Dry
Dunes	Deep pale sands. Full spade penetration possible.	Dry	Dry
Beaches	Deep pale sands.	n.a.	n.a.
	Sand and coral fragments.	n.a.	n.a.

n.a. = not applicable.

Samples were taken from the principal vegetation units within the major geomorphic units. During the initial survey, 33 sites were sampled across all representative vegetation units and in all major geomorphic elements on the islands. Cliffs and beaches were excepted, however, as these are not suitable earthworm habitats.

Sampling effort was concentrated on soils within vine-thicket communities with the vegetation unit code TpGffMe[6] (see Chapter 3 *Terrestrial flora*) since this has the tallest and densest foliage cover and was most likely to have a well-developed litter layer.

Table 4-7: Number of earthworm sampling sites across geomorphic units and vegetation types on the Maret Islands

Geomorphic unit	Vegetation type	Number of samples
Lateritic plateau	TpGffMe	1
Lateritic plateau	Shrublands and woodlands	1
Lateritic plateau	Herblands and grasslands	4
Fringing cliffs and slopes	TpGffMe	3
Swales between dunes and slopes	TpGffMe	4
Dunes	TpGffMe	4

[6] Dominated by the trees *Terminalia petiolaris*, *Garuga floribunda* var. *floribunda* and *Mimusops elengi*.

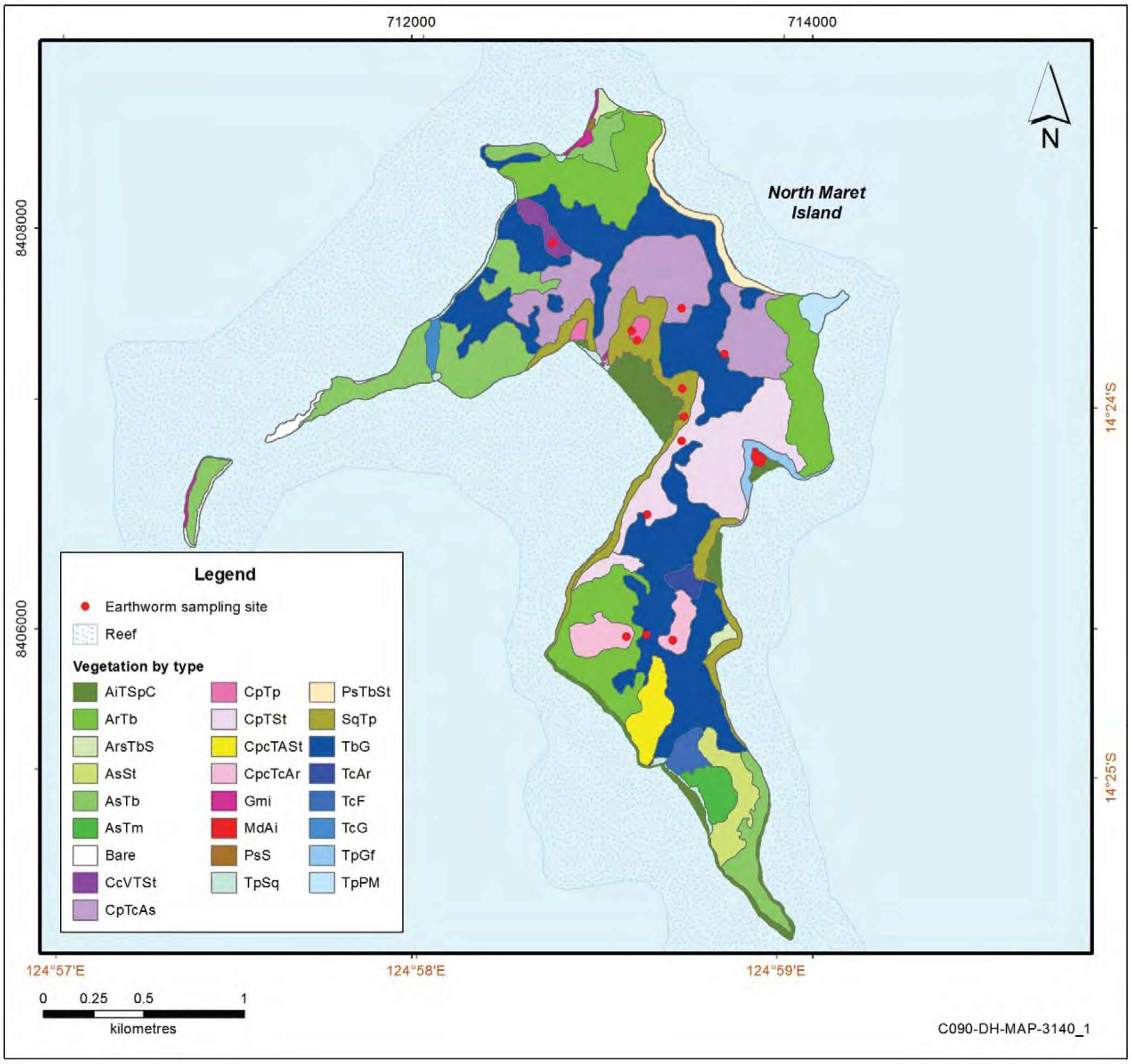

Figure 4-13: North Maret Island earthworm sampling sites (February 2007) (see Table 3-13 for descriptions of the vegetation units)

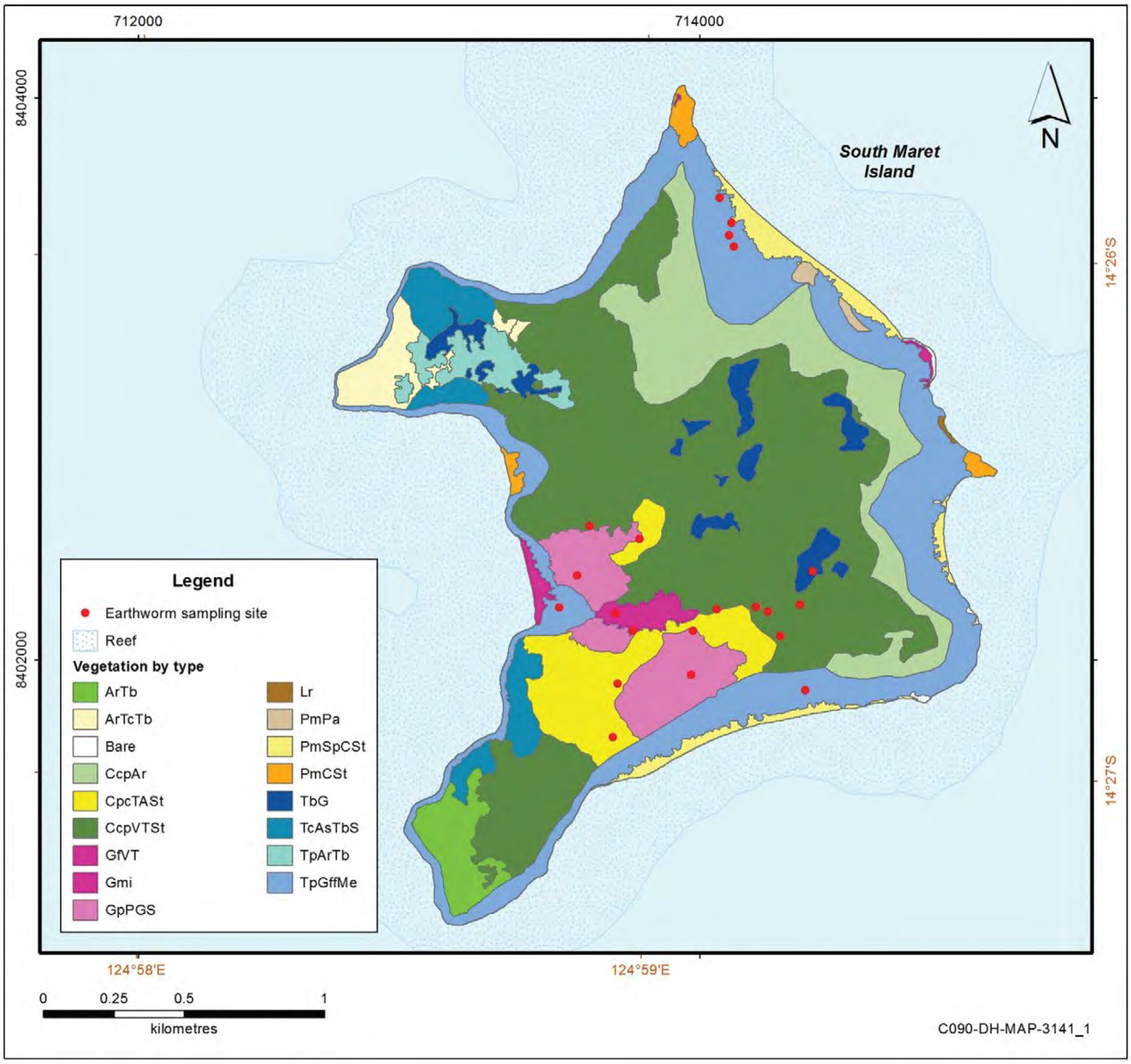

Figure 4-14: South Maret Island earthworm sampling sites (February 2007) (see Table 3-13 for descriptions of the vegetation units)

Although the formal earthworm survey between 16 and 23 February 2007 yielded no specimens, further earthworm surveys were continued in conjunction with later vertebrate fauna investigations in all vegetation groups on North Maret Island and South Maret Island, Berthier Island, East Montalivet Island, Prudhoe Island and Lamarck Island. Specimens were collected opportunistically on South Maret Island and Berthier Island on these occasions. Earthworm specimens were kept temporarily in moist soil in plastic specimen jars and kept cool for later preservation. They were washed and killed in 40% ethanol and then preserved in 70% ethanol for later examination. They are held in the collection of the Western Australian Museum.

The taxonomy of the Australian earthworm fauna is relatively well known despite large gaps in collection coverage. Extensive published faunas (Blakemore 2006; Dyne & Jamieson 2004; Jamieson 2000) generally allow the identification to genus and species level of sexually developed native and non-native specimens. The material collected from the Maret Islands was compared with published descriptions and appears to be assignable to the genus *Diplotrema* and to represent two undescribed species. However, as the specimens are sexually immature they are unsuitable for the preparation of formal descriptions.

Arthropods

Arthropod survey sites were selected on the basis of maps, aerial photographs, written reports and data contained within the Western Australian Museum's collections targeting the Kimberley and offshore islands. The sites were chosen to represent the various habitats on the Maret Islands and Berthier Island and to fit within limits imposed by the terrain and the apparent habitat diversity of the islands. The locations of the sampling sites for arthropods on the Maret Islands and Berthier Island are shown in Figure 4-15.

Representative specimens of all short-range endemic taxa were collected by hand at survey stations established within habitats such as vine thickets, open woodlands and closed woodlands. Within these survey station areas, searches were undertaken in microhabitats in vegetated and unvegetated areas, in hard and soft substrates (including all soil types, with and without plant litter), and on and under dead plants (e.g. under decaying fallen branches) and living plants (e.g. on foliage and under bark). Samples of leaf litter were collected for subsequent analysis. At night, head torches were used to search for spiders and other nocturnal groups.

Litter samples and arthropod samples were stored in collecting containers and jars for live transport to the Western Australian Museum.

Where possible, specimens were identified at the Western Australian Museum to species level using literature searches and by comparing them with specimens in the museum's collections. However, many invertebrate groups in Western Australia are currently under taxonomic revision or are in need of revision, and the lack of taxonomic resolution and the limited collections that have been made of some invertebrate groups make it difficult to identify such invertebrates or to assess their broader distributions.

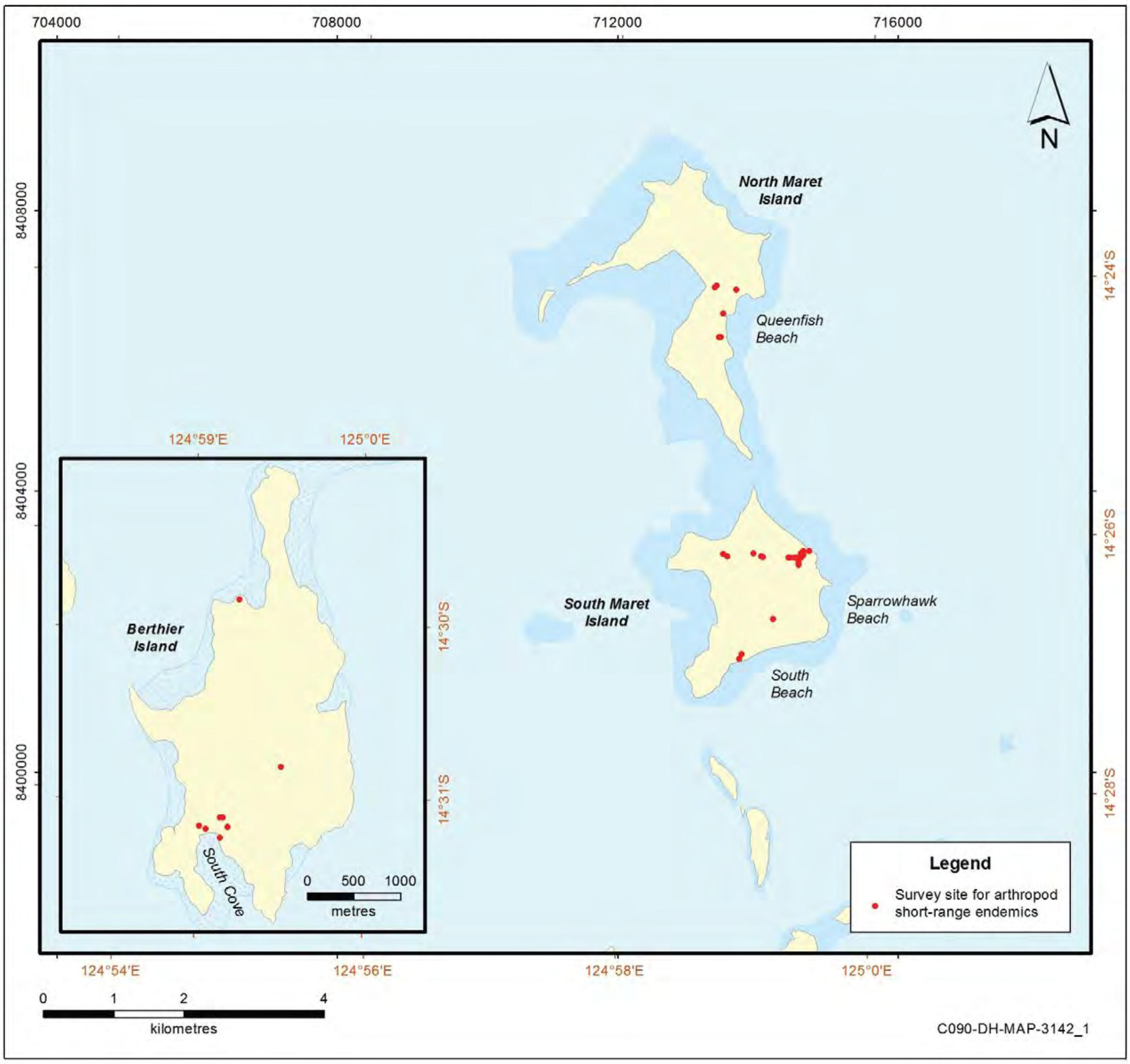

Figure 4-15: The locations of arthropod survey sites on the Maret Islands and Berthier Island

All specimens collected during the survey were deposited in the Western Australian Museum's collections as voucher specimens after being labelled and registered on the museum's database.

RESULTS

Vertebrate fauna

Amphibians

Three frog species were hand-collected on Bigge Island during the July–August 2006 survey: these were Copland's rock frog (*Litoria coplandi*), the bilingual froglet (*Crinia bilingua*), and the small toadlet (*Uperoleia minima*).

An unidentified frog of the genus *Uperoleia* was heard calling on East Montalivet Island and West Montalivet Island; these records were of frogs calling from beneath boulders alongside a stream (East Montalivet Island) and from beneath the overhanging bank of a pool (West Montalivet Island). The call recorded on East Montalivet Island does not match the known calls of *Uperoleia* species in the west Kimberley, but it should be noted that the calls of some species of this genus are as yet undescribed. The frog calls on the two islands were similar and it is likely that both frogs were of the same species.

Conservation significance—amphibians

- Conservation significance 1: no amphibians identified to species level and no amphibians of the genus *Uperoleia* are listed as "threatened" under the EPBC Act and/or the *Wildlife Conservation Act 1950* (WA).
- Conservation significance 2: the amphibians of the genus *Uperoleia* heard calling on East Montalivet Island and West Montalivet Island should be considered to be of conservation significance 2 as they may be found to be an undescribed species and these islands certainly fall outside the known range of the genus.
- Conservation significance 3: the amphibians of the genus *Uperoleia* heard calling on East Montalivet Island and West Montalivet Island may also be considered to be of conservation significance 3.

Reptiles

Reptiles were captured on the Maret Islands, Berthier Island, East Montalivet Island, Prudhoe Island and Lamarck Island using cage, Elliott, funnel and pitfall traps as part of the formal survey program. However, reptiles were also collected opportunistically by hand on these islands as well as on Albert Island, West Montalivet Island and Bigge Island (Table 4-2).

In all, 1589 individual reptiles, representing 7 families and 22 species, were trapped during the surveys. A further 11 species were observed, hand-caught in the trapping area or identified from skins, but not caught in the traps (Table 4-8).

Of the six islands intensively surveyed in 2007, Prudhoe Island and South Maret Island had the highest species richness with 21 species each, compared with 18 species on East Montalivet Island, 18 species on Berthier Island, 13 species on North Maret Island and 13 species on Lamarck Island. The only species that was recorded from the Maret Islands, but was not recorded on any of the reference islands (Berthier Island, East Montalivet Island, Prudhoe Island or Lamarck Island), was the zigzag velvet gecko (*Oedura rhombifer*).

Table 4-8: Reptile species caught by trap and opportunistically by hand during the surveys on islands in the Bonaparte Archipelago

	North Maret Island	South Maret Island	Berthier Island	East Montalivet Island	West Montalivet Island	Prudhoe Island	Lamarck Island	Albert Island	Bigge Island
Gekkonidae (geckos)									
Cyrtodactylus kimberleyensis	–	–	–	✓	–	–	–	–	–
Oedura obscura	–	–	–	–	–	✓	–	–	–
Oedura gracilis	–	–	–	–	–	✓	–	–	–
Oedura rhombifer	–	✓	–	–	–	–	–	–	–
Gehyra nana	–	–	–	–	–	✓	–	–	–
Gehyra occidentalis	–	–	–	–	–	–	–	–	✓
Gehyra xenopus	–	✓	✓	✓	✓	✓	✓	–	✓
Heteronotia planiceps	–	–	–	–	–	✓	–	–	–
Heteronotia binoei	✓	✓	✓	✓	✓	✓	✓	–	✓

Table 4-8: Reptile species caught by trap and opportunistically by hand during the surveys on islands in the Bonaparte Archipelago (continued)

	North Maret Island	South Maret Island	Berthier Island	East Montalivet Island	West Montalivet Island	Prudhoe Island	Lamarck Island	Albert Island	Bigge Island
PYGOPODIDAE (legless lizards)									
Delma borea	✓	✓	✓	✓	–	✓	–	–	–
Lialis burtonis	–	✓	✓	–	–	–	–	–	–
SCINCIDAE (skinks)									
Carlia johnstonei	✓	✓	✓	✓	✓	✓	✓	✓	–
Carlia sp.	–	–	–	✓	–	–	–	–	–
Carlia triacantha	✓	✓	✓	✓	–	✓	✓	–	–
*Cryptoblepharus plagiocephalus**	–	✓	✓	✓	–	✓	✓	–	–
Ctenotus inornatus	✓	✓	✓	✓	✓	✓	✓	✓	–
Cyclodomorphus maximus	–	✓	✓	✓	–	–	–	–	–
Eremiascincus isolepis	✓	✓	✓	✓	–	✓	✓	–	–
Lerista walkeri	✓	✓	–	✓	–	✓	–	–	–
Morethia ruficauda	✓	✓	✓	✓	–	✓	✓	✓	✓
Notoscincus ornatus	✓	✓	–	✓	–	✓	✓	–	–
VARANIDAE (monitors or goannas)									
Varanus acanthurus	✓	✓	✓	✓	–	✓	–	–	–
Varanus glauerti	–	–	✓	–	–	✓	–	–	–
Varanus glebopalma	–	–	–	–	–	✓	✓	–	✓
TYPHLOPIDAE (blind snakes)									
Ramphotyphlops kimberleyensis	–	✓	–	–	–	✓	–	–	–
BOIDAE (pythons)									
Antaresia childreni	✓	✓	✓	✓	–	✓	✓	–	–
Liasis olivaceus	–	✓	–	–	–	–	✓	–	–
Morelia carinata	–	–	–	–	–	–	–	–	✓
COLUBRIDAE (back-fanged snakes)									
Boiga irregularis	–	–	–	–	–	–	–	–	✓
Dendrelaphis punctulatus	–	✓	✓	–	–	–	–	–	–
ELAPIDAE (front-fanged snakes)									
Demansia olivacea	✓	✓	✓	✓	–	–	–	–	–
Furina ornata	–	–	✓	–	–	–	–	–	–
Pseudechis weigeli	✓	✓	✓	✓	–	✓	✓	–	–
Total number of species	**13**	**21**	**18**	**18**	**4**	**21**	**13**	**3**	**7**

✓ = species recorded.

– = species not found.

* The Australian members of the genus *Cryptoblepharus* were revised in 2007 (Horner 2007). The specimens of *C. plagiocephalus* collected on South Maret, Berthier, East Montalivet, Prudhoe and Lamarck islands in the course of this survey, and held by the Western Australian Museum, will have to be re-examined in the light of Horner's findings.

Fourteen reptile species caught on the islands had not previously been reported or collected from this area. Of these, 13 were expected to be found in this region on the basis of their broader distribution and one species of gecko was a new record for the Kimberley region. Thought at the time of capture to be possibly a species of the genus *Nactus*, it was later found to be a new species in the genus *Cyrtodactylus* and was described by Bauer and Doughty (2012) as *Cyrtodactylus kimberleyensis*, the Kimberley bent-toed gecko.

Overall, the reptile assemblages on the islands were low in species richness and similar in composition, with the rough brown rainbow-skink (*Carlia johnstonei*), the northern bar-lipped skink (*Eremiascincus isolepis*), the bar-shouldered skink (*Ctenotus inornatus*) and Bynoe's gecko (*Heteronotia binoei*) (Figure 4-16) being the most frequently encountered species.

As funnel traps proved to be the most effective form of trapping across all islands, only the funnel-trap data have been used for further comparison. The standardised capture rates of reptile species on the Maret Islands and on the four reference islands are presented in Table 4-9 and Figure 4-17.

Photographs courtesy of Christine Lamont

Figure 4-16: The bar-shouldered skink (*Ctenotus inornatus*) (left) and Bynoe's gecko (*Heteronotia binoei*) (right)

Table 4-9: Capture rates of reptile species caught in funnel traps on the Maret Islands and the four reference islands, standardised to 50 trap nights

Species	North Maret Island	South Maret Island	Berthier Island	East Montalivet Island	Prudhoe Island	Lamarck Island
Gekkonidae (geckos)						
Cyrtodactylus kimberleyensis	–	–	–	0.9	–	–
Gehyra xenopus	–	–	–	0.9	–	–
Gehyra nana	–	–	–	–	0.8	–
Heteronotia binoei	18.4	17.7	2.5	42.8	25.9	7.9
Pygopodidae (legless lizards)						
Delma borea	12.8	–	0.9	3.2	4.2	–
Lialis burtonis	–	1.3	2.0	–	–	–
Scincidae (skinks)						
Carlia johnstonei	7.1	31.1	49.6	7.0	6.0	96.2
Carlia sp.	–	–	–	15.6	–	–
Carlia triacantha	3.5	6.5	–	18.4	59.2	–
Ctenotus inornatus	165.1	298.6	84.2	121.1	88.6	93.3
Cyclodomorphus maximus	–	0.5	11.5	0.9	–	–
Eremiascincus isolepis	7.1	37.8	26.2	37.9	17.5	19.9
Lerista walkeri	–	–	–	0.9	6.7	–
Morethia ruficauda	5.4	4.2	2.7	2.0	10.8	23.7
Notoscincus ornatus	2.5	1.0	–	–	10.0	8.8
Varanidae (monitors or goannas)						
Varanus acanthurus	1.3	1.5	10.3	–	–	–
Varanus glebopalma	–	–	–	–	0.8	–
Typhlopidae (blind snakes)						
Ramphotyphlops kimberleyensis	–	3.6	–	–	0.8	–
Boidae (pythons)						
Antaresia childreni	1.4	1.3	4.5	0.9	–	–
Elapidae (venomous snakes)						
Demansia olivacea	2.7	4.1	4.8	4.6	–	–
Furina ornata	–	–	2.5	–	–	–
Pseudechis weigeli	3.3	1.3	–	–	3.3	11.6

– = species not found.

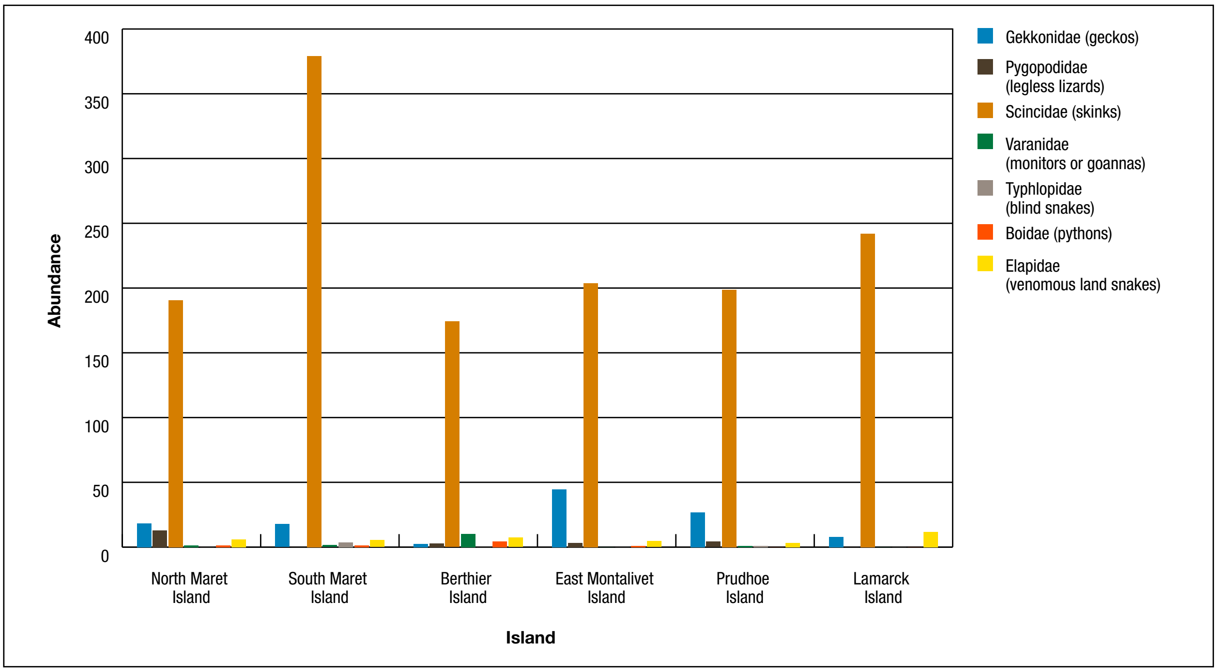

Figure 4-17: Standardised number of individuals of each reptile family recorded on each island

North Maret Island

One hundred and twenty traps (21 pitfall, 54 funnel, and 45 Elliott) were set on North Maret Island. The survey effort (number of traps × number of trap nights) for the island was 860. Reptiles were also caught opportunistically by hand. The most commonly encountered reptile species on North Maret Island was the bar-shouldered skink (*Ctenotus inornatus*), which was represented in all seven broad habitat groupings (Table 4-10). It was most abundant in *Triodia* and *Sorghum* grasslands on the upland plateau. When the standardised data were compared, this species did not appear to favour sand substrates over rock.

Fewer reptiles were recorded in the vine-thicket habitat and in woodland or shrubland habitats although they were not entirely absent from any of these. *Heteronotia binoei* was far less abundant than *Ctenotus inornatus* but was also present in most habitat types except for the *Triodia* grassland on gravel.

Carlia johnstonei and *Antaresia childreni* were found only in the vine-thicket habitat on the slopes of North Maret Island. However, *Antaresia childreni* was also found in *Triodia* grassland on rock during a head-torch survey on the island in July 2006, showing that it does have a broader habitat distribution. In contrast, *Notoscincus ornatus*, another skink species recorded in low numbers, was only found in the *Triodia* grassland on sand on the island's plateau. *Pseudechis weigeli* was recorded in low numbers although it appeared to occupy a broad range of habitats. *Delma borea* was recorded in low numbers across five of the seven habitats both on the plateau and in slope vine thicket.

Table 4-10: North Maret Island: capture rates of reptiles in funnel traps in each habitat, standardised to 50 trap nights

Species	Habitat*						
	1	2	3	4	5	6	7
Gekkonidae (geckos)							
Heteronotia binoei	0.5	5.8	3.8	3.7	2.1	–	2.5
Pygopodidae (legless lizards)							
Delma borea	–	5.8	3.8	0.7	–	–	2.5
Scincidae (skinks)							
Carlia johnstonei	7.1	–	–	–	–	–	–
Carlia triacantha	–	0.8	–	–	–	1.4	1.3
Ctenotus inornatus	8.6	18.3	21.8	12.5	37.5	26.4	40.0
Eremiascincus isolepis	2.4	0.8	–	–	–	1.4	2.5
Morethia ruficauda	1.0	1.7	1.3	–	–	1.4	–
Notoscincus ornatus	–	–	–	–	–	–	2.5
Varanidae (monitors or goannas)							
Varanus acanthurus	–	–	1.3	–	–	–	–
Boidae (pythons)							
Antaresia childreni	1.4	–	–	–	–	–	–
Elapidae (front-fanged snakes)							
Demansia olivacea	0.5	0.8	–	–	–	1.4	–
Pseudechis weigeli	0.5	–	–	0.7	2.1	–	–

– = species not found.

* The habitat descriptions in these footnotes are based on field observations made by the scientists conducting the fauna surveys. They are not directly related to the detailed vegetation units described in Chapter 3 *Terrestrial flora*.

Habitat descriptions:

1: Vine thicket and margin. Sands over buried lateritic colluvium or aeolianite.
2: *Corymbia* woodland over speargrass. Shallow sand with gravel, cobbles and stones over laterite.
3: *Corymbia* woodland over *Triodia*. Many cobbles and stones; shallow red or brown loam; gravel.
4: Shrubland over speargrass. Many cobbles and stones; shallow red or brown loam; gravel.
5: Speargrass grassland and herbland. Many cobbles and stones; shallow red or brown loam; gravel.
6: *Triodia* grassland. Moderately deep sand with few gravels over laterite.
7: *Triodia* grassland. Sandy; cobbles and stones; shallow red or brown loam; gravel.

South Maret Island

One hundred and thirty-six traps (15 pitfall, 59 funnel, 46 Elliott and 16 cage) were set on South Maret Island. The survey effort (number of traps × number of trap nights) for the island was 645. Reptiles were also caught opportunistically by hand. Fourteen species of reptile were trapped and a further seven species were observed on the island. The most frequently encountered reptile was the skink *Ctenotus inornatus*, which was represented in all habitat types (Table 4-11). It was most abundant in the sandy zone between the foredunes and the vine thicket, and was recorded in high numbers in all of the upland vegetation communities except for the upland vine thicket where it was far less numerous. It was recorded in low numbers in the lowland vine thicket, as was also the case on North Maret Island.

The gecko *Heteronotia binoei* was caught only in the upland vine thicket and within the upland *Acacia* and *Corymbia* woodlands. This is a more restricted distribution for the species from that noted for North Maret Island, where it was trapped in almost all habitats. It is also interesting to note that it was not trapped in the lowland vine thicket on South Maret Island as this was considered to be a habitat roughly equivalent to the vine-thicket margin, on sand, of North Maret Island. The skink *Eremiascincus isolepis* was trapped in greater numbers and had a higher standardised capture rate on South Maret Island than on North Maret Island, but shared a similar distribution with respect to vegetation groups. Its distribution was similar to that of *Heteronotia binoei* but it was also trapped in the lowland vine thicket.

Another species which was apparently more abundant on South Maret Island was the skink *Carlia johnstonei*, with the greatest numbers being detected in the upland and lowland vine thickets.

The snake-lizard *Lialis burtonis*, the blind snake *Ramphotyphlops kimberleyensis* and the blue-tongue *Cyclodomorphus maximus* were trapped on South Maret Island, although they were not detected on North Maret Island. A single specimen of *Delma borea* was observed, but not trapped, in the upland vine thicket on South Maret Island (Figure 4-18).

This vine thicket appeared equivalent in habitat structure to the vine thicket and margin on sand on North Maret Island, but no delmas were detected there.

No olive pythons (*Liasis olivaceus*) were trapped or observed on South Maret Island, although an incidental observation of an olive python swimming offshore suggests that they are able to swim between the islands.

Photograph courtesy of Christine Lamont

Figure 4-18: The rusty-topped delma (*Delma borea*)

Table 4-11: South Maret Island: capture rates of reptiles in funnel traps in each habitat, standardised to 50 trap nights

Species	Habitat*							
	1	2	3	4	5	6	7	8
Gekkonidae (geckos)								
Heteronotia binoei	1.1	3.9	2.5	6.0	–	–	4.2	–
Pygopodidae (legless lizards)								
Lialis burtonis	–	–	1.3	–	–	–	–	–
Scincidae (skinks)								
Carlia johnstonei	6.4	2.6	1.3	–	–	20.8	–	–
Carlia triacantha	–	–	1.3	1.0	–	–	4.2	–
Ctenotus inornatus	6.4	38.2	31.3	32.0	84.4	4.2	58.3	43.8
Cyclodomorphus maximus	0.5	–	–	–	–	–	–	–
Eremiascincus isolepis	15.4	6.6	8.8	7.0	–	–	–	–
Morethia ruficauda	–	–	–	–	–	–	4.2	–
Notoscincus ornatus	–	–	–	1.0	–	–	–	–
Varanidae (monitors or goannas)								
Varanus acanthurus	0.5	–	–	1.0	–	–	–	–
Typhlopidae (blind snakes)								
Ramphotyphlops kimberleyensis	0.5	–	–	–	–	–	–	3.1
Boidae (pythons)								
Antaresia childreni	–	–	1.3	–	–	–	–	–
Elapidae (front-fanged snakes)								
Demansia olivacea	1.6	–	2.5	–	–	–	–	–
Pseudechis weigeli	–	1.3	–	–	–	–	–	–

– = species not found.

* The habitat descriptions in these footnotes are based on field observations made by the scientists conducting the fauna surveys. They are not directly related to the detailed vegetation units described in Chapter 3 *Terrestrial flora*.

Habitat descriptions:

1: Upland vine thicket. Many cobbles and stones; shallow red or brown loam; gravel.

2: *Acacia* and *Corymbia* woodland over *Triodia*. Many cobbles and stones; shallow red or brown loam; gravel.

3: *Acacia* and *Corymbia* woodland over grasses. Many cobbles and stones; shallow red or brown loam; gravel.

4: Upland vine-thicket elements transitional with *Acacia* and *Corymbia* woodland. Many cobbles and stones; shallow red or brown loam; gravel.

5: Speargrass between foredunes and lowland vine thicket. Low-relief primary foredunes.

6: Lowland vine thicket. Moderately steep slopes with sands over buried laterite colluvium or aeolianite.

7: *Acacia* open shrubland over *Triodia*, speargrass, and herbs. Laterite pavement and extremely shallow gravelly loam; cobbles on shallow loam.

8: Open low woodland of *Acacia*, *Corymbia* and upland vine thicket. Cobbles and stones on red or brown sandy loam.

Berthier Island

One hundred and four traps (5 pitfall, 44 funnel, 45 Elliott and 10 cage) were set on Berthier Island. Twelve species of reptiles were trapped and a further six species were observed or hand-caught. *Ctenotus inornatus* was the most commonly encountered reptile and was caught in all habitats (Table 4-12). It was most commonly recorded in areas of tall grass with scattered vine thicket and in *Spinifex longifolius* communities over white sand.

The next most frequently encountered species was *Carlia johnstonei*, which was found across all habitats except in areas of *Spinifex longifolius* on white sand. The greatest numbers (once standardised) were trapped within the lowland vine thicket, which was also the case on North Maret Island and South Maret Island. *Eremiascincus isolepis* was mainly trapped in upland habitats, open vine thicket and *Corymbia* woodland, with one individual found in the *Spinifex longifolius* community.

Heteronotia binoei was recorded in lower numbers on Berthier Island than on the Maret Islands, while *Cyclodomorphus maximus* was recorded in higher numbers on Berthier Island than on the Maret Islands. *Heteronotia binoei* was most commonly recorded in habitats on the Maret Islands that have no equivalent on Berthier Island. *Cyclodomorphus maximus* was trapped in open vine-thicket habitat and in the tall grass in scattered vine thicket. Of the islands that were surveyed, these communities were only found on Berthier Island.

The python *Antaresia childreni* and the whipsnake *Demansia olivacea* were more numerous on Berthier Island than on North Maret Island and South Maret Island. The skinks *Lerista walkeri* and *Notoscincus ornatus* and the blind snake *Ramphotyphlops kimberleyensis* were all apparently absent from Berthier Island. These three species were only rarely encountered on the other islands, however, and it may be that they are present on Berthier Island but simply escaped detection.

Table 4-12: Berthier Island: capture rates of reptiles in funnel traps in each habitat, standardised to 50 trap nights

Species	Habitat*					
	1	2	3	4	5	6
Gekkonidae (geckos)						
Heteronotia binoei	–	–	1.8	0.7	–	–
Pygopodidae (legless lizards)						
Delma borea	–	–	0.9	–	–	–
Lialis burtonis	–	–	–	–	–	2.0
Scincidae (skinks)						
Carlia johnstonei	26.7	5.0	9.7	5.7	2.5	–
Ctenotus inornatus	3.3	15.0	0.8	2.1	25.0	38.0
Cyclodomorphus maximus	–	–	6.5	–	5.0	–
Eremiascincus isolepis	–	7.5	8.1	8.6	–	2.0
Morethia ruficauda	–	–	–	0.7	–	2.0
Varanidae (monitors or goannas)						
Varanus acanthurus	–	5.0	0.8	–	2.5	2.0
Boidae (pythons)						
Antaresia childreni	–	–	2.4	2.1	–	–
Elapidae (front-fanged snakes)						
Demansia olivacea	–	–	1.6	0.7	2.5	–
Furina ornata	–	–	–	–	2.5	–

– = species not found.

* The habitat descriptions in these footnotes are based on field observations made by the scientists conducting the fauna surveys. They are not directly related to the detailed vegetation units described in Chapter 3 *Terrestrial flora*.

Habitat descriptions:

1: Lowland vine thicket. Brown sand.

2: Open vine thicket and tall grasses. Lateritic rocks, cobbles and soil.

3: Open vine thicket. Lateritic rocks and cobbles.

4: Open *Corymbia* woodland with grasses and *Grevillea* and *Acacia* shrubs. Lateritic rocks, cobbles, gravel and soil.

5: Tall grasses with scattered vine thicket. Basalt cobbles, gravel and soil.

6: *Spinifex longifolius* and *Ipomoea*. White sand.

East Montalivet Island

One hundred and fifty-two traps (13 pitfall, 66 funnel, 42 Elliott and 31 cage) were set on East Montalivet Island. The survey effort (number of traps × number of trap nights) for the island was 740. A total of 14 reptile species were trapped and a further four species were observed but not trapped.

The bar-shouldered skink *Ctenotus inornatus* was the most commonly encountered reptile. It was found in six of the seven habitat types (Table 4-13). *Heteronotia binoei* and *Carlia triacantha* were also relatively easily found in the same six habitats, while *Eremiascincus isolepis* was trapped in five vegetation communities. The gecko *Gehyra xenopus* was found only on basalt boulders.

Table 4-13: East Montalivet Island: capture rates of reptiles in funnel traps in each habitat, standardised to 50 trap nights

Species	Habitat*						
	1	2	3	4	5	6	7
Gekkonidae (geckos)							
Cyrtodactylus kimberleyensis	0.9	–	–	–	–	–	–
Gehyra xenopus	–	–	0.9	–	–	–	–
Heteronotia binoei	12.7	4.3	1.8	6.0	9.1	8.9	–
Pygopodidae (legless lizards)							
Delma borea	0.9	1.4	0.9	–	–	–	–
Scincidae (skinks)							
Carlia johnstonei	3.6	1.4	–	2.0	–	–	–
Carlia sp.	8.2	3.6	1.8	2.0	–	–	–
Carlia triacantha	6.4	2.9	0.9	2.0	1.8	4.4	–
Ctenotus inornatus	6.4	27.9	11.8	11.0	31.8	32.2	–
Cyclodomorphus maximus	–	–	0.9	–	–	–	–
Eremiascincus isolepis	10.0	5.7	5.5	14.0	2.7	–	–
Lerista walkeri	–	–	0.9	–	–	–	–
Morethia ruficauda	–	–	0.9	–	–	1.1	–
Boidae (pythons)							
Antaresia childreni	–	–	–	–	0.9	–	–
Elapidae (front-fanged snakes)							
Demansia olivacea	–	–	0.9	1.0	2.7	–	–

– = species not found.

* The habitat descriptions in these footnotes are based on field observations made by the scientists conducting the fauna surveys. They are not directly related to the detailed vegetation units described in Chapter 3 *Terrestrial flora*.

Habitat descriptions:

1: Slope vine thicket. Bauxitic rocks and gravelly red soil.

2: Lowland vine thicket and margins. Pale sand.

3: Stunted vine thicket and *Mucuna* thicket. Basalt boulders; pale sand.

4: *Corymbia* and *Acacia* tall, dense shrubland. Deep litter over bauxite rocks.

5: *Triodia* grassland with scattered shrubs. Basalt platform with bauxitic gravel.

6: *Triodia* grassland with scattered shrubs. Bauxite rocks and gravel.

7: Sparse vegetation. Basalt.

Several specimens of a skink of the genus *Carlia* were found on East Montalivet Island in several vegetation communities, including those containing vine-thicket elements and in *Corymbia* and *Acacia* shrubland; it was not found on the other islands surveyed. A specimen has been lodged in the collection of the Western Australian Museum and is awaiting formal identification.

A single specimen of a gecko, thought at first to be of the genus *Nactus*, was collected in the slope vine thicket. This was subsequently formally described in 2012 as the Kimberley bent-toed gecko *Cyrtodactylus kimberleyensis* Bauer & Doughty and it is the first record of this genus for Western Australia (Figure 4-19).

Prudhoe Island

One hundred and thirteen traps (23 pitfall, 60 funnel, 20 Elliott and 10 cage) were set on Prudhoe Island. The survey effort (number of traps × number of trap nights) for the island was 708, although reptiles were also caught opportunistically by hand. The number of reptile species captured on Prudhoe Island during the dry-season survey was similar to the numbers captured on the other islands during the wet season. Thirteen reptile species were trapped on the island and a further eight species were captured by hand, giving a total of 21. Along with South Maret Island, this was the highest species richness recorded for reptiles on the islands surveyed.

Photograph courtesy of Robert Browne-Cooper

Figure 4-19: The Kimberley bent-toed gecko *Cyrtodactylus kimberleyensis*

The most commonly encountered reptile on Prudhoe Island was the skink *Ctenotus inornatus*. It was found in all surveyed habitats except those with very little vegetation cover on exposed sandstone (Table 4-14). It appeared to be most abundant in open woodland and grassland habitats, a similar situation to that observed on the other islands surveyed. The capture rates for this species were lower than on the Maret Islands and East Montalivet Island but similar to those on Berthier Island.

The rainbow-skink *Carlia triacantha* was the next most commonly encountered reptile and, as with *Ctenotus inornatus*, it was found across all vegetation communities except those on exposed sandstone. It was more abundant on Prudhoe Island than on any of the other islands surveyed. *Carlia johnstonei* was less abundant on Prudhoe Island than it was on South Maret Island and Berthier Island, but had similar numbers to those recorded for East Montalivet Island and North Maret Island. *Heteronotia binoei* was also found in a broad range of vegetated habitats, but was absent from the exposed sandstone sites. *Pseudechis weigeli* was recorded in low numbers on the island as was also the case with this species on the Maret Islands. *Ramphotyphlops kimberleyensis*, which had previously only been recorded on South Maret Island, was also recorded on Prudhoe Island.

Table 4-14: Prudhoe Island: capture rates of reptiles in funnel traps in each habitat, standardised to 50 trap nights

Species	Habitat*						
	1	2	3	4	5	6	7
Gekkonidae (geckos)							
Gehyra nana	–	–	–	0.8	–	–	–
Heteronotia binoei	6.7	2.5	–	4.2	5.8	6.7	–
Pygopodidae (legless lizards)							
Delma borea	2.5	–	–	–	–	1.7	–
Scincidae (skinks)							
Carlia johnstonei	–	1.7	–	3.3	–	–	1.0
Carlia triacantha	0.8	3.3	–	13.3	5.8	35.0	1.0
Ctenotus inornatus	18.3	20.0	–	5.8	28.3	14.2	2.0
Eremiascincus isolepis	1.7	–	–	5.8	1.7	8.3	–
Lerista walkeri	1.7	0.8	–	2.5	1.7	–	–
Morethia ruficauda	1.7	0.8	–	3.3	1.7	3.3	–
Notoscincus ornatus	–	–	–	7.5	–	2.5	–
Varanidae (monitors or goannas)							
Varanus glebopalma	–	0.8	–	–	–	–	–
Typhlopidae (blind snakes)							
Ramphotyphlops kimberleyensis	0.8	–	–	–	–	–	–
Elapidae (front-fanged snakes)							
Pseudechis weigeli	0.8	–	–	–	–	2.5	–

– = species not found.

* The habitat descriptions in these footnotes are based on field observations made by the scientists conducting the fauna surveys. They are not directly related to the detailed vegetation units described in Chapter 3 *Terrestrial flora*.

Habitat descriptions:

1: *Eucalyptus* woodland over dense *Sorghum*. Brown loam with embedded rocks.

2: *Triodia* hummock grassland. White sand.

3: *Triodia* and shrubs near some sites at base of sandstone cliff. Rock and white sand.

4: *Acacia* and *Eucalyptus* woodland over speargrass. Rock and brown loam.

5: Open woodland over *Triodia*. Red-brown sandy loam with some lateritic gravel.

6: Open woodland over *Sorghum*. Brown clayey loam.

7: Scattered shrubs. Flat, scattered sandstone boulders and breakaway.

Photograph courtesy of Christine Lamont

Figure 4-20: The gracile velvet gecko (*Oedura gracilis*)

The only reptile that was recorded on South Maret Island, Berthier Island and East Montalivet Island but was absent from Prudhoe Island, was *Cyclodomorphus maximus*. It was found only in vine-thicket habitat on the other islands and there is no vine thicket on Prudhoe Island. Conversely, several species were recorded on Prudhoe Island that were not recorded from the other islands, including *Gehyra nana*, *Oedura gracilis* (Figure 4-20), *Oedura obscura* and *Varanus glebopalma* (Figure 4-21). All of these species were found in habitats dominated by exposed sandstone or basalt rocks which do not occur on the other islands surveyed, except for Lamarck Island.

Photograph courtesy of Christine Lamont

Figure 4-21: The black-palmed monitor (*Varanus glebopalma*)

Lamarck Island

One hundred and three traps (23 pitfall, 50 funnel, 20 Elliott and 10 cage) were set on Lamarck Island. The survey effort (number of traps × number of trap nights) for the island was 597. Reptiles were also caught opportunistically by hand. Despite the survey being carried out in the dry season, 13 reptile species were recorded from the island. Seven of these were captured in traps, five were caught by hand and one was identified from a sloughed skin.

The species with the highest capture rate was the skink *Ctenotus inornatus*, followed by *Carlia johnstonei*. *Ctenotus inornatus* was present in all habitats but was less abundant in vine thickets than in other vegetation communities (Table 4-15). *Carlia johnstonei* was more abundant in habitats with vine-thicket species. This is a similar pattern of distribution for these species to that on the other islands surveyed.

Fourteen Weigel's black snakes (*Pseudechis weigeli*) were caught on Lamarck Island, the highest number for any of the islands surveyed. While this does suggest that Lamarck Island supports a larger population than the other islands, the high capture rate could also have been a seasonal effect.

The lined firetail skink (*Morethia ruficauda*) was found in all habitat types except for the *Acacia* open woodland with exposed sandstone and *Eremiascincus isolepis* was found in all habitat types except for the *Triodia* grassland and mixed vine thicket and *Acacia* low forest.

Two shed skins of the olive python (*Liasis olivaceus*) were found on Lamarck Island but no live specimens were seen or caught.

Table 4-15: Lamarck Island: capture rates of reptiles in funnel traps in each habitat, standardised to 50 trap nights

Species	Habitat*					
	1	2	3	4	5	6
Gekkonidae (geckos)						
Heteronotia binoei	–	5.6	1.4	–	0.9	–
Scincidae (skinks)						
Carlia johnstonei	5.8	27.8	8.3	24.5	11.8	18.0
Ctenotus inornatus	8.3	8.3	21.5	29.4	21.8	4.0
Eremiascincus isolepis	3.3	–	4.2	–	6.4	6.0
Morethia ruficauda	2.5	11.1	2.1	2.0	–	6.0
Notoscincus ornatus	3.3	2.8	–	–	2.7	–
Elapidae (front-fanged snakes)						
Pseudechis weigeli	0.8	–	1.4	3.9	5.5	–

– = species not found.

* The habitat descriptions in these footnotes are based on field observations made by the scientists conducting the fauna surveys. They are not directly related to the detailed vegetation units described in Chapter 3 *Terrestrial flora*.

Habitat descriptions:

1: Edge of species-poor vine thicket and *Triodia* hummock grassland. Light grey sand.

2: Mixed species-poor vine thicket and *Acacia* low forest over grasses on slopes with exposed sandstone. Dark brown sandy loam.

3: *Acacia* shrubland over speargrass and/or *Triodia* with scattered *Corymbia*, tall *Acacia* and vine-thicket trees on generally rocky ground. Dark brown silty sand.

4: *Triodia* grassland with scattered vine-thicket trees. White sand.

5: *Acacia* open woodland with scattered shrubs, much exposed sandstone and patches of speargrass. Brown silty shallow soil.

6: Species-poor vine thicket in a broad gully. Brown silty soil.

Conservation significance—terrestrial reptiles

- Conservation significance 1: no terrestrial reptile species of conservation significance 1 were recorded from any of the surveyed islands.
- Conservation significance 2: two terrestrial reptile species of conservation significance 2 were recorded during this study:
  - the Kimberley bent-toed gecko *Cyrtodactylus kimberleyensis*. It is known from only a single specimen, a gravid adult female captured in a funnel trap in vine thicket on East Montalivet Island by R. Browne-Cooper on 26 April 2007. At first thought to be a member of the genus *Nactus*, it was found to be a species of the bent-toed gecko genus *Cyrtodactylus* and was described in 2012.
  - *Carlia* sp.: a rainbow-skink that could not be assigned to any known species was found on East Montalivet Island in several vegetation types, including those containing vine-thicket elements.
- Conservation significance 3: reptile species that are unlikely to be able to swim between the islands of the archipelago are considered to be of conservation significance 3. Although most of the 14 species listed below are otherwise widespread with substantial populations, they qualify for inclusion in this category because they possibly contribute to biodiversity at the genetic variation level and are likely to be sensitive to impacts such as habitat fragmentation:
  - *Oedura rhombifer*: the zigzag velvet gecko appears to be uncommon and may occur only in plateau woodland. In the Bonaparte Archipelago it is presently recorded only from the Maret Islands but is known to be widespread on the Kimberley mainland. Its cryptic behaviour may explain its absence from the trapping records for other islands but it is possible that it is indeed absent from the other islands.

- *Gehyra xenopus*: the crocodile-faced dtella was collected from only a small area of East Montalivet Island and appears to be restricted to basalt rock habitats.
- *Delma borea*: the rusty-topped delma is possibly widespread in the Maret Islands, but appears to be uncommon.
- *Lialis burtonis*: Burton's snake-lizard is present but uncommon on South Maret Island and was not recorded on North Maret Island.
- *Carlia triacantha*: the desert rainbow-skink appears to be confined to open rocky habitats over laterite on most islands, but also on basalt on East Montalivet Island. This species is of interest as the populations on the Maret Islands may be very small.
- *Carlia johnstonei*: the rough brown rainbow-skink is virtually confined to vine thicket and associated habitats.
- *Cyclodomorphus maximus*: the giant slender blue-tongue was found on all islands except North Maret Island (where it was not recorded but may be present). It is restricted to rocky areas under dense vegetation, so its total population may be small.
- *Notoscincus ornatus*: the ornate soil-crevice skink was found on most islands. It appears to occur only in small numbers and may be restricted to upland grasslands.
- *Varanus acanthurus*: the spiny-tailed monitor is a widespread medium-sized goanna that may be vulnerable because of small population size.
- *Ramphotyphlops kimberleyensis*: the Kimberley shallow-soil blind snake is uncommon and was recorded only on South Maret Island and on Prudhoe Island.
- *Antaresia childreni*: Children's python is a widespread snake that may be vulnerable because of small population size.
- *Dendrelaphis punctulatus*: the common tree snake was recorded only on South Maret Island and Berthier Island in woodland with vine-thicket elements. It is likely to occur in small numbers, making it vulnerable to population decline if its habitat is reduced.
- *Demansia olivacea*: the olive whipsnake is a widespread snake that may be vulnerable because of its small population size.
- *Pseudechis weigeli*: Weigel's black snake is a widespread species that may be vulnerable because of its small population size and its preference for upland habitats.

Landbirds

The avifauna of the west Kimberley includes over 200 species, of which at least 152 have been recorded on islands in the Bonaparte Archipelago. In total, 89 land- and shorebird species have been recorded from the Maret Islands, Berthier Island, the Montalivet Islands, Prudhoe Island, Lamarck Island, Albert Island and Bigge Island by Burbidge and Mackenzie (1978) and by this survey (RPS 2007). This number is made up of 63 landbird species and 26 shorebird species).

Six islands were intensively censused for landbirds for this study: North Maret Island, South Maret Island, Berthier Island, East Montalivet Island, Prudhoe Island and Lamarck Island. However, opportunistic observations of landbirds were also made on these islands as well as on West Montalivet Island, Albert Island and Bigge Island. For the islands intensively surveyed, species abundance and species richness of landbirds was assessed by census, with the number of landbirds within a 25 m radius of each sampling point being recorded.

All told, this study recorded 51 species of landbirds from the nine islands listed above (Table 4-16).

A total of 31 species of landbirds were recorded for the six islands surveyed during the formal census, ranging from 11 for Prudhoe Island to 20 for Lamarck Island. The numbers of species observed on each of the laterite islands—the Maret Islands, Berthier Island and East Montalivet Island—during the intensive landbird surveys of February to May 2007 were very similar, ranging from 19 for East Montalivet Island to 16 and 15 for North Maret Island and South Maret Island respectively (Table 4-17).

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Table 4-16: Landbirds recorded on islands surveyed either intensively or opportunistically in the Bonaparte Archipelago

Species	North Maret Island	South Maret Island	Berthier Island	East Montalivet Island	West Montalivet Island	Prudhoe Island	Lamarck Island	Albert Island	Bigge Island
Bar-shouldered dove	✓	✓	✓	✓	✓	✓	✓	✓	✓
Black-faced cuckoo-shrike	–	–	✓	–	–	✓	✓	✓	–
Black-faced woodswallow	–	–	–	–	–	–	–	–	✓
Blue-winged kookaburra	–	–	–	–	–	–	✓	–	–
Broad-billed flycatcher	✓	✓	✓	✓	✓	–	✓	✓	–
Brown falcon	✓	✓	✓	–	–	–	–	–	–
Brown goshawk	✓	–	✓	✓	–	✓	✓	–	–
Brown honeyeater	✓	✓	✓	✓	✓	✓	✓	✓	✓
Brown quail (species not determined)	✓	–	–	✓	–	✓	–	–	–
Bush stone-curlew	✓	✓	–	–	–	–	–	–	–
Button-quail	–	–	–	–	–	–	✓	–	–
Collared sparrowhawk	–	–	✓	–	–	–	–	✓	✓
Dollarbird	✓	–	–	–	–	–	✓	–	–
Emerald dove	✓	✓	✓	✓	✓	–	–	–	–
Fairy martin	–	–	–	✓	–	–	–	–	–
Fork-tailed swift	–	✓	✓	✓	–	–	–	–	–
Gerygone (species not determined)	–	–	–	–	–	–	✓	–	–
Great bowerbird	–	–	–	–	–	✓	–	–	✓
Horsfield’s bronze-cuckoo	–	–	–	–	–	–	✓	–	–
Leaden flycatcher	–	–	–	–	–	✓	–	–	✓
Little bronze-cuckoo	–	✓	–	✓	–	–	–	–	–
Little corella	–	–	–	–	–	✓	–	–	–
Little woodswallow	–	–	–	–	–	–	–	–	✓
Magpie-lark	–	–	–	✓	–	–	–	–	–
Mangrove golden whistler	✓	✓	✓	✓	✓	–	✓	✓	–
Mistletoebird	✓	✓	✓	✓	✓	✓	✓	–	✓
Northern fantail	–	–	–	–	–	–	✓	–	✓
Olive-backed oriole	–	–	–	–	–	–	✓	–	–
Orange-footed scrubfowl	✓	✓	✓	✓	✓	–	✓	✓	–
Peaceful dove	–	✓	–	–	–	–	–	–	–
Pheasant coucal	✓	✓	✓	✓	–	✓	✓	–	–
Pied imperial-pigeon	–	–	–	–	–	–	✓	–	✓
Rainbow bee-eater	✓	✓	✓	✓	✓	–	–	–	–
Rainbow pitta	✓	✓	?	✓	–	–	✓	–	–
Red-headed honeyeater	–	–	–	–	–	–	✓	–	–
Red-tailed black-cockatoo	–	–	–	–	–	✓	–	–	–
Rose-crowned fruit-dove	✓	✓	?	✓	✓	–	✓	✓	✓
Rufous fantail	✓	✓	✓	✓	✓	–	✓	–	–
Sacred kingfisher	✓	✓	✓	✓	–	✓	✓	–	–

Table 4-16: Landbirds recorded on islands surveyed either intensively or opportunistically in the Bonaparte Archipelago (continued)

Species	North Maret Island	South Maret Island	Berthier Island	East Montalivet Island	West Montalivet Island	Prudhoe Island	Lamarck Island	Albert Island	Bigge Island
Sandstone shrike-thrush	–	–	–	–	–	–	–	–	✓
Silver-crowned friarbird	–	–	✓	–	–	✓	–	–	✓
Spotted nightjar	✓	✓	–	✓	–	✓	–	–	–
Swiftlet	–	–	–	–	✓	–	–	–	–
Torresian crow	–	–	–	–	–	–	–	–	✓
Varied triller	–	–	–	–	–	–	✓	–	✓
Wedge-tailed eagle	✓	–	✓	–	–	–	–	–	–
Whistling kite	✓	✓	–	–	–	–	✓	–	–
Willie wagtail	✓	✓	✓	✓	✓	–	✓	✓	✓
Yellow oriole	✓	✓	✓	✓	✓	–	✓	✓	✓
Yellow-tinted honeyeater	–	✓	–	–	–	–	–	–	–
Yellow white-eye	✓	✓	✓	✓	✓	✓	✓	✓	–
Total number of species	**24**	**24**	**21**	**23**	**14**	**15**	**27**	**11**	**17**

– = species not found.

? = unconfirmed identification.

Table 4-17: Numbers (non-standardised) of each species of landbird recorded at the Maret Islands and the four reference islands between January and May 2007

Species	North Maret Island	South Maret Island	Berthier Island	East Montalivet Island	Prudhoe Island	Lamarck Island
Bar-shouldered dove	75	157	102	141	3	79
Black-faced cuckoo-shrike	–	–	2	–	4	5
Broad-billed flycatcher	14	14	12	35	–	74
Brown goshawk	–	–	1	2	1	1
Brown honeyeater	94	70	109	12	10	21
Brown quail	5	–	–	1	6	–
Button-quail (species not determined)	–	–	–	–	–	1
Emerald dove	3	35	3	2	–	–
Fairy martin	–	–	–	4	–	–
Fork-tailed swift	–	–	9	11	–	–
Gerygone (species not determined)	–	–	–	–	–	8
Great bowerbird	–	–	–	–	7	–
Leaden flycatcher	–	–	–	–	3	–
Little bronze-cuckoo	–	2	–	–	–	–
Little corella	–	–	–	–	2	–
Magpie-lark	–	–	–	1	–	–

Table 4-17: Numbers (non-standardised) of each species of landbird recorded at the Maret Islands and the four reference islands between January and May 2007 (continued)

Species	North Maret Island	South Maret Island	Berthier Island	East Montalivet Island	Prudhoe Island	Lamarck Island
Mangrove golden whistler	35	45	2	27	–	35
Mistletoebird	13	25	6	2	35	34
Northern fantail	–	–	–	–	–	16
Orange-footed scrubfowl	1	3	2	3	–	10
Pheasant coucal	3	–	4	–	–	4
Rainbow bee-eater	–	34	16	30	–	–
Rainbow pitta	2	1	–	6	–	5
Red-headed honeyeater	–	–	–	–	–	1
Rose-crowned fruit-dove	29	31	–	10	–	29
Rufous fantail	28	10	9	6	–	15
Sacred kingfisher	4	3	2	–	1	1
Silver-crowned friarbird	–	–	4	–	–	–
Willie wagtail	9	–	–	1	–	15
Yellow oriole	34	23	39	63	–	73
Yellow white-eye	208	138	65	396	9	239
Number of individuals	**557**	**591**	**387**	**753**	**81**	**666**
Number of species	**16**	**15**	**17**	**19**	**11**	**20**

– = species not found.

The extent of the survey effort, measured as number of census points × number of days, varied between islands and was as follows:

- North Maret Island 468
- South Maret Island 300
- Berthier Island 261
- East Montalivet Island 330
- Prudhoe Island 490
- Lamarck Island 290.

The overall rate at which landbirds (regardless of species) were recorded per census point per day varied between the islands: North Maret Island had a rate of 1.2, South Maret Island had 2.0, Berthier Island had 1.5, and East Montalivet Island had 2.3. Thus, although the survey effort on North Maret Island was considerably greater than that on East Montalivet Island, the rate at which birds were recorded there, per census point per day, was much lower. Birds were most abundant on East Montalivet Island primarily because of the large numbers of yellow white-eyes. North Maret Island had the lowest abundance of birds. Species abundance appeared to be related to the extent of vine-thicket coverage on the islands, with higher abundances of birds recorded on those islands having greater vine-thicket coverage.

The number of landbird species observed on the sandstone reference islands, Prudhoe and Lamarck, varied considerably. Both were surveyed in the dry season but the vegetation communities of the two islands are noticeably different, with Lamarck Island being more similar to the laterite islands with its vine-thicket component; Prudhoe Island has no vine thickets. Fifteen species were recorded on Prudhoe Island and 27 on Lamarck Island, giving Lamarck the highest species count for any of the islands surveyed during this study. The survey effort on Prudhoe Island was 490, while the effort on Lamarck Island was 290. However, the recording rate for birds per census point per day on Prudhoe Island was 0.2, indicating the lowest overall bird abundance for all of the islands visited, despite the much higher survey effort there. The recording rate on Lamarck Island was 2.4, indicating the highest overall bird abundance for the islands surveyed.

The avifauna community compositions for each island are shown in figures 4-22 to 4-27. These relative densities are affected by the high numbers of yellow white-eyes on some islands. The majority of species, however, are fairly consistent in their relative densities. For example, the bar-shouldered dove was consistently abundant on all of the laterite islands, with a proportional representation ranging from 13.5% on North Maret Island to 26.5% on South Maret Island. The bar-shouldered dove had a similar contribution to the bird assemblage on Lamarck Island at 12%, but was far less dominant on Prudhoe Island, which lacks vine thickets, making up only 4% of the bird assemblage.

Four bird species that were recorded on Prudhoe Island were absent from the other five members of the intensively surveyed islands. These were the leaden flycatcher, the great bowerbird, the red-tailed black-cockatoo and the little corella. These species are most likely present because of the existence of suitable habitat, coupled with the relatively close proximity of the island to sources of fresh water on Bigge Island and the Kimberley mainland.

Several species were also recorded from Lamarck Island that were absent from the Maret Islands and the other reference islands. These were Horsfield's bronze-cuckoo, the pied imperial-pigeon, the blue-winged kookaburra, the red-headed honeyeater, the button-quail, the gerygone, the northern fantail, the varied triller and the olive-backed oriole. (It should be noted that some of these species were observed opportunistically and not as part of the formal survey; they have therefore been omitted from Figure 4-27 below.) As noted earlier, Lamarck Island's proximity to the mainland may be the reason for the slightly different bird assemblage.

Overall, the compositions of the bird communities on the islands that have vine thickets were found to be broadly similar, and the size of the vine thickets appears to be an important factor in determining the make-up of the different assemblages. Prudhoe Island, for example, was substantially different in terms of avifauna community composition, but it is not known if this can be attributed predominantly to the lack of vine-thicket habitat or to a combination of the nature of the vegetation communities, the sandstone substrate and the dry-season sampling. Of the 14 bird species recorded on all of the surveyed islands with vine thickets, 10 were found to be closely associated with vine-thicket habitats. Similarly, of the eight species with a proportional abundance of 5% or more on at least one island (excluding Prudhoe Island), six are vine-thicket species (Price, Woinarski & Robinson 1999; Woinarski et al. 2005).

The majority of species displayed fairly consistent relative abundances between islands. However, several species had notably different abundances between islands. These included the yellow white-eye, the bar-shouldered dove, the broad-billed flycatcher, the yellow oriole, the brown honeyeater, the rainbow bee-eater, the mangrove golden whistler, the rose-crowned fruit-dove, the emerald dove, the orange-footed scrubfowl and the rainbow pitta. This is thought to be related primarily to differences in habitat preferences, with most of these species displaying a preference for vine-thicket communities.

The rose-crowned fruit-dove is a vine-thicket specialist and was present on four of the six islands, but absent from Prudhoe Island and Berthier Island. Its absence from Prudhoe Island is not unexpected as the island has no vine-thicket communities, but Berthier Island does have vine thickets and was notable for the absence of rose-crowned fruit-doves as well as for the scarcity of another vine-thicket specialist, the mangrove golden whistler (which was not recorded from Prudhoe Island). The emerald dove was generally uncommon on four of the six islands (North Maret Island, Berthier Island, East Montalivet Island and South Maret Island) and was absent from Prudhoe Island and Lamarck Island. All three species were seen most often in vine thicket and associated vegetation communities.

The orange-footed scrubfowl and the rainbow pitta were recorded on all islands that had vine thicket and were absent from Prudhoe Island.

The bar-shouldered dove was consistently abundant on five of the six islands, but was scarce on Prudhoe Island.

The broad-billed flycatcher was also consistently present on the laterite islands despite having a low abundance. This pattern of consistent, but fairly low proportional abundance was also seen with the yellow oriole on the laterite islands. However on Prudhoe Island neither species was observed, and on Lamarck Island both species were relatively more abundant.

The brown honeyeater was abundant on all islands except East Montalivet Island and Lamarck Island. The mistletoebird was less abundant than the brown honeyeater and had an even representation on all islands except for East Montalivet Island, where the abundance was very low, and Prudhoe Island where the abundance was much higher. East Montalivet Island has less *Corymbia* woodland with its associated mistletoes, which suggests that the abundance of the brown honeyeater and the mistletoebird may be correlated with *Corymbia* woodland habitat on the islands of the Bonaparte Archipelago.

Rainbow bee-eaters were only recorded on the islands further offshore, including the Maret Islands, Berthier Island and East Montalivet Island, and were absent from Prudhoe Island and Lamarck Island. However, this is a migrant species and the islands further offshore were sampled during migration when numbers may have been higher than at other times.

North Maret Island

During the survey period, a total of 557 birds were recorded on North Maret Island, and the overall density was 146 birds/ha. Around two-thirds of the birds (366) were observed in vine thickets and 191 recorded in other habitats. This pattern was most pronounced on North Maret Island, where 14 species at a density of 64 birds/ha were recorded in vine thicket (Figure 4-22). In contrast, nine species at a total density of only 9 birds/ha were recorded in shrubland over speargrass, while eight species at a total density of 27 birds/ha were recorded in woodland over speargrass.

Grasslands were also generally low in bird species richness and abundance. On North Maret Island, the different grassland communities had lower levels of abundance (but not necessarily lower numbers of species) than the vine-thicket and woodland vegetation communities. *Triodia* grasslands had a higher than expected bird density given the sort of vegetation present, but much of this was attributable to yellow white-eyes observed flying across the grassland between two areas of vine thicket.

The species with the highest densities across all habitat types on North Maret Island were the yellow white-eye (58 birds/ha), the bar-shouldered dove (21 birds/ha) and the brown honeyeater (23 birds/ha). The densities of vine-thicket specialists were generally low, at 6 birds/ha for the mangrove golden whistler, 0.5 birds/ha for the emerald dove, <0.2 birds/ha for the orange-footed scrubfowl, <0.5 birds/ha for the rainbow pitta, 5 birds/ha for the rose-crowned fruit-dove and 8 birds/ha for the yellow oriole.

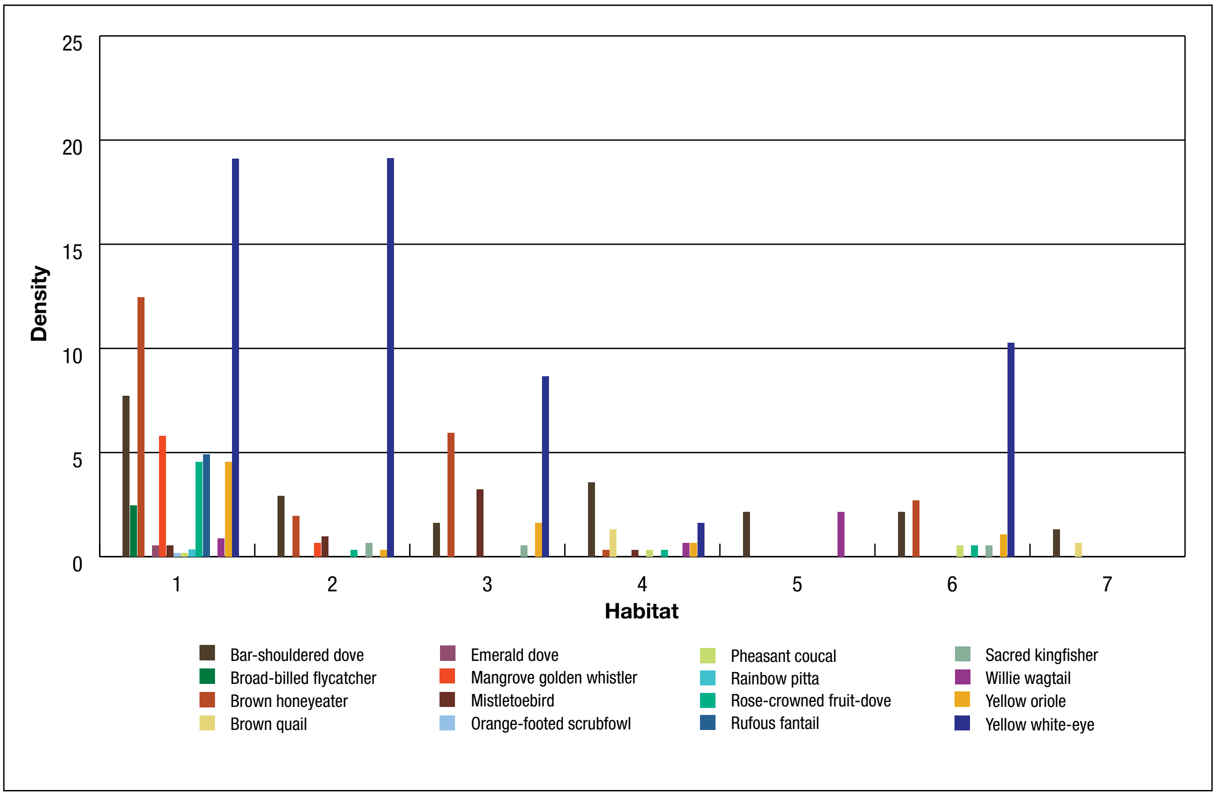


Figure 4-22: Density (observations per hectare) of birds recorded on North Maret Island

Habitat descriptions:

1. Vine thicket and margin
2. *Corymbia* woodland over speargrass
3. *Corymbia* woodland over *Triodia*
4. Shrubland over speargrass
5. Speargrass grassland and herbfield
6. *Triodia* grassland
7. *Triodia* grassland

South Maret Island

A total of 591 birds were recorded on South Maret Island with an overall density of 364 birds/ha. Bird assemblages in vine thickets and habitats with vine-thicket elements on South Maret Island were generally more species-rich (572 records) and had higher bird densities (Figure 4-23).

Acacia and *Corymbia* woodland over grasses (also with vine-thicket species), supported the highest total density of 71 birds/ha, with 10 species recorded. Several species, including some usually associated with vine thicket such as the mangrove golden whistler (6 birds/ha), and the yellow white-eye (21 birds/ha), were particularly common in this vegetation type.

The vegetation on the plateau of South Maret Island is very complex, contains many vine-thicket species and varies over short distances. This may enable birds to utilise more open vegetation types that they would not normally access.

The species with the highest densities on South Maret Island were the same as those on North Maret Island, although the values were higher. The species recorded at the highest rate were the yellow white-eye at 94 birds/ha, the bar-shouldered dove at 90 birds/ha, and the brown honeyeater at 45 birds/ha. The vine-thicket species were more abundant on South Maret Island compared with North Maret Island, reflecting the greater area of vine-thicket habitat. The density of the emerald dove was 22 birds/ha, of the mangrove golden whistler 24 birds/ha, of the rose-crowned fruit-dove 15 birds/ha, and of the yellow oriole 11 birds/ha. The densities of the rainbow pitta and orange-footed scrubfowl were still very low on South Maret Island (<1 bird/ha) despite the greater area of vine thicket in comparison with North Maret Island.

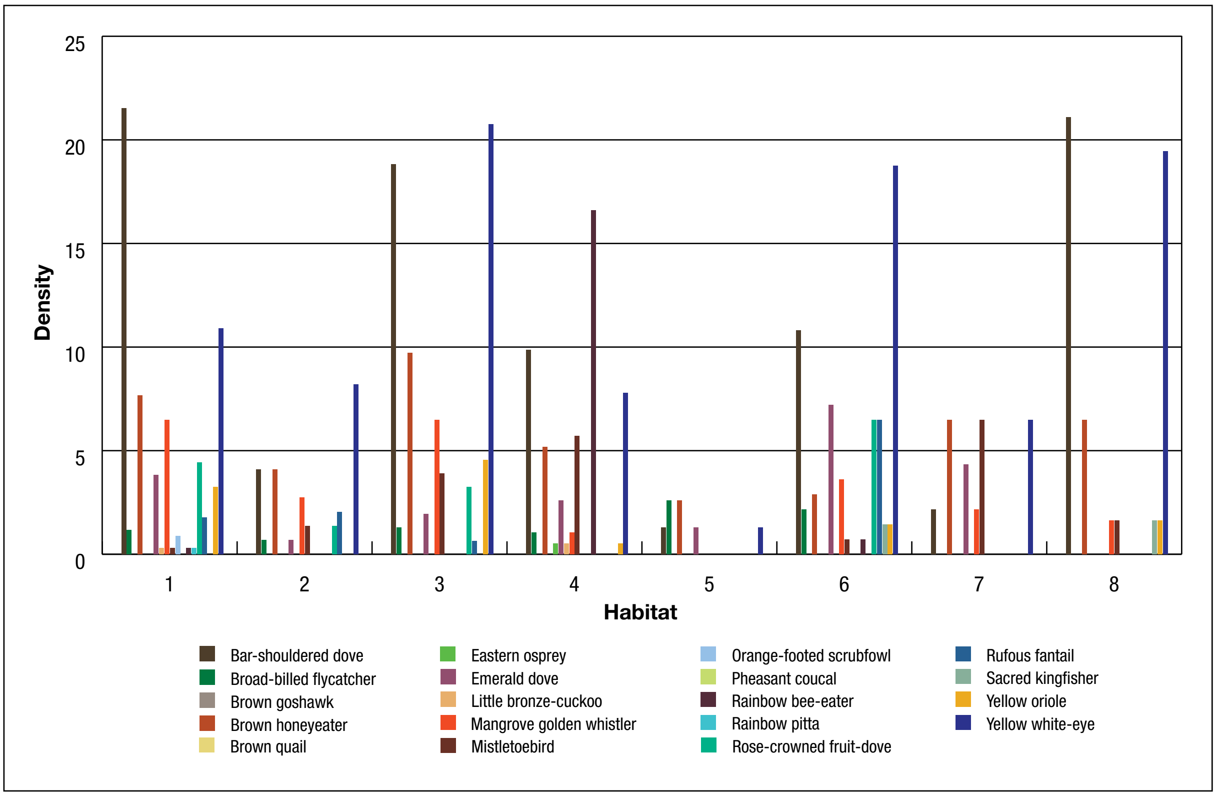


Figure 4-23: Density (observations per hectare) of birds recorded on South Maret Island

Habitat descriptions:

1. Upland vine thicket
2. *Acacia* and *Corymbia* over *Triodia*
3. *Acacia* and *Corymbia* woodland over grasses
4. Upland vine-thicket elements transitional with *Acacia* and *Corymbia* woodland
5. Speargrass between foredunes and lowland vine thicket
6. Lowland vine thicket
7. *Acacia* open shrubland over *Triodia*, speargrass and herbs
8. Open low woodland of *Acacia*, *Corymbia* and upland vine thicket

Berthier Island

A total of 387 birds were recorded on Berthier Island during the survey period with an overall density of 260 birds/ha. Vine thicket on Berthier Island supported the highest density of birds at 86/ha (Figure 4-24). Open vine thicket, on either basalt or laterite, supported densities of fewer than 20 birds/ha. *Corymbia* woodland on Berthier Island supported 63 birds/ha. Over half of this density was accounted for by brown honeyeaters, which appeared to be feeding on flowering *Corymbia* and mistletoe.

The species with the highest densities on Berthier Island were the bar-shouldered dove (85 birds/ha), the yellow white-eye (56 birds/ha) and the brown honeyeater (42 birds/ha). The densities of some of the vine-thicket specialists were low when compared with South Maret Island. These species included the emerald dove at 2 birds/ha and the mangrove golden whistler at 3 birds/ha. There were no confirmed sightings of the rainbow pitta and the rose-crowned fruit-dove. However, the density of the yellow oriole was higher than that of South Maret Island at 25 birds/ha.

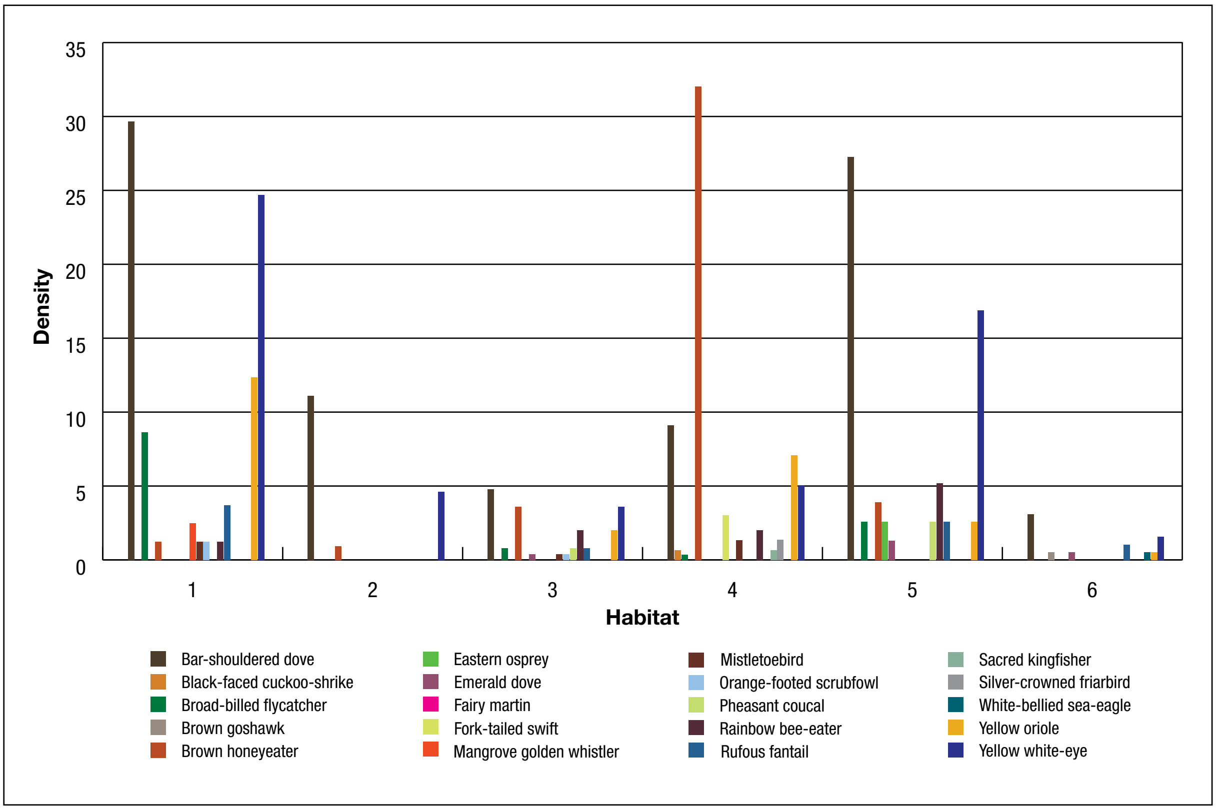


Figure 4-24: Density (observations per hectare) of birds recorded on Berthier Island

Habitat descriptions:

1. Lowland vine thicket
2. Open vine thicket and tall grasses
3. Open vine thicket
4. Open *Corymbia* woodland, *Grevillea* and *Acacia* shrubs, grasses
5. Tall grasses with scattered vine thicket
6. *Spinifex longifolius* and *Ipomoea*

East Montalivet Island

A total of 753 birds were recorded on East Montalivet Island with an overall density of 386 birds/ha (Figure 4-25). This represents the second-highest density of all of the islands surveyed. This high overall density was greatly influenced by the high numbers of the yellow white-eye, which reached a density of 73 birds/ha in lowland vine thicket, and 210 birds/ha across all habitats.

The bar-shouldered dove had the second highest density at 74 birds/ha and the yellow oriole at 30 birds/ha. The density of brown honeyeaters (5 birds/ha) was low compared with the Maret Islands.

The vine thicket, both on the slopes and on the sandy soils of the lowlands, had the highest bird densities at 127 birds/ha and 99 birds/ha respectively (Figure 4-29), although the slope vine thicket had only nine species, compared with 16 in the lowland vine thicket. The densities of the vine-thicket species, however, were not as high as those on South Maret Island, with the emerald dove at 1 bird/ha, the mangrove golden whistler at 14 birds/ha, and the rose-crowned fruit-dove at 5 birds/ha. In contrast, the rainbow pitta was more abundant on East Montalivet Island than on South Maret Island, with a density of 5 birds/ha.

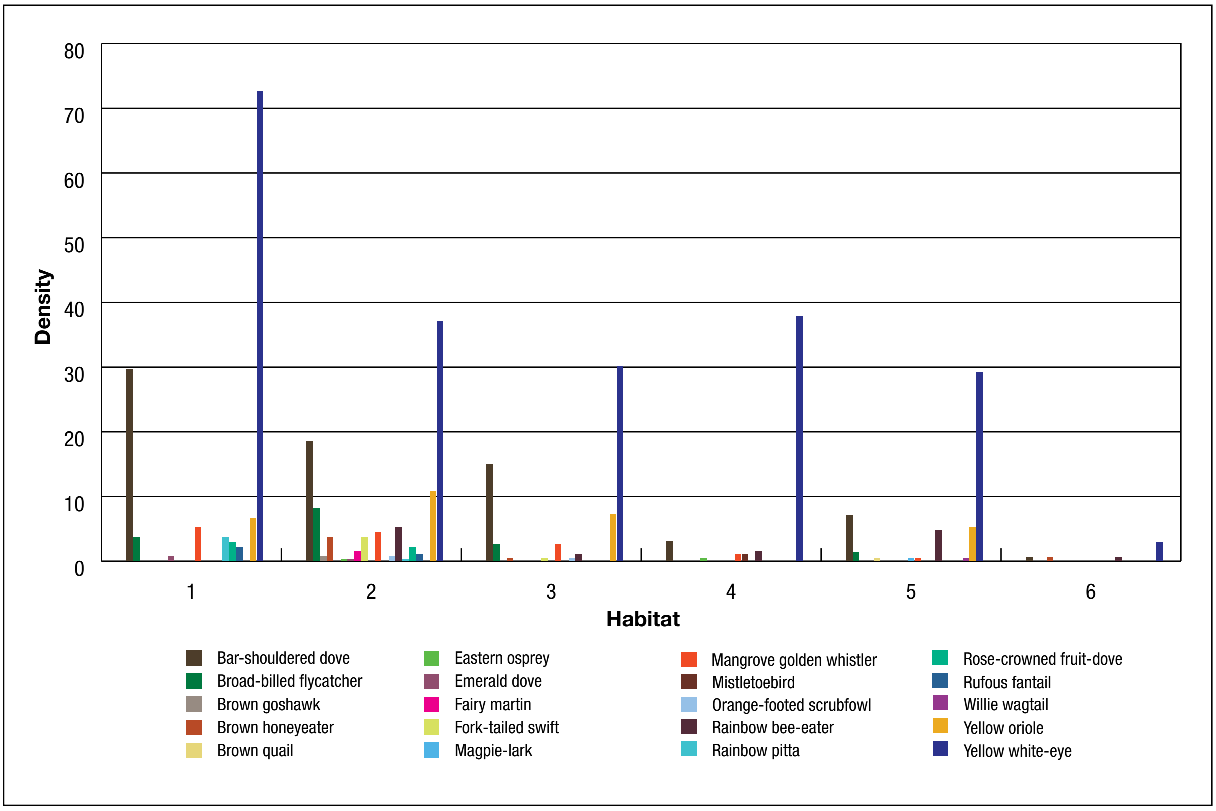


Figure 4-25: Density (observations per hectare) of birds recorded on East Montalivet Island

Habitat descriptions:

1. Slope vine thicket
2. Lowland vine thicket and margins
3. Stunted vine thicket and *Mucuna* thicket
4. *Corymbia* and *Acacia* tall, dense shrubland
5. *Triodia* grassland with scattered shrubs
6. *Triodia* grassland with scattered shrubs

Prudhoe Island

Prudhoe Island was the most species-poor of the islands surveyed and had the lowest bird density. Only 81 birds were recorded during the survey period with an overall density of 34 birds/ha. The highest densities were recorded in the *Acacia* (11 birds/ha) and *Corymbia* (10 birds/ha) woodlands (Figure 4-26). Densities declined as the vegetation cover reduced, with very few or no birds recorded in the open grasslands and exposed sandstone sites. There is no vine-thicket habitat on Prudhoe Island.

Mistletoebirds were the most abundant species on the island, with a density of 15 birds/ha. The only species that were found to be associated with vine thickets on the other islands and that were also present on Prudhoe Island, were the bar-shouldered dove (1 bird/ha) and the yellow white-eye (3 birds/ha).

Lamarck Island

Of the islands surveyed, Lamarck Island had the second-highest individual bird count (666) (behind East Montalivet Island) and the greatest number of species (22) compared with the other islands surveyed. The highest densities were recorded in vine-thicket communities, followed by habitat adjacent to vine thicket, *Acacia* open woodland and *Triodia* grassland (Figure 4-27). Bird density was lowest in the *Acacia* shrubland.

The birds present in the highest densities on Lamarck Island included the yellow white-eye (147 birds/ha), bar-shouldered dove (55 birds/ha), broad-billed flycatcher (52 birds/ha) and the yellow oriole (47 birds/ha). Birds with densities between 10 and 30 birds/ha included the brown honeyeater, the mangrove golden whistler, the mistletoebird, the northern fantail and the rose-crowned fruit-dove. Both the rainbow pitta (4 birds/ha) and the orange-footed scrubfowl (5 birds/ha) were present in relatively high densities.

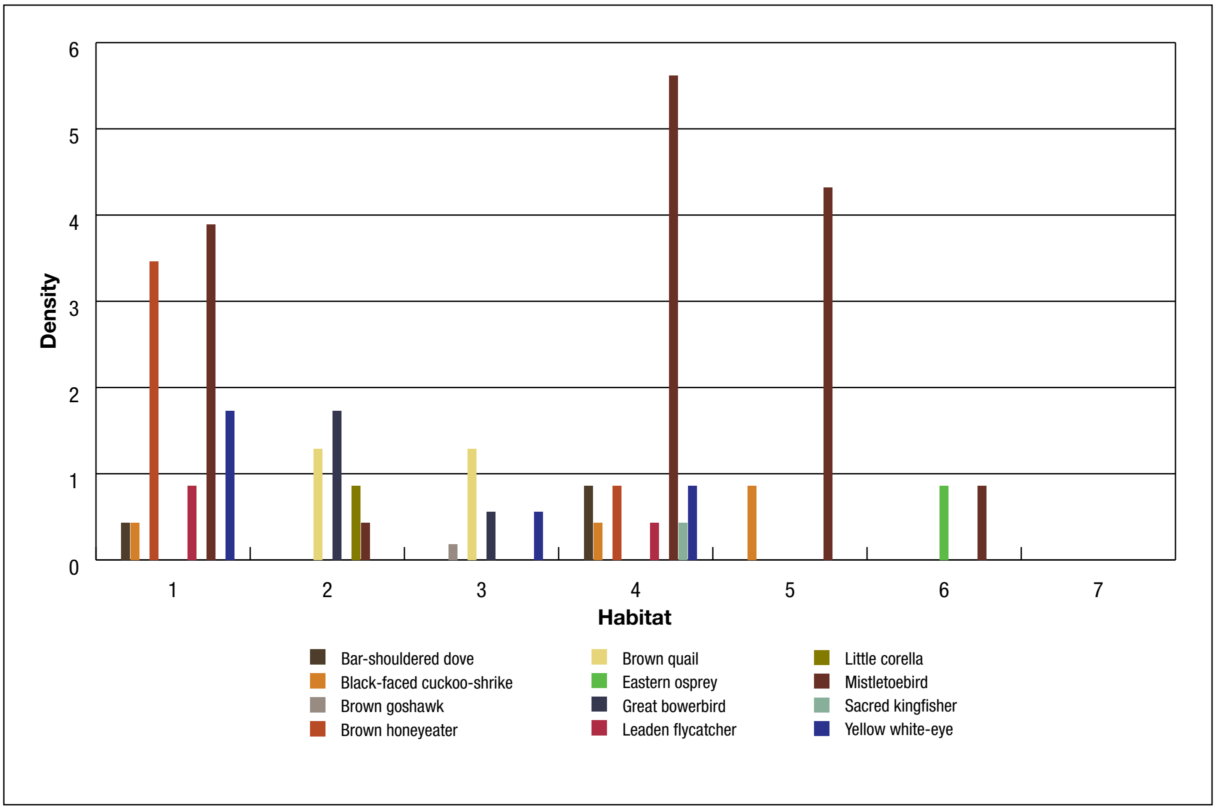


Figure 4-26: Density (observations per hectare) of birds recorded on Prudhoe Island

Habitat descriptions:

1. *Corymbia* woodland over dense *Sorghum*
2. *Triodia* hummock grassland
3. Base of sandstone cliffline; *Triodia* and shrubs near some sites
4. *Acacia* and *Corymbia* woodland over speargrass
5. Open woodland over *Triodia*
6. Open woodland over *Sorghum*
7. Scattered shrubs

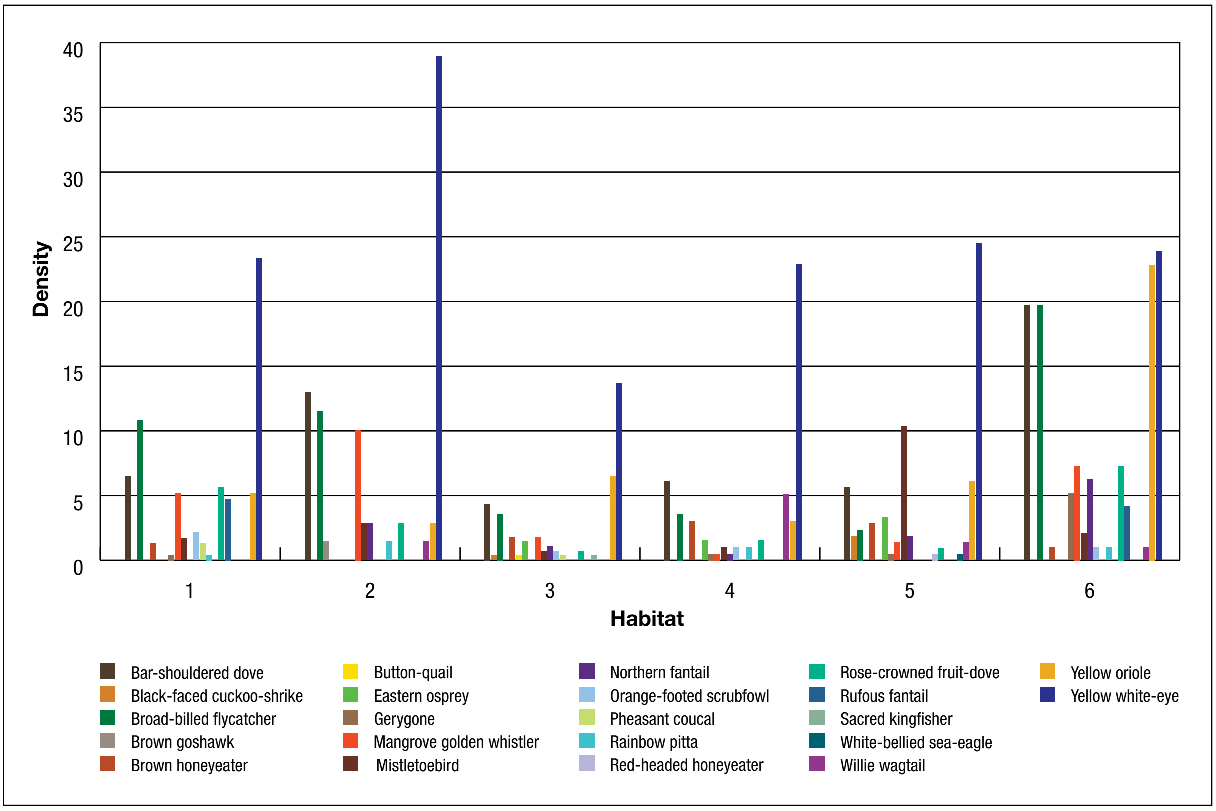


Figure 4-27: Density (observations per hectare) of birds recorded on Lamarck Island

Habitat descriptions:

1. Edge of species-poor vine thicket and spinifex hummock grassland
2. Mixed species-poor vine thicket and *Acacia* low forest over grasses on slope with exposed sandstone
3. *Acacia* shrubland over speargrass and/or *Triodia* with scattered *Corymbia*, tall *Acacia* and vine-thicket trees on generally rocky ground
4. *Triodia* grassland with scattered vine-thicket trees
5. *Acacia* open woodland with scattered shrubs, much exposed sandstone and patches of speargrass
6. Species-poor vine thicket on sand in broad gully

Conservation significance—landbirds

- Conservation significance 1: three species of conservation significance 1 were recorded during the surveys. These were the rainbow bee-eater, the fork-tailed swift and the rufous fantail, all of which are listed as "migratory" under the EPBC Act.
- Conservation significance 2: one landbird species of conservation significance 2 was recorded during this study, the bush stone-curlew. This bird is very conspicuous because of its loud calls and pairs were observed on both South Maret Island and North Maret Island. However, as no others were recorded, these may have been the only bush stone-curlews present on the islands at the time of the surveys.
- Conservation significance 3: as vine-thicket habitat is regarded as being under threat on the Kimberley mainland (Gambold & Woinarski 1993) and has not been comprehensively assessed on the archipelagos offshore, large populations of birds that are closely associated with vine thickets and have poor dispersal capabilities are considered to be of conservation significance 3 and regionally significant. These species include the orange-footed scrubfowl (*Megapodius reinwardt*), the emerald dove (*Chalcophaps indica*), the rose-crowned fruit-dove (*Ptilinopus regina*), the rainbow pitta (*Pitta iris*), the yellow oriole (*Oriolus flavocinctus*) and the yellow white-eye (*Zosterops luteus*).

Migratory shorebirds and seabirds

Coastal bird census

A total of 2971 shorebirds and seabirds of 33 species were recorded around 36 islands and their associated rocks and reefs (Table 4-18). West Montalivet Island had the highest species richness with 18 species, followed by North Maret Island and the Albert Islands group with 14 species each and South Maret Island with 13 species. Lamarck Island had 11 species. Trig Rock was the only island where no shorebirds or seabirds were recorded.

The bridled tern was the most abundant seabird, with 1360 individuals recorded. Most of these were seen near Albert Island where 1070 birds were observed showing nesting behaviour. The remainder were spread across five of the islands in the Maret Island group: South Maret Island (40), Berthier Island (40 birds), the rocky islet near South Maret Island (10), Corvisart Island (140), and Suffren Island[7] (60).

The crested tern was the second most abundant seabird and was observed over much of the survey area, with 401 seen on West Montalivet Island, 50 observed on the rocky outcrop near South Maret Island, 34 on North Maret Island, and 25 on Combe Island.

The red-necked stint, a migratory wader, was recorded on West Montalivet Island where 276 individuals were observed. This species was not seen elsewhere in the study area.

Brown boobies (151 individuals), eastern reef egrets (151), sooty oystercatchers (56), and eastern ospreys (53, many with nests) were recorded throughout the region. Common noddies (100 individuals) were observed feeding over the submerged Heritage Reef but were not seen elsewhere during the survey.

North Maret Island supported the highest abundance of sooty oystercatchers (*Haematopus fuliginosus ophthalmicus*). This subspecies is restricted to northern Australia.

[7] Suffren Island is the southernmost island of the Albert Islands group and the only one that bears a formal name.

Table 4-18: Abundance of shorebirds and seabirds on all islands

Species recorded	Maret Islands group: North Maret Island	South Maret Island	Berthier Island's three satellite islets	Berthier Island	Combe Island	The "Unnamed Islands" immediately south of South Maret Island	Rocky outcrop South Maret Island	Turbin Island	Ripple Rock	Trig Rock	Albert Islands (six islands and islets excluding Suffren Island)	Corvisart Island and its satellite islet	Suffren Island (southernmost island of Albert Islands group)	Montalivet Islands group: East Montalivet Island	West Montalivet Island	Isthmus between Don and Patricia islands	Don Island	The "Unnamed Island" off Don Island's south-west coast	Patricia Island	Walker Island	Walker Island's three satellite islets	Other: Lamarck Island	Heritage Reef	Open sea	Total
Brown booby	10	–	–	1	40	1	21	–	–	–	1	–	–	–	75	–	–	–	–	–	–	1	1	–	**151**
Australasian darter	1	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	**3**
Lesser frigatebird	–	2	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	**3**
Pied cormorant	–	–	–	–	–	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	**2**
Eastern reef egret	14	3	3	13	2	1	–	3	–	–	13	4	–	5	13	9	2	3	1	4	10	48	–	–	**151**
Striated heron	1	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	2	–	–	**4**
Eastern osprey*	13	3	1	7	–	3	–	–	–	–	3	3	1	2	7	–	3	1	–	–	1	5	–	–	**53**
Brahminy kite	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**2**
White-bellied sea-eagle†	1	1	–	1	–	1	–	–	–	–	2	–	–	–	1	–	–	–	–	2	–	1	–	–	**8**
Whimbrel	5	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**7**
Common sandpiper	4	1		3	–	–	–	–	–	–	5	1	2	–	20	4	–	–		2	2	6	–	–	**50**
Grey-tailed tattler	–	4	–	1	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	1	–	–	–	–	**7**
Ruddy turnstone	–	–	–	–	–	–	–	–	–	–	6	–	–	–	5	–	–	–	–	–	–	–	–	–	**11**
Red knot	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	–	–	–	**1**
Great knot	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	**1**
Red-necked stint	–	–	–	–	–	–	–	–	–	–	–	–	–	–	276	–	–	–	–	–	–	–	–	–	**276**
Beach stone-curlew	4	2	–	2	–	–	–	–	–	–	4	–	–	–	9	–	2	–	–	–	1	4	–	–	**28**
Australian pied oystercatcher	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	**1**
Sooty oystercatcher	12	2	2	4	–	2	–	–	–	–	5	6	1	3	6	–	–	1	–	–	9	5	–	–	**58**
Pacific golden plover	–	1	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	–	–	–	–	–	–	–	**2**
Red-capped plover	–	–	–	–	3	–	–	–	–	–	–	–	–	–	54	–	–	–	–	–	–	–	–	–	**57**
Lesser sand plover	–	5	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	**7**
Greater sand plover	–	–	–	–	–	–	–	–	–		2	–	–	–	4	–	–	–	–	–	–	–	–	–	**6**

4 TERRESTRIAL FAUNA

Table 4-18: Abundance of shorebirds and seabirds on all islands (continued)

	Maret Islands group													Montalivet Islands group								Other			
Species recorded	North Maret Island	South Maret Island	Berthier Island's three satellite islets	Berthier Island	Combe Island	The "Unnamed Islands" immediately south of South Maret Island	Rocky outcrop South Maret Island	Turbin Island	Ripple Rock	Trig Rock	Albert Islands (six islands and islets excluding Suffren Island)	Corvisart Island and its satellite islet	Suffren Island (southernmost island of Albert Islands group)	East Montalivet Island	West Montalivet Island	Isthmus between Don and Patricia islands	Don Island	The "Unnamed Island" off Don Island's south-west coast	Patricia Island	Walker Island	Walker Island's three satellite islets	Lamarck Island	Heritage Reef	Open sea	Total
Silver gull	2	–	–	–	2	–	–	–	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	**6**
Common noddy	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–	**100**
Crested tern	34	6	–	2	25	–	50	–	15	–	–	4	–	2	401	–	–	20	–	1	–	1	–	24	**585**
Lesser crested tern	–	–	–	–	–	–	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**2**
Roseate tern‡	–	–	–	–	–	–	–	–	–	–	~500	–	–	–	–	–	–	–	–	–	–	–	–	5	**5**
Bridled tern	–	40	–	–	–	–	10	–	–	–	1070†	140	60	–	–	–	–	–	–	–	–	–	4	6	**1330**
Sooty tern	–	–	–	–	3	–	–	–	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	**6**
Whiskered tern	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	4	–	**4**
Little tern	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	**1**
Fork-tailed swift§	20	–	–	21	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1	–	–	**43**
Total number of individuals	**123**	**72**	**6**	**54**	**76**	**8**	**83**	**3**	**18**	**0**	**1114**	**161**	**64**	**12**	**879**	**13**	**7**	**25**	**1**	**11**	**23**	**74**	**109**	**35**	**2971**
Total number of species	**14**	**13**	**3**	**9**	**7**	**5**	**4**	**1**	**2**	**0**	**13**	**8**	**4**	**4**	**18**	**2**	**3**	**4**	**1**	**6**	**5**	**10**	**4**	**3**	**33**

Note: As the Maret Islands were surveyed on several occasions (Table 4-4), the records used here are of the highest count for a survey. The surveys were carried out in such a way as to ensure that double-counting of birds was minimised.

* Many of the eastern ospreys were observed in association with nests.

† Nesting behaviour was observed on Albert Island.

‡ Approximately 500 roseate terns were observed feeding between Albert Island and Berthier Island in July and August 2006; these numbers were not included in the table totals.

§ The fork-tailed swift is not a shorebird nor a seabird but was recorded during the shorebird surveys.

– = species not found.

In some cases only single birds of a species were recorded during the survey. These included a red knot on Corvisart Island and a great knot on Walker Island.

The Montalivet Islands group did not have the richness of species nor the number of individuals of the Maret Islands group. Nineteen species were recorded and 971 individuals were observed, 879 of which were seen on West Montalivet Island. The remaining 92 individuals were shared between East Montalivet Island, Don and Patricia islands, and the Walker Islands group.

Many birds were observed foraging on the reefs around Lamarck Island. Eastern reef egrets were easily identified and 48 were observed feeding in pools across the reef. Ten species were seen on the island and 74 individual birds were observed. Only a single little tern was observed during the survey period and this was feeding in the water just off a small beach on Lamarck Island.

Heritage Reef was submerged during the survey period, but four species of seabird were observed in a large feeding party, flying over the reef and plunge-diving into the water. The flock was made up of 100 common noddies, 1 brown booby, 4 whiskered terns and 4 bridled terns. This was the only occasion during the survey that whiskered terns and common noddies were seen.

Albert Island and the nearby islands and islets appear to support an active colony and provide roosting sites for bridled terns. Around 1070 were seen on the islands in the grassland on the top and scattered round the edges. Viewing of these birds was clear and their distinctive "yap" call could be heard as they wheeled above the island when disturbed, indicating probable early nesting behaviour. In July 2006, large numbers of roseate terns (around 500) were foraging between Berthier Island and Albert Island, and roosting on islets near Albert Island.

Offshore seabird census

During the cetacean surveys (see Chapter 9 *Cetaceans* for methodology), 19 913 seabirds of 23 species were recorded during the offshore vessel surveys around the Maret Islands, Browse Island, Camden Sound and Pender Bay (Table 4-19). Fourteen of these species were additional to those listed in Table 4-18. The dominant species were terns (sooty terns together with several unidentified species) and boobies (brown, red-footed and masked), which accounted for 87% of the sightings. Significantly fewer birds were seen between 15 August and 3 September 2006 (1406) than between 9 September and 28 September 2006 (6293) and between 4 October and 23 October 2006 (9462).

In the period 29 October to 7 November 2006 a total of 2752 birds were seen; this included only 10 survey days, during which only the Browse Island and Maret Islands areas were sampled. The most species-rich areas were Browse Island with nine species and Pender Bay with eight, while seven each were seen at the Maret Islands and Camden Sound.

Table 4-19: List of seabird species recorded during the offshore vessel surveys conducted in conjunction with the cetacean surveys in 2006

Common name	Scientific name
Herald petrel	*Pterodroma heraldica*
Bulwer's petrel	*Bulweria bulwerii*
Red-tailed tropicbird	*Phaethon rubricauda*
White-tailed tropicbird	*Phaethon lepturus*
Matsudaira's storm-petrel	*Hydrobates matsudairae*
Wilson's storm-petrel	*Oceanites oceanicus*
White-faced storm-petrel	*Pelagodroma marina*
Short-tailed shearwater	*Ardenna tenuirostris*
Streaked shearwater	*Calonectris leucomelas*
Lesser frigatebird	*Fregata ariel*
Christmas Island frigatebird	*Fregata andrewsi*
Abbott's booby	*Papasula abbotti*
Masked booby	*Sula dactylatra*
Brown booby	*Sula leucogaster*
Common noddy	*Anous stolidus*
Bridled tern	*Onychoprion anaethetus*
Sooty tern	*Onychoprion fuscata*
Little tern	*Sternula albifrons*
Gull-billed tern	*Gelochelidon nilotica*
Common tern	*Sterna hirundo*
Lesser crested tern	*Thalasseus bengalensis*
Crested tern	*Thalasseus bergii*
Silver gull	*Chroicocephalus novaehollandiae*

Coastal birds of prey

Fifty-three eastern ospreys (*Pandion cristatus*) were observed during the shorebird survey in November 2006, with 21 nests recorded on nine islands (Figure 4-28). Ospreys were present at most nests, which were probably being used as roosting sites. The eastern osprey is "listed" under the EPBC Act as a migratory species.

Eastern ospreys breed between April and February in Australia, with breeding commencing later in the year as latitude increases (DoE 2013). They breed from April to July in the Kimberley islands, which constitute an important breeding area for this species in Western Australia. Although South Maret Island was mentioned by Johnstone and Storr (1998) as a favoured site, only one nest was recorded there during the survey. Ospreys were relatively abundant on North Maret Island, with six nests observed—the highest number of nests and the greatest abundance of individual birds (13) for any island in the survey area.

Taken together, the Maret Islands, Berthier Island, Corvisart Island and Albert Island had 15 osprey nests (including two older ones) and 34 birds, while the Montalivet group had six nests. The Maret Islands, Berthier Island, Corvisart Island, Albert Island and associated rocks and unnamed islands collectively represent a larger nesting area than the Montalivet Islands group, as they provide more suitable nesting sites.

A pair of white-bellied sea-eagles (*Haliaeetus leucogaster*) were seen nesting (with eggs) on Albert Island in July 2006.

Conservation significance—migratory shorebirds and seabirds

- Conservation significance 1: the migratory shorebirds of the islands surveyed were typical of the region and none are listed as "threatened" under the EPBC Act and/or the *Wildlife Conservation Act 1950* (WA). However, 19 wading bird species recorded during the surveys are protected under the Japan–Australia (JAMBA), China–Australia (CAMBA) and the Republic of Korea – Australia (ROKAMBA) bilateral migratory bird agreements (DoFA 1981; DFAT 1988; DFAT 2006). These treaties recognise the need to protect the staging habitats of migratory birds.

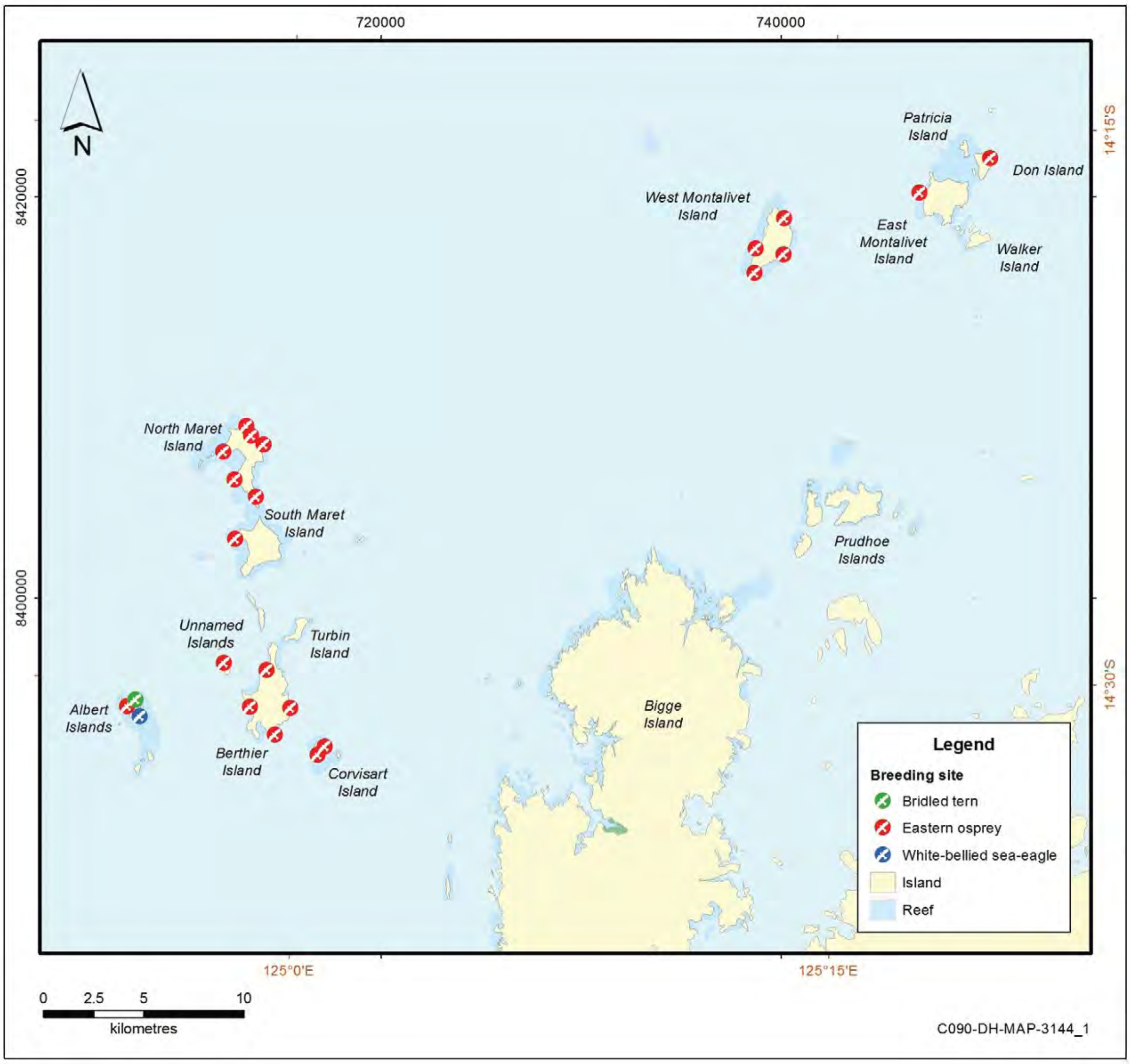


Figure 4-28: The distribution of osprey nests in the Maret Islands and adjacent islands in November 2006. Also shown are the locations of the nest of a white-bellied sea-eagle and of a breeding colony of bridled terns

Six migratory seabirds from the study area are listed on the JAMBA and/or the CAMBA and ROKAMBA treaties and under the EPBC Act as migratory marine birds. In addition, the eastern osprey is listed as migratory under the EPBC Act but is not listed by the JAMBA, CAMBA or ROKAMBA treaties.

The survey sightings of these seven species are discussed below:

- *Onychoprion anaethetus*: over 1000 bridled terns were recorded on Albert Island and apparently nest there. The waters surrounding the Maret Islands, the Albert Islands and Browse Island appear to be important feeding grounds for this species.
- *Sula leucogaster*: brown boobies were observed resting in small groups on rocks on many islands within the region and feeding in high numbers in the waters surrounding the islands. Although they breed on Browse Island, no breeding populations were found on the Maret Islands, Berthier Island or the Montalivet Islands.
- *Fregata ariel*: lesser frigatebirds were recorded flying over the islands or feeding at sea around the Maret Islands.
- *Thalasseus bergii*: individuals and small groups of crested terns were seen roosting on beaches or rocks by the water on North Maret Island, South Maret Island, Berthier Island and many of the surrounding regional islands. Several adults were seen interacting with juveniles, which suggests breeding activity in the area.
- *Sterna dougallii*: roseate terns were observed, sometimes in high numbers, feeding in the open seas surrounding the Maret Islands and other regional islands. They do not, however, appear to breed in the area.
- *Haliaeetus leucogaster*: several adult white-bellied sea-eagles and one juvenile were seen over the Maret Islands during the 2006 survey. A pair was seen nesting (with eggs) on Albert Island in July 2006. Adults were also seen at various times between February and May 2007.
- *Pandion cristatus*: eastern ospreys were regularly seen flying over the Maret Islands and feeding close to shore. Most of the islands in the region provide resting, feeding and breeding areas for the ospreys, and the islands of the Kimberley in general constitute an important breeding location for these birds in Western Australia. North Maret Island had the highest number of ospreys and nests in the area surveyed.

- Conservation significance 2: no shorebird or seabird species of conservation significance 2 were recorded from any of the surveyed islands.
- Conservation significance 3: no shorebird or seabird species of conservation significance 3 were recorded from any of the surveyed islands.

Mammals

No resident mammals were recorded on North Maret Island, South Maret Island, Berthier Island, Prudhoe Island or Lamarck Island during the 2006 and 2007 surveys. The Kimberley rock-rat (*Zyzomys woodwardi*) was observed on East Montalivet Island.

The AnaBat II bat detector was used on all six islands, but although bat calls were recorded at South Maret Island, Prudhoe Island and Lamarck Island, they were faint and distant and not analysable.

One black flying-fox (*Pteropus alecto*) was seen in a tree on South Maret Island but is believed to have been a vagrant as there was no evidence of regular roosting or of a resident population. One common sheathtail-bat (*Taphozous georgianus*) and one northern cave bat (*Vespadelus caurinus*) were recorded flying over South Maret Island in August 2007 (Mr N.L. McKenzie, Principal Research Scientist, Department of Environment and Conservation, Perth, pers. comm. November 2007). However, it is unknown whether these bats were resident on the island or vagrants.

There was no evidence of roosts or resident colonies of bats on South Maret Island. One small bat was seen foraging at night on Berthier Island. This was most likely a northern cave bat although the identification was not confirmed. It is possible that this bat was resident on Berthier Island although no colonies were found there. Resident populations of the northern cave bat and the common sheathtail-bat were found in caves on West Montalivet Island. One dead specimen of the little red flying-fox (*Pteropus scapulatus*) was found on East Montalivet Island, although again there was no evidence of a resident population. The northern cave bat and common sheathtail-bat were both detected on Prudhoe Island and there was an unconfirmed observation on Lamarck Island. A dead ghost bat (*Macroderma gigas*) was found on an islet just off Prudhoe Island.

The only ground-dwelling terrestrial mammal recorded during the survey program was the Kimberley rock-rat (*Zyzomys woodwardi*); it was observed on East Montalivet Island on a basalt outcrop near the beach during the April 2007 survey. However, none were caught during the survey despite an intensive targeted trapping program on this island. It had been previously recorded on East Montalivet Island by the Western Australian Museum. Two were caught in cage traps on Prudhoe Island; one was in breeding condition and was possibly pregnant.

There was no evidence of ground-dwelling terrestrial mammals on Lamarck Island.

Invertebrate short-range endemics

Land snails

Land snail species richness ranged from two to nine species at each survey site and the family Camaenidae was represented at nearly every location. The other gastropod families identified from the survey samples are the Pupillidae, Helicarionidae, Helicodiscidae, Helicinidae, and Subulinidae. Very small, early juvenile shells have been tentatively identified as belonging to the families Cerastidae and Charopidae.

The representation of each taxon across the surveyed islands is presented in Table 4-20. The distributions of the snail taxa collected during the survey are recorded by sampling station numbers for the different islands in appendices 11 and 12 in RPS (2007).

Table 4-20: The percentage of sampling sites on each surveyed island where particular land snail species were recorded

Station summary	North Maret Island	South Maret Island	East Montalivet Island	West Montalivet Island	Lamarck Island	Berthier Island	Patricia Island	Walker Island	Don Island	Albert Island	Unnamed Island*
Number of sampling sites	47	46	17	16	4	7	2	3	4	1	1
Camaenidae											
Amplirhagada sp.	59.5	67.4	82.3	81.0	50.0	85.7	100	33.3	100	–	100
?*Hadra* sp.	–	–	–	–	100	–	–	–	–	–	–
Amplirhagada sp. cf. *combeana*	51	76.1	–	–	–	71.4	–	–	–	100	–
Damochlora sp. cf. *millepunctata*	53.2	56.5	–	–	–	–	–	–	–	–	–
Setobaudinia sp. cf. *interrex*	19.1	39.1	70.5	56.2	–	57.1	–	100	75	100	–
Torresitrachia sp. cf. *regula*	–	–	–	–	100	–	–	–	–	–	–
?*Quistrachia* sp. or ?*Kimboraga* sp.	38.3	45.6	–	6.2	25	14.3	–	–	–	–	–
Pupillidae											
Pupoides pacificus	32	36.2	11.7	25	–	57.1	–	33.3	25	–	–
Gastrocopta pediculus	70.2	82.6	52.9	68.7	75	57.1	50	66.6	100	–	–
Helicarionidae											
Westracystis lissus	70.2	80.4	11.7	18.7	100	100	100	–	–	–	–
Helicodiscidae											
Stenopylis coarctata	53.2	63	41.1	62.5	75	28.5	–	66.6	100	–	–
Helicinidae											
Pleuropoma walkeri	23.4	43.5	23.5	18.5	75	14.2	–	66.6	75	100	–
Subulinidae											
Eremopeas interioris	21	2.2	–	12.5	–	–	–	–	–	–	–
?Cerastidae											
?*Amimopina* sp. (juvenile)	2.1	–	–	–	–	–	–	–	–	–	–
Charopidae											
?*Discocharopa* sp. (juvenile)	–	–	5.9	–	–	–	–	–	–	–	–

* "Unnamed Island" is the unnamed islet off the south-west coast of Don Island (see Figure 4-1).

– = species not found.

Family Camaenidae

Genus *Amplirhagada*

The genus *Amplirhagada* is endemic to the Kimberley region and is by far the most diverse camaenid genus in the region with 55 species having been recorded by 1997 (Solem 1997), mainly in the western Kimberley. As with most other Australian camaenid genera, it is largely made up of allopatric species with confined ranges and therefore has the potential to give rise to short-range endemic forms.

Amplirhagada sp. cf. *combeana*

Populations of a relatively small, ribbed *Amplirhagada* species (Figure 4-29) were found to be widespread on North Maret Island, South Maret Island, Berthier Island and Albert Island. On the basis of shell characters these populations appeared to be closest to *A. combeana* Iredale, 1938, which has been previously recorded from Cassini Island to the north of the Bonaparte Archipelago (Western Australian Museum collection).

Photographs courtesy of Corey Whisson (Western Australian Museum)
Figure 4-29: *Amplirhagada* sp. cf. *combeana*

Amplirhagada sp.

Specimens of an unidentified species of *Amplirhagada* (Figure 4-30), which were larger than those of the snail specimens discussed above as possibly assignable to *A. combeana*, were collected from each of the surveyed islands, except for Albert Island. These individuals were abundant and widespread among and beneath boulders, mainly on the hill slopes but also on the plateaux. The locations where they were collected on the Maret Islands are shown in Figure 4-31 (North Maret Island) and Figure 4-32 (South Maret Island).

Photograph courtesy of Corey Whisson (Western Australian Museum)
Figure 4-30: *Amplirhagada* sp.

The *Amplirhagada* specimens collected during this study most closely resemble descriptions of *A. alta intermedia* Solem, 1981. However, adult snails vary considerably in mean size, shape and colour pattern, both within and between populations. Such variation had been observed among the few samples from the Bonaparte Archipelago available for Solem's 1981 studies (Solem 1981a, 1981b), when he described the subspecies *A. alta intermedia* from localities in the Bonaparte Archipelago including South Maret Island, North Maret Island and East Montalivet Island.

Genetic analyses of the *Amplirhagada* specimens from 41 sample locations across 16 islands and two mainland sites[8] which were studied by Johnson, O'Brien and Fitzpatrick (2010) identified four major clades corresponding with four different geographic regions:

- the Maret Islands group, consisting of North Maret Island, South Maret Island, the unnamed double island immediately to the south of South Maret Island (informally called "Natfe Island" but designated "Unnamed Islands" in this chapter), Turbin Island, Berthier Island and Albert Island
- the Montalivet Islands group, consisting of East Montalivet Island, Don Island and its adjacent "Unnamed Island", Patricia Island, and Walker Island, but excluding West Montalivet Island
- West Montalivet Island
- Wilson Point (on the Kimberley mainland) and the adjacent Lulim Island and Wailgwin Island.

[8] The majority of the specimens analysed were collected by members of the RPS survey team, but the specimens from Boongaree Island (in Prince Frederick Harbour) and the adjacent mainland south of the Maret Islands, and from Wilson Point and the adjacent Lulim Island and Wailgwin Island south-west of the Maret Islands, were collected independently by Roy Teale of Biota Environmental Sciences Pty Ltd of Perth.

These studies revealed high levels of genetic divergence of the *Amplirhagada* specimens between and within islands. North Maret Island displayed the highest level of divergence, with two distinct subclades and indications of genetic divergence between the populations on the west coast of the island and those on the east coast (Johnson, O'Brien & Fitzpatrick 2010).

[**Editor's note:** the information on the genus *Amplirhagada* presented above represents the state of knowledge at the time the original report (RPS 2007) was written. However, subsequent work on the systematics of the genus, particularly in the Bonaparte Archipelago, has shed considerable light on the taxonomy of *Amplirhagada* (Johnson, O'Brien & Fitzpatrick 2010; Köhler & Johnson 2012). Amongst other findings, Köhler and Johnson took the conservative taxonomic approach to the distinct mitochondrial clades identified on the Maret Islands and on the "Unnamed Islands" south of South Maret Island and included all of them as the single species *Amplirhagada intermedia* Solem, 1981.]

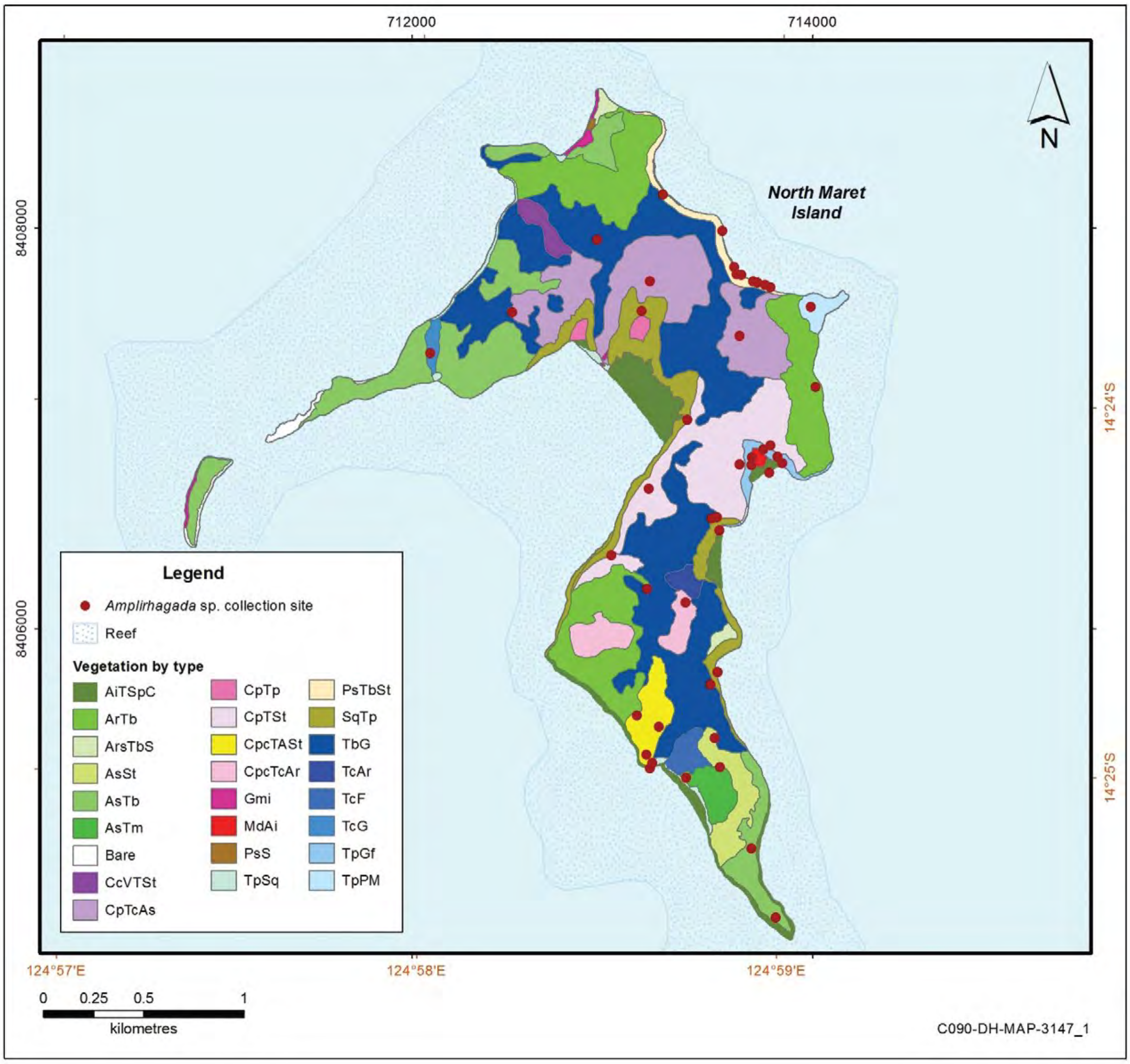


Figure 4-31: Collecting locations for *Amplirhagada* sp. on North Maret Island (see Table 3-13 for descriptions of the vegetation units)

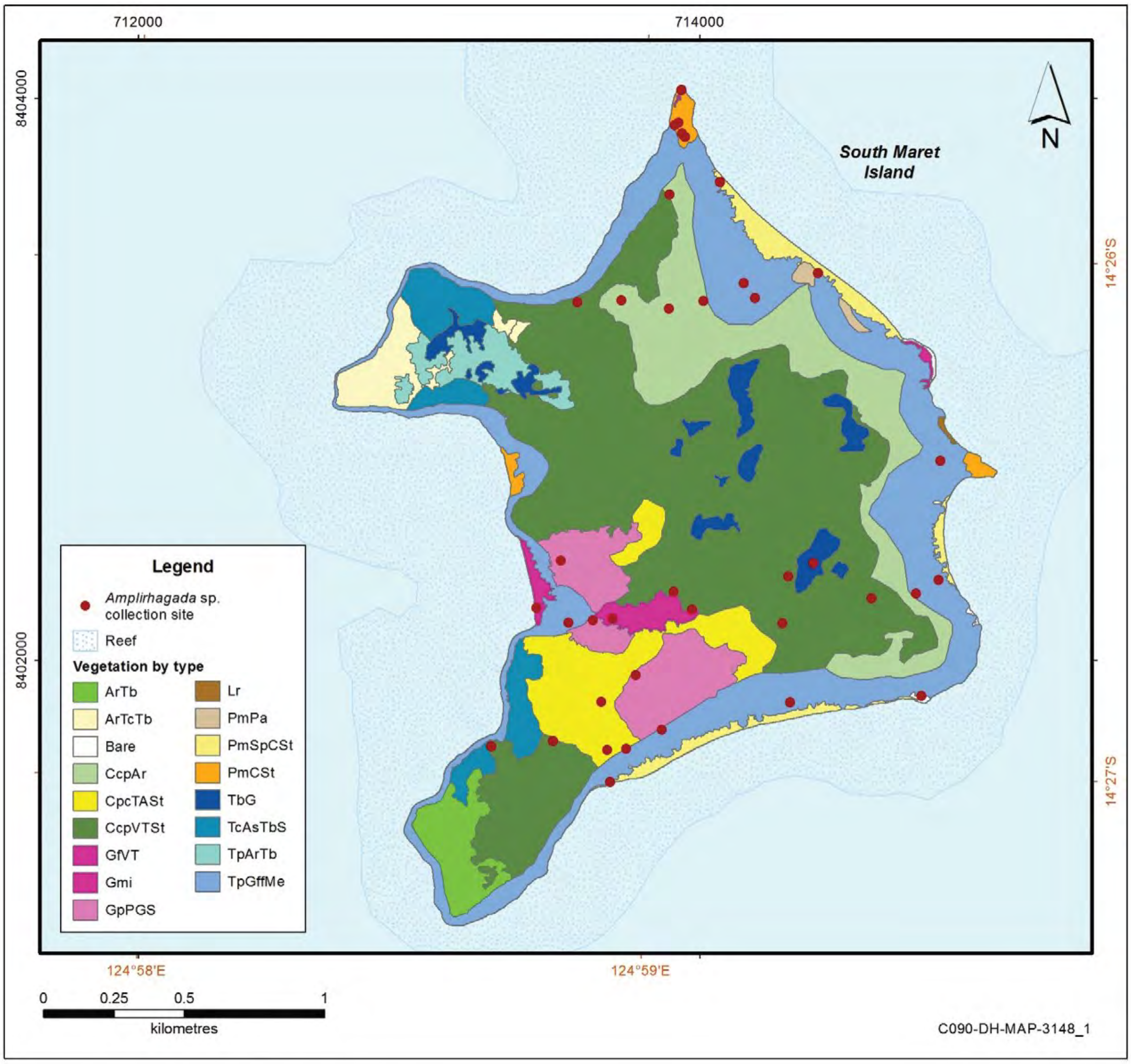


Figure 4-32: Collecting locations for *Amplirhagada* sp. on South Maret Island (see Table 3-13 for descriptions of the vegetation units)

?*Hadra* sp.

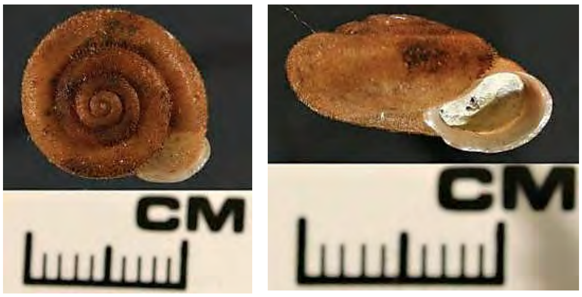
Shells which are larger and more globose than those of the *Amplirhagada* species (which are also distinguished by their unpatterned white shells covered with yellow periostracum) have been tentatively placed in the genus *Hadra* by the Western Australian Museum. Numerous species of this genus inhabit wet forested areas of Queensland, and also occur in New Guinea. Only one species, *Hadra wilsoni*, has been identified in the Western Australian fauna (Solem 1979). Solem described this species from a few shells, mostly damaged, from the Prince Regent River Reserve.

Specimens of the presumed *Hadra* species were found only on Lamarck Island, where dead and mostly broken shells were collected at each of that island's four survey stations (Table 4-20). Too little material is available to make a decision on whether the Lamarck specimens are conspecific with *Hadra wilsoni*, but the isolation of the island from the Kimberley mainland renders it possible that this is an undescribed species.

Damochlora sp. cf. *millepunctata* (E.A. Smith, 1894)

This closely hirsute snail with a flattened shape (Figure 4-33) was found to be widespread on the Maret Islands (figures 4-34 and 4-35) but was not found on any of the other Bonaparte Archipelago islands surveyed.

The relatively large size of the shell (*c*.12 mm diameter) and the dense covering of short periostracal hairs, persistent in all live-taken specimens, are characters typical of the endemic Western Australian genus *Damochlora*. However, the thin, barely reflected shell lip is more fragile and the shells are flatter than either of the recorded species of *Damochlora*, namely *Damochlora millepunctata* from Baudin Island and Cassini Island and *Damochlora rectilabrum* (E.A. Smith, 1894) from the Kalumburu area.



Photographs courtesy of Corey Whisson (Western Australian Museum)

Figure 4-33: *Damochlora* sp. cf. *millepunctata* from the Maret Islands

Setobaudinia sp. cf. *interrex* Solem, 1985

This land snail was widespread on the Maret Islands (figures 4-36 and 4-37), East Montalivet Island, West Montalivet Island, Berthier Island, Walker Island, Don Island and Albert Island, but was not found on Lamarck Island, Patricia Island or the "Unnamed Island" off the south-west coast of Don Island.

Setobaudinia interrex was described from specimens on the Kimberley mainland from inland areas of the Prince Regent River Reserve and from Beverley Springs Station (now called Charnley River Station) to the south. No species of *Setobaudinia* of a similar size, shell morphology or character of the periostracal setal covering (apparently readily abraded as it is present in only a few of the survey specimens) has been previously recorded from the Bonaparte Archipelago (Figure 4-38).

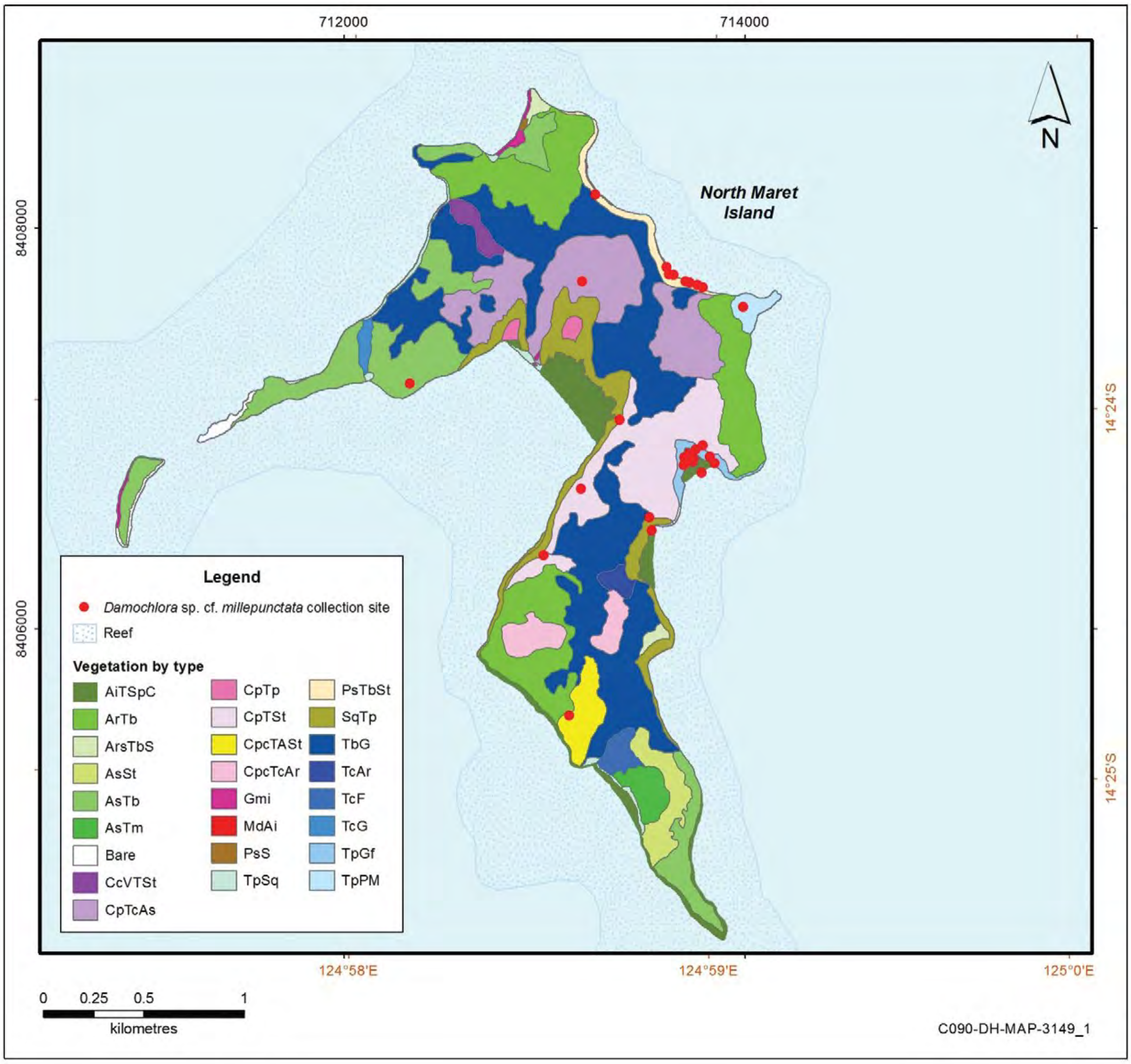


Figure 4-34: Collecting locations for *Damochlora* sp. cf. *millepunctata* on North Maret Island (see Table 3-13 for descriptions of the vegetation units)

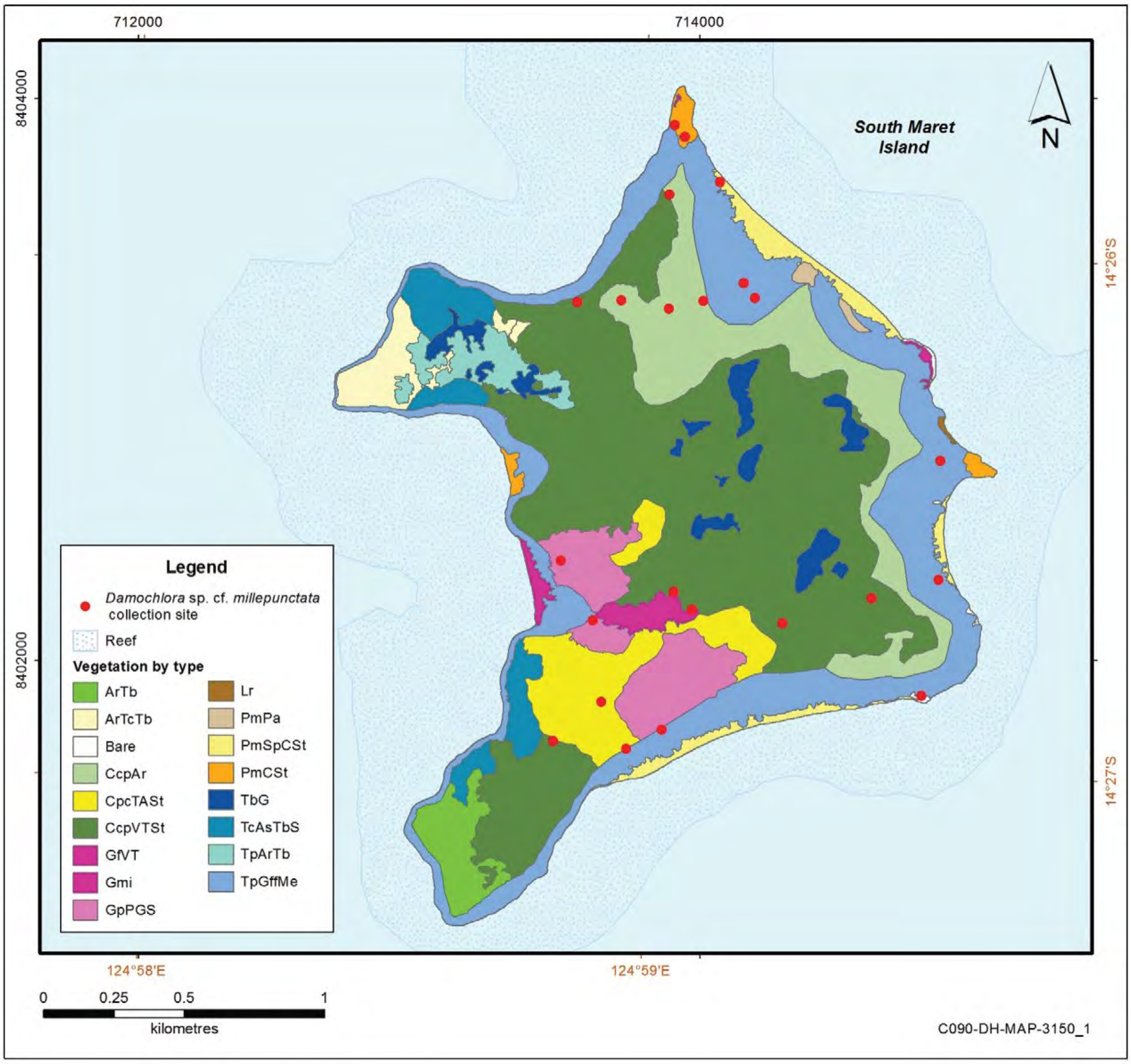


Figure 4-35: Collecting locations for *Damochlora* sp. cf. *millepunctata* on South Maret Island (see Table 3-13 for descriptions of the vegetation units)

Torresitrachia sp. cf. *regula* Solem, 1979

With the exception of a single species in New Guinea, the genus *Torresitrachia* has a northern Australian distribution, both in coastal and in inland areas. The shell characters of the survey specimens fit the generic diagnosis given by Solem (1979). Of all the localities surveyed during this study, this taxon was found only at the four stations on Lamarck Island.

Torresitrachia regula was described from specimens from various localities within the Prince Regent River Reserve and it is of interest that, of the islands surveyed, Lamarck Island is closest to that area. The specimens from Lamarck Island resemble *Torresitrachia regula* in their size, their low spire, the nature and distribution of their radial ribbing, their colour and the nature of the pustules within the umbilicus.

?*Quistrachia* sp. or ?*Kimboraga* sp.

Specimens of what may be an undescribed species of camaenid land snail were widespread on the Maret Islands. They were also found on West Montalivet Island, Lamarck Island and Berthier Island but were less widespread in these locations. No specimens were found on any of the other islands.

The specimens do not correspond with any named species, nor do they seem to fit within any of the genera recorded from the western Kimberley region. Some of their shell characters agree with those of the genus *Quistrachia* Iredale, 1939, and some with the genus *Kimboraga* Iredale, 1939, as defined by Solem (1985).

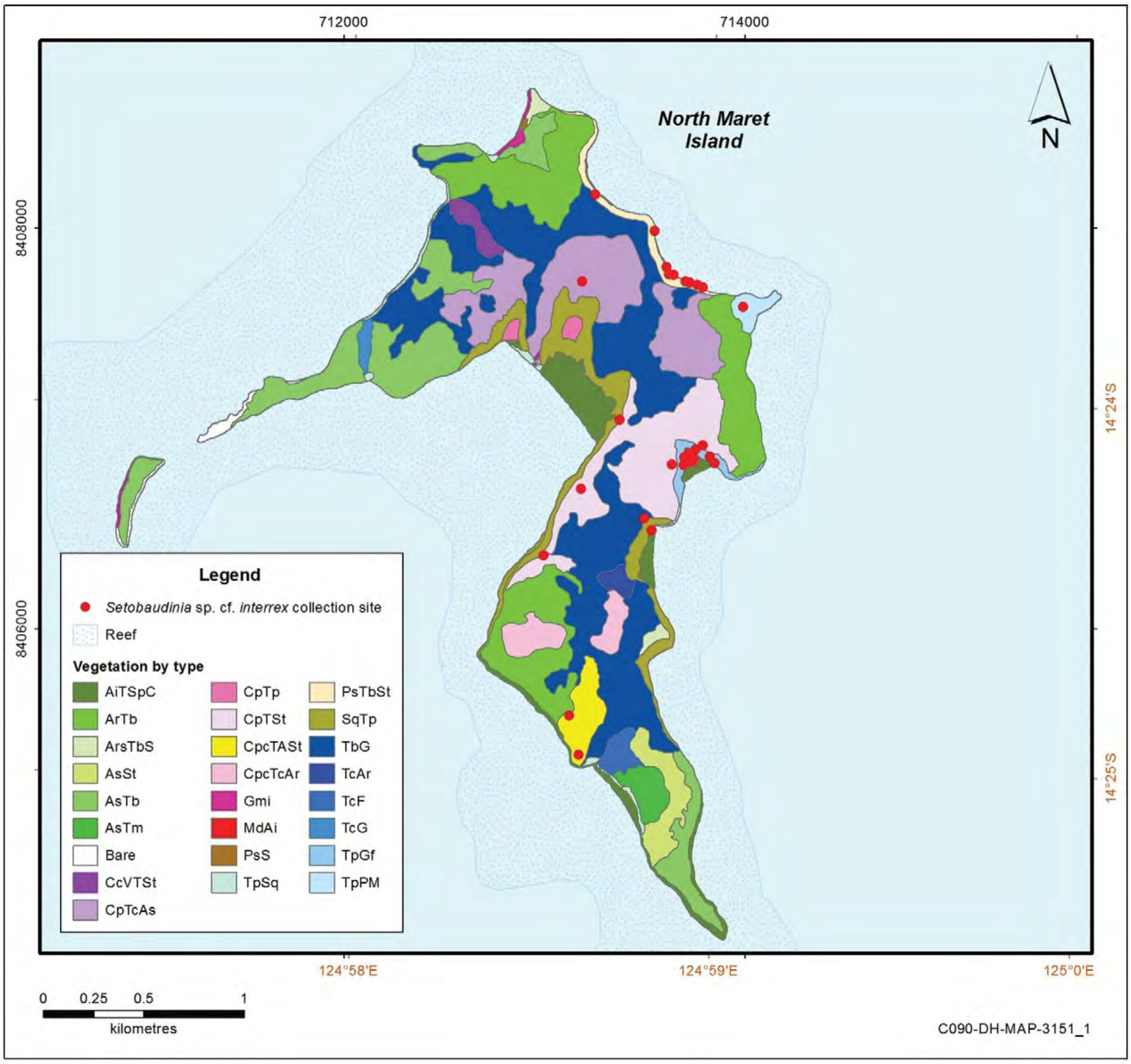


Figure 4-36: Collecting locations for *Setobaudinia* sp. cf. *interrex* on North Maret Island (see Table 3-13 for descriptions of the vegetation units)

They resemble members of the genus *Kimboraga* in their size range; elevated spire; rounded, inflated and rapidly expanding body whorl; and slightly thickened, slightly reflected lip. However, the snail differs markedly from the western Kimberley species in its lack of limitation of post-apical sculpture to growth lines, and from these and other members of the genus in the presence of extremely fine and slightly tubercular radial ridges on its apical whorls.

In this last character it fits well into the genus *Quistrachia* and resembles some of the Pilbara species in other shell characters. However, it has very little in common with the two Kimberley species, having a much more fragile, less rounded and unbanded shell than *Quistrachia leptogramma*, and a much higher, less planate, more rapidly expanding body whorl than *Quistrachia monogramma*.

The genus *Quistrachia* appears to be endemic to Western Australia and is most abundant and species-rich in the Pilbara region. In the Kimberley region, two species were placed in this genus by Solem (1985, 1997). Both inhabit areas well to the south of the Bonaparte Archipelago, *Quistrachia monogramma* (Ancey, 1898) in inland parts of the south Kimberley and *Quistrachia leptogramma* (Pfeiffer, 1846) in Dampierland[9].

The genus *Kimboraga* is also endemic to Western Australia but appears to be confined to the Kimberley region. Two of its six named species inhabit the islands and adjacent mainland of Yampi Sound (*K. yampiensis* and *K. koolanensis*), one inhabits the Prince Regent River Reserve (*K. exanimus*), and the other three are found inland in the Napier Range area (*K. mccorryi*, *K. micromphala*, and *K. yammerana*).

[9] Dampierland is one of the 89 regions of the Interim Biogeographic Regionalisation for Australia (IBRA). It is located in the West Kimberley in the hinterland of Broome (DSEWPaC 2013).

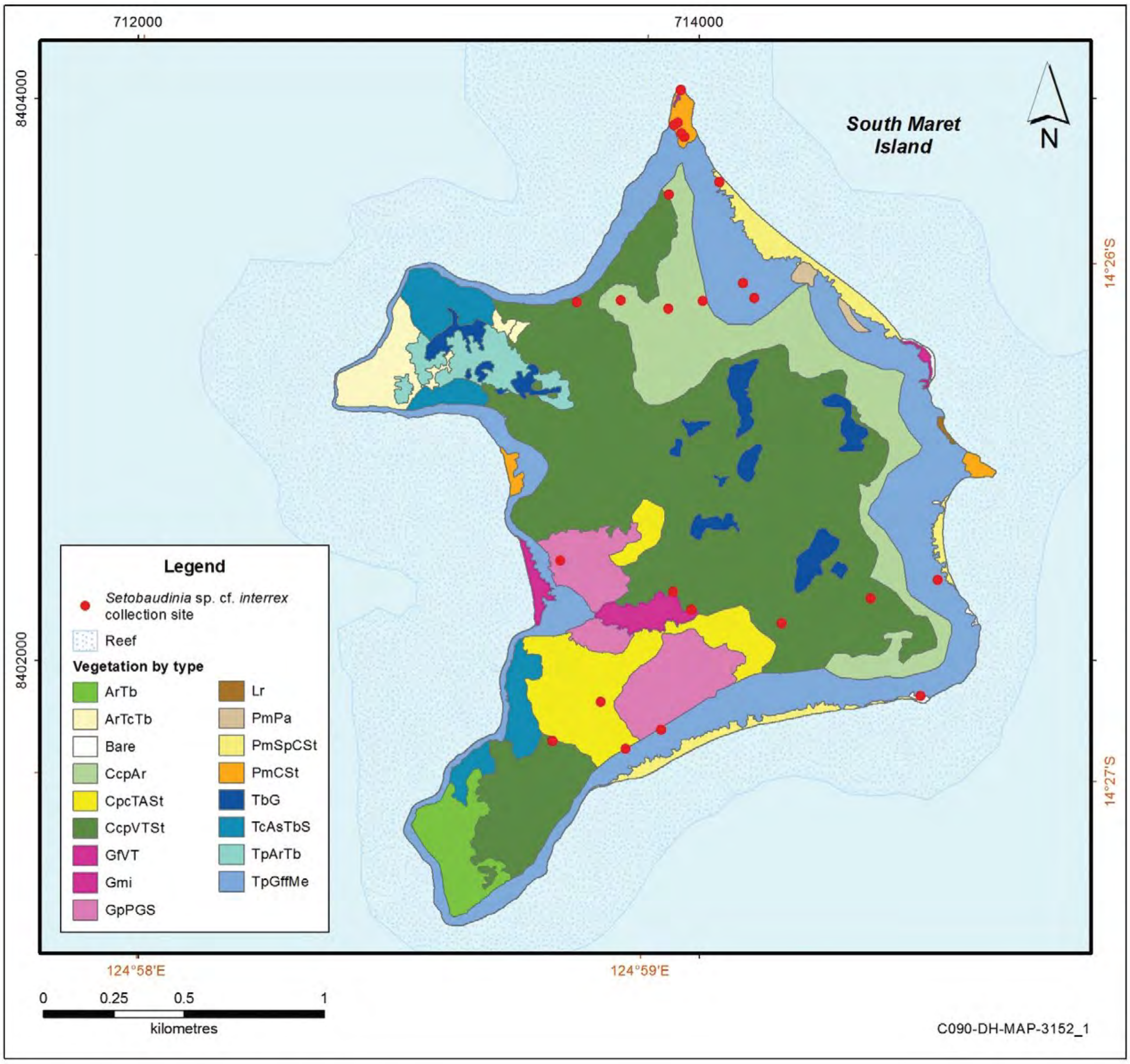


Figure 4-37: Collecting locations for *Setobaudinia* sp. cf. *interrex* on South Maret Island (see Table 3-13 for descriptions of the vegetation units)

Photographs courtesy of Corey Whisson (Western Australian Museum)

Figure 4-38: *Setobaudinia* sp. cf. *interrex* from the Maret Islands and other islands surveyed in the Bonaparte Archipelago

Family Pupillidae

Pupoides pacificus (Pfeiffer, 1846)

This species is endemic to northern Australia, being widely dispersed throughout the Kimberley, the Northern Territory and Queensland, and extending southwards into New South Wales. It was found to be widespread across the surveyed islands, except for Patricia Island, the "Unnamed Island" off the south-west coast of Don Island, Albert Island and Lamarck Island where no specimens were collected.

Gastrocopta pediculus (Shuttleworth, 1852)

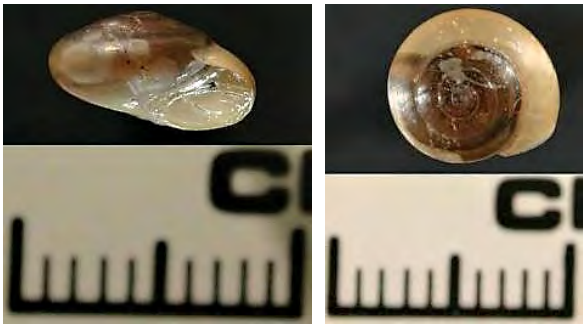
Gastrocopta pediculus is endemic to northern Australia, inhabiting the Kimberley and the Northern Territory. This tiny snail was found to be widespread across most of the surveyed islands but was not found on Albert Island or on the "Unnamed Island" off the south-west coast of Don Island.

Family Helicarionidae

Westracystis lissus (E.A. Smith, 1894)

A number of species of this family are known from northern Australia, mainly from inland and more eastern areas. *Westracystis lissus* (Figure 4-39) is a widespread species, endemic to the Kimberley region of Western Australia.

This snail was found to be widespread on North Maret Island, South Maret Island, Lamarck Island, Berthier Island and Patricia Island. Specimens were also collected, but at fewer stations, on East Montalivet Island and West Montalivet Island. It was not found on Walker Island, Don Island, the "Unnamed Island" off the south-west coast of Don Island, or Albert Island.



Photographs courtesy of Corey Whisson (Western Australian Museum)

Figure 4-39: Westracystis lissus from the Maret Islands and other islands surveyed in the Bonaparte Archipelago

Family Helicodiscidae

Stenopylis coarctata (Von Möllendorff, 1894)

Stenopylis coarctata is widespread throughout northern Australia as well as in Indonesia, the Philippines and the Solomon Islands. However, it is rarely collected or recorded because of its small size.

Specimens of this snail were collected widely across the survey islands except for Patricia Island, Albert Island and the "Unnamed Island" (off the south-west coast of Don Island) where no specimens were found (Table 4-20).

Family Helicinidae

Pleuropoma walkeri (E.A. Smith, 1894)

Pleuropoma walkeri is endemic to northern Australia and occurs widely throughout the Kimberley region and probably the Northern Territory. It was widespread across the islands surveyed, except for Patricia Island and the "Unnamed Island" off the south-west coast of Don Island.

Family Subulinidae

Eremopeas interioris (Tate, 1894)

This Australian endemic species is widespread in the north of Western Australia, in central Australia and in western Queensland. In this study it was found to be widespread across North Maret Island, South Maret Island and West Montalivet Island.

Family ?Cerastidae

?*Amimopina* sp.

One minute juvenile snail was collected on North Maret Island and has been tentatively identified as belonging to the family Cerastidae. The only cerastid species currently recorded from the Kimberley region is *Amimopina macleayi* (Brazier, 1876), which is found in Papua New Guinea as well as in the Northern Territory and Queensland.

Family Charopidae

?*Discocharopa* sp.

The family Charopidae is much more diverse in southern, more temperate areas of Australia. The single, minute, dead juvenile shell found on East Montalivet Island appears to belong to the charopid genus *Discocharopa*. The only species of this genus previously recorded from the western Kimberley is *Discocharopa aperta* (Von Möllendorff, 1888).

Conservation significance—land snails

- Conservation significance 1: no land snail species identified from the surveyed islands are currently listed as "threatened" under state or Commonwealth Acts.
- Conservation significance 2: no land snail species identified from the surveyed islands are currently listed as Priority species by the Department of Environment and Conservation. However, a number of specimens or groups of specimens are currently unidentified and are considered likely to represent new species. Such taxa are therefore potentially classifiable as being of conservation significance 2 and are listed below:
  - A possibly undescribed camaenid land snail tentatively placed in the genus *Hadra* was collected on Lamarck Island.
  - An undescribed camaenid land snail, *Damochlora* sp. cf. *millepunctata*, was collected on North Maret Island and South Maret Island. (*Damochlora millepunctata* itself is a Priority species.)
  - An undescribed camaenid land snail, *Setobaudinia* sp. cf. *interrex* Solem, 1985, was collected on most of the islands surveyed.
  - A possibly undescribed camaenid of the genus *Quistrachia* or the genus *Kimboraga* was collected on the Maret Islands, West Montalivet Island, Lamarck Island and Berthier Island.

- – A possibly undescribed land snail tentatively placed in the family Cerastidae and genus *Amimopina* was collected on North Maret Island.
  – A possibly undescribed land snail tentatively placed in the charopid genus *Discocharopa* was collected on East Montalivet Island.
- Conservation significance 3: genetic studies have revealed high levels of divergence within populations of *Amplirhagada* species on the Maret Islands and other regional islands of the Bonaparte Archipelago (Johnson, O'Brien & Fitzpatrick 2010). At the time the survey was carried out, it was not known whether the populations represented several species of the same genus or one highly variable species, but there was a reasonable expectation that at least the Maret Island populations would be found to contain new species. In fact, several new species of *Amplirhagada* from the Bonaparte Archipelago have been described by Köhler and Johnson (2012) since the 2006–2007 survey. These include *A. ambulator* (East Montalivet Island), *A. fitzpatricki* (West Montalivet Island), *A. berthierana* (Berthier Island), *A. turbinensis* (Turbin Island), and *A. albertiana* (Albert Island). These authors took the conservative taxonomic approach to the distinct mitochondrial clades identified on the Maret Islands and the adjacent "Natfe Island"[10] by Johnson, O'Brien and Fitzpatrick (2010) and included all of them as the single species *Amplirhagada intermedia* Solem, 1981.

  It is clear that extremely high levels of short-range endemism are present in *Amplirhagada* species in the Bonaparte Archipelago and all of the island species named by Köhler and Johnson (2012) are of conservation significance 3.

Earthworms

A formal earthworm survey was conducted at 12 sites on North Maret Island and 21 sites on South Maret Island in February 2007. Soil conditions on the plateaux of North Maret Island and South Maret Island did not appear to favour earthworm activity at the time of the initial survey in February 2007. Although the survey was conducted in the wet season, superficial soils were dry at the time of sampling. The soil and litter were dry to the touch at all sites and no free water was found anywhere on the islands. No earthworms were found on the Maret Islands during the initial survey.

Soils in the vine thickets growing on the hill slopes were dry loose sands which spilled easily from the spade. No earthworms were found. Litter accumulation under this vegetation was markedly less than that under trees on the lateritic plateau, indicating either lower rates of litterfall or higher rates of comminution and incorporation of the litter.

Although the formal earthworm survey in February 2007 yielded no specimens, further earthworm surveys took place in conjunction with later vertebrate fauna surveys in all vegetation communities on North Maret Island and South Maret Island, Berthier Island, East Montalivet Island, Prudhoe Island and Lamarck Island. One earthworm specimen was collected in late February 2007 from beneath a rock on the laterite plateau of South Maret Island. Further specimens were collected on South Maret Island in March 2007 (Figure 4-40) and on Berthier Island in April 2007. The specimens were mostly sexually immature and were difficult to identify (as genital features are commonly used to distinguish species and these are only adequately developed in sexually mature animals). The external features of the most mature specimens were consistent with those found in the genus *Diplotrema*. However, none of the collected specimens match the nearest species from the Kimberley mainland, *Diplotrema macleayi*.

As noted earlier, the approximately 6500 years of separation of the islands from each other and from the mainland render it likely that any earthworm populations found will be short-range endemics. Based on experience from the 1988–1989 survey in vine-thicket patches on the Kimberley mainland, where earthworms of the genus *Diplotrema* were recorded at 10 of the 15 sites sampled and each patch had its own apparently unique species (McKenzie & Dyne 1991), it is considered likely that there are two undescribed species in the material collected on South Maret Island and Berthier Island during the survey.

The South Maret Island earthworms were found within *Corymbia* woodland and vine thicket on the plateau. The majority of specimens were found in soil less than 100 mm deep and overlain with gravel and leaf litter. The soil was red–brown and appeared to contain earthworm castings. This soil type is found over a large proportion of both North Maret Island and South Maret Island. Although some rain had fallen not long before the survey, the soils were not moist.

The specimen captured on Berthier Island in April 2007 was captured in soil under vine-thicket vegetation on a hill slope under basalt rocks.

[10] "Natfe" Island was the informal name given by the survey team to the small double island immediately to the south of South Maret Island. Elsewhere in this chapter the islands are called the "Unnamed Islands" (see Figure 4-1).

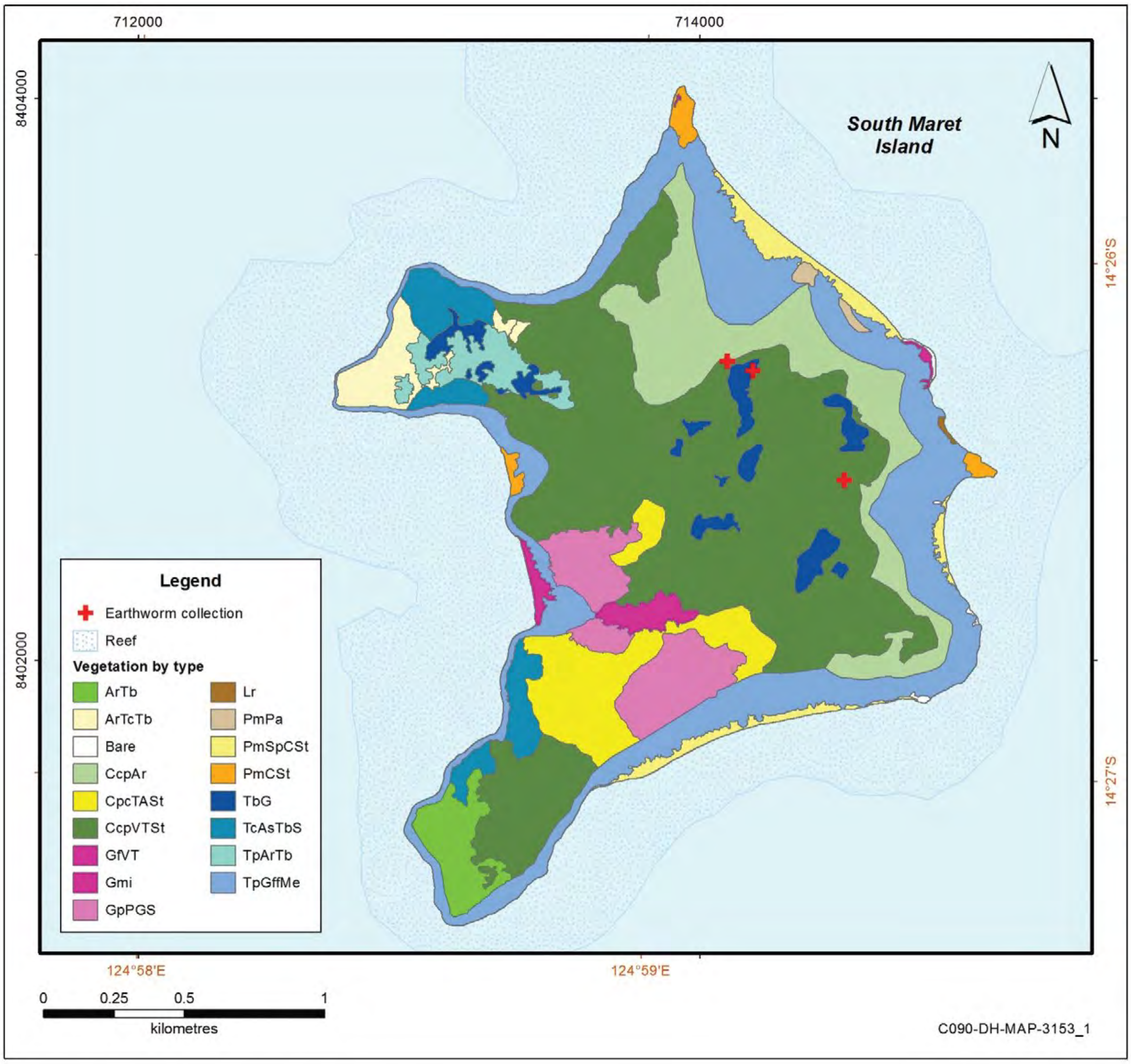


Figure 4-40: Collecting locations for earthworms on South Maret Island (see Table 3-13 for descriptions of the vegetation units)

Conservation significance—earthworms

- Conservation significance 1: earthworms of the genus *Diplotrema* are not listed as "threatened" under the EPBC Act or Western Australia's *Wildlife Conservation Act 1950*.
- Conservation significance 2: very few earthworm specimens were recorded from the Maret Islands. However, although all of the specimens collected appear to be assignable to the genus *Diplotrema*, they were sexually immature and could not be identified to species level. It is likely, however, that the earthworm populations on the Maret Islands and the surrounding islands are genetically distinct at species level as a consequence of their geographical isolation and will be classifiable as being of conservation significance 2.
- Conservation significance 3: it is possible that the *Diplotrema* earthworms on the surveyed islands may be classifiable as being of conservation significance 3 if they are found to represent isolated populations of more widespread species.

Arthropods

Arthropods were hand-collected at six survey stations on North Maret Island, 25 on South Maret Island and eight on Berthier Island. Specimens were also collected opportunistically by hand at locations on Lamarck Island and East Montalivet Island.

Three mygalomorph spider species (all probably undescribed), 13 pseudoscorpions (10 of which are probably undescribed), one undescribed terrestrial schizomid species, two undescribed scorpions, one centipede and one undescribed terrestrial (epigean) millipede were identified from the Maret Islands, Berthier Island, Lamarck Island and East Montalivet Island during this survey (Table 4-21). Many specimens could not be identified to genus or species level, either because they were juveniles, or because the taxonomy for their groups is not yet sufficiently advanced to permit determinations to be made.

In addition, during a separate troglofauna survey in 2007 and 2008, possibly two undescribed species of troglobitic schizomid of the genus *Bamazomus* and one of the genus *Trithyreus* were collected from North Maret Island and South Maret Island. A single thysanuran was collected from South Maret Island and was identified as an undescribed species of the family Nicoletiidae. Thirty-four mostly juvenile specimens of an undescribed subterranean (hypogean) species of polyxenid millipede were also collected from boreholes on North Maret Island and South Maret Island; this species is possibly not a true troglobite although it does possess troglobitic characteristics. These specimens are discussed in more detail in Chapter 5 *Troglofauna* and are included in Table 4-21 below.

Table 4-21: Arthropod species found at each island investigated in the Bonaparte Archipelago

Arthropod group and family	Genus	North Maret Island	South Maret Island	Berthier Island	Lamarck Island	East Montalivet Island
Mygalomorph spiders						
Nemesiidae	A nemesiid which was not identified but is likely to be an undescribed species	–	–	✓	–	–
Theraphosidae	*Selenocosmia* sp.	–	–	✓	–	–
	Another theraphosid which was not identified but is likely to be an undescribed species	–	–	–	–	✓
Pseudoscorpions						
Chthoniidae	*Lagynochthonius* sp. 1	✓	✓	–	–	–
	Paraliochthonius sp. 1	–	–	✓	–	–
	Tyrannochthonius sp. 1	✓	✓	✓	–	–
Feaellidae	*Feaella anderseni*	✓	–	✓	–	–
Hyidae	*Indohya* sp. “Maret Islands”	✓	✓	–	–	–
Parahyidae	*Parahya submersa*	–	–	✓	–	–
Syarinidae	*Ideoblothrus* sp. “Kimberley 1”	✓	✓	–	–	–
	Ideoblothrus sp. “Kimberley 2”	–	–	✓	–	–
	Ideoblothrus sp. “Kimberley 3”	–	✓	–	–	–
Olpiidae	*Euryolpium granulosum*	✓	✓	✓	–	–
Cheiridiidae	Cheiridiidae sp. 1	✓	✓	✓	–	–
Sternophoridae	*Afrosternophorus* sp. 1	–	✓	–	–	–
Cheliferidae	*Lissochelifer* sp. 1	–	–	–	✓	–
Schizomids						
Hubbardiidae	*Bamazomus* sp. “Maret Islands”	✓	✓	–	–	–
	Bamazomus spp. (at least one, but possibly two, troglobitic species of this genus)	✓	✓	–	–	–
	Trithyreus sp.	–	✓	–	–	–

Table 4-21: Arthropod species found at each island investigated in the Bonaparte Archipelago (continued)

Arthropod group and family	Genus	North Maret Island	South Maret Island	Berthier Island	Lamarck Island	East Montalivet Island
Scorpions						
Hormuridae	*Hormurus* sp. “WA1”	✓	✓	✓	✓	–
Urodacidae	*Urodacus* sp.	✓	✓	–	–	–
Centipedes						
Scolopendridae	*Ethmostigmus rubripes*	✓	–	–	–	–
Millipedes						
Unknown	Undescribed terrestrial millipede. Unidentifiable to family and genus level at this stage	–	✓	–	–	–
Unknown	Undescribed subterranean millipede of the order Polyxenida. Unidentifiable to family and genus level at this stage	✓	✓	–	–	–
Thysanurans						
Nicoletiidae	Undescribed troglobitic silverfish	–	✓	–	–	–

– = species not found.

Infraorder Mygalomorphae—mygalomorph spiders

Two mygalomorph spiders, one from the family Theraphosidae and one from the family Nemesiidae, were collected from Berthier Island. The localities of the collection sites are shown in Figure 4-47.

The theraphosid was a single adult male of the genus *Selenocosmia* (Figure 4-41) but its identification to species level was not possible as the taxonomy of this genus has not been fully resolved. It was captured in a funnel trap in open *Corymbia* woodland with *Grevillea* and *Acacia* shrubs, vine thicket and low grasses on lateritic rocks, cobbles and soil. The broader distribution of this species is unknown.

The nemesiid spider was a juvenile and cannot be identified below family level. This specimen was captured by hand in slope vine thicket over basalt rocks.

A third mygalomorph spider was collected from East Montalivet Island. As it was a juvenile, however, it could not be identified.

The Kimberley vine thickets were virtually unexplored in terms of spider systematics and zoogeography until 1988 (Main 1991). However, work carried out in 1988 and 1989 for the Kimberley Rainforest Survey across eight vine-thicket patches with a total area of 173 ha revealed that spiders of the family Theraphosidae were restricted to vine-thicket patches while spiders of the family Nemesiidae (as Dipluridae) were also found in adjacent sclerophyll forest (Main 1991). Both of these mygalomorph spider families are classified by Main as sedentary (territorial), fossorial (soil and small-rock substrate) spiders, restricted to habitats suitable for burrowing. Presumably these behavioural traits also restrict their ability to disperse, which increases the likelihood of these spiders being relatively frequently recorded as short-range endemics. Harvey (2002) has previously recognised mygalomorph spiders as one of the groups that exhibit patterns of short-range endemism.

It is therefore likely that these nemesiid and theraphosid spiders represent undescribed short-range endemic species, but further material would have to be collected to decide the matter.

Photograph courtesy of Wes Bancroft

Figure 4-41: The mygalomorph spider (genus *Selenocosmia*) collected on Berthier Island

Order Pseudoscorpiones—pseudoscorpions

Eleven genera from nine families of pseudoscorpion were collected from the Maret Islands, Berthier Island and Lamarck Island. They were collected from leaf litter, from under tree bark and from the intertidal zone. The pseudoscorpion assemblage included ten possibly undescribed species: five from the Maret Islands. two from Berthier Island, one from Lamarck Island, and two which occur both on the Maret Islands and on Berthier Island.

The distributions of all of the pseudoscorpion taxa detected within the survey area and in the broader region are described below.

Family Chthoniidae

Lagynochthonius sp. 1

The genus *Lagynochthonius* occurs in a variety of tropical and subtropical habitats around the world. Only a few species have been described from Western Australia, including three species from troglobitic habitats in the Pilbara region (Edward & Harvey 2008).

The specimens from the Maret Islands were recorded at three sites on North Maret Island and eight sites on South Maret Island (Figure 4-42). All of them were collected from leaf litter in the slope vine thicket or plateau vine-thicket habitats. Specimens resembling this species have been collected from vine thickets on the Kimberley mainland.

Paraliochthonius sp. 1

A population of *Paraliochthonius* sp. 1 was found under basalt rocks on a beach on Berthier Island. Members of this genus live in intertidal habitats in many areas of the world. This as yet undescribed Australian species has also been found on beaches in Darwin in the Northern Territory, suggesting that it is widely distributed on coastlines in northern Australia (Harvey 2009).

Tyrannochthonius sp. 1

The genus *Tyrannochthonius* occurs in most tropical and subtropical regions of the world and, with over 130 named species, is the second-largest genus in the family Chthoniidae. The Western Australian fauna was studied by Edward and Harvey (2008) who found several species in the Pilbara region, including troglomorphic forms. The Kimberley fauna is largely unstudied, although *Tyrannochthonius laevis* was described from the Kimberley Research Station near Wyndham by Beier (1966).

The specimens from the Bonaparte Archipelago surveys came from one site on North Maret Island, three sites on South Maret Island and one site on Berthier Island (Figure 4-42). All of the specimens were found in vine-thicket leaf litter. Specimens resembling this species have previously been collected from vine thickets on the Kimberley mainland.

Family Feaellidae

Feaella anderseni Harvey, 1989

The family Feaellidae has a highly disjunct distribution in Africa, Madagascar, the Seychelles, India and Australia (Harvey 2013). The sole named Australian species, *Feaella anderseni*, was recorded from two vine-thicket communities in the Kimberley (Harvey 1989) and has since been found at several other localities in the region. It typically exists in isolated populations in vine-thicket patches (Dr M.S. Harvey, Senior Curator and Head, Department of Terrestrial Zoology, Western Australian Museum, Perth, pers. comm. November 2007). Specimens of *F. anderseni* were collected from two vine-thicket sites on North Maret Island and from one site on Berthier Island (Figure 4-42). No specimens were found on South Maret Island.

Family Hyidae

Indohya sp. "Maret Islands"

The family Hyidae has a highly disjunct distribution, despite its broad range, with two species of the genus *Hya* in south-eastern Asia and 12 named species of the genus *Indohya* from Western Australia, India and Madagascar (Harvey 1993; Harvey & Volschenk 2007). The nine Western Australian species occur in the soil and leaf litter of vine thickets in the Kimberley region and in cave systems in the Kimberley and Cape Range regions. Two further subterranean species have been recognised (Harvey & Volschenk 2007), but insufficient material was available to formally describe and name them.

Several specimens of an undescribed species of *Indohya* were collected from one site on North Maret Island and one site on South Maret Island (Figure 4-42). All were collected from leaf litter within vine-thicket communities. This species is considered likely to be endemic to the Maret Islands.

Family Parahyidae

Parahya submersa (Bristowe, 1931)

Parahya submersa occurs in intertidal habitats across parts of Australasia (Harvey 1991b; Harvey et al. 2007). Populations have recently been found in northern Western Australia and the Northern Territory. During the survey this species was found at one site in the intertidal zone on Berthier Island. The specimens found here only slightly extend the known range of the species.

Family Syarinidae

Ideoblothrus sp. "Kimberley 1"

The genus *Ideoblothrus* occurs in leaf litter and cave habitats in most tropical regions of the world. A recent review of the *Ideoblothrus* fauna of Western Australia (Harvey & Edward 2007) listed six species, including five from subterranean habitats and one, *Ideoblothrus descartes*, from Descartes Island in the Bonaparte Archipelago.

The undescribed species *Ideoblothrus* sp. "Kimberley 1" is known only from the Maret Islands, which are 80 km south-west of Descartes Island. Several specimens were collected from two sites on North Maret Island and three sites on South Maret Island (Figure 4-42), from *Corymbia* and *Ficus* leaf litter and under rocks in vine thickets. It is larger and much more robust than any other species of the genus.

Ideoblothrus sp. "Kimberley 2"

Several specimens of an undescribed species were collected from one vine-thicket site on Berthier Island (Figure 4-42). It is very similar to *Ideoblothrus descartes* from Descartes Island, but is slightly larger.

Ideoblothrus sp. "Kimberley 3"

Two specimens of an undescribed species, *Ideoblothrus* sp. "Kimberley 3", were collected from leaf litter at a single site on the edge of the plateau vine thicket on South Maret Island (Figure 4-42). *Ideoblothrus* sp. "Kimberley 3" is larger than *Ideoblothrus descartes* and *Ideoblothrus* sp. "Kimberley 2" but is smaller than *Ideoblothrus* sp. "Kimberley 1".

Family Olpiidae

Euryolpium granulosum (Hoff, 1947)

The pseudoscorpion genus *Euryolpium* consists of 10 named species from Asia and two species from Australia. *Euryolpium granulosum* occurs in many of the drier regions of Western Australia where it is found under rocks, under tree bark and in leaf litter. It is common in many different regions and was collected in vine-thicket habitat at a number of sites on North Maret Island, South Maret Island and Berthier Island.

Family Cheiridiidae

Cheiridiidae sp. 1

The pseudoscorpion family Cheiridiidae is widely distributed around the world, but the classification at genus level is unreliable and many Australian species cannot be satisfactorily assigned to any existing genera. Cheiridiid specimens were collected from one site on North Maret Island, one site on South Maret Island and one site on Berthier Island in vine-thicket leaf litter (Figure 4-42). Specimens resembling this species have been collected from vine thickets on the Kimberley mainland.

Family Sternophoridae

Afrosternophorus sp. 1

Representatives of the genus *Afrosternophorus* occur over much of mainland Australia but are most frequently found in the tropical regions of northern Australia. Only four of the Australian species collected to date have been named (Harvey 1985) and no further work has been conducted on this group since 1985. Most sternophorids have flattened bodies that enable them to live under the bark of trees.

A single species, *Afrosternophorus* sp. 1, was found on South Maret Island. This species (or a similar species) also occurs on the Kimberley mainland where it is fairly common.

Family Cheliferidae

Lissochelifer sp. 1

The genus *Lissochelifer* occurs in eastern Africa, Asia, India and Vanuatu. No species have been named from Australia, but several as yet unnamed species have been collected from tropical northern Australia. A single specimen of an unnamed species was collected from under the bark of a tree on Lamarck Island. Specimens resembling this species have been collected from vine thickets on the Kimberley mainland.

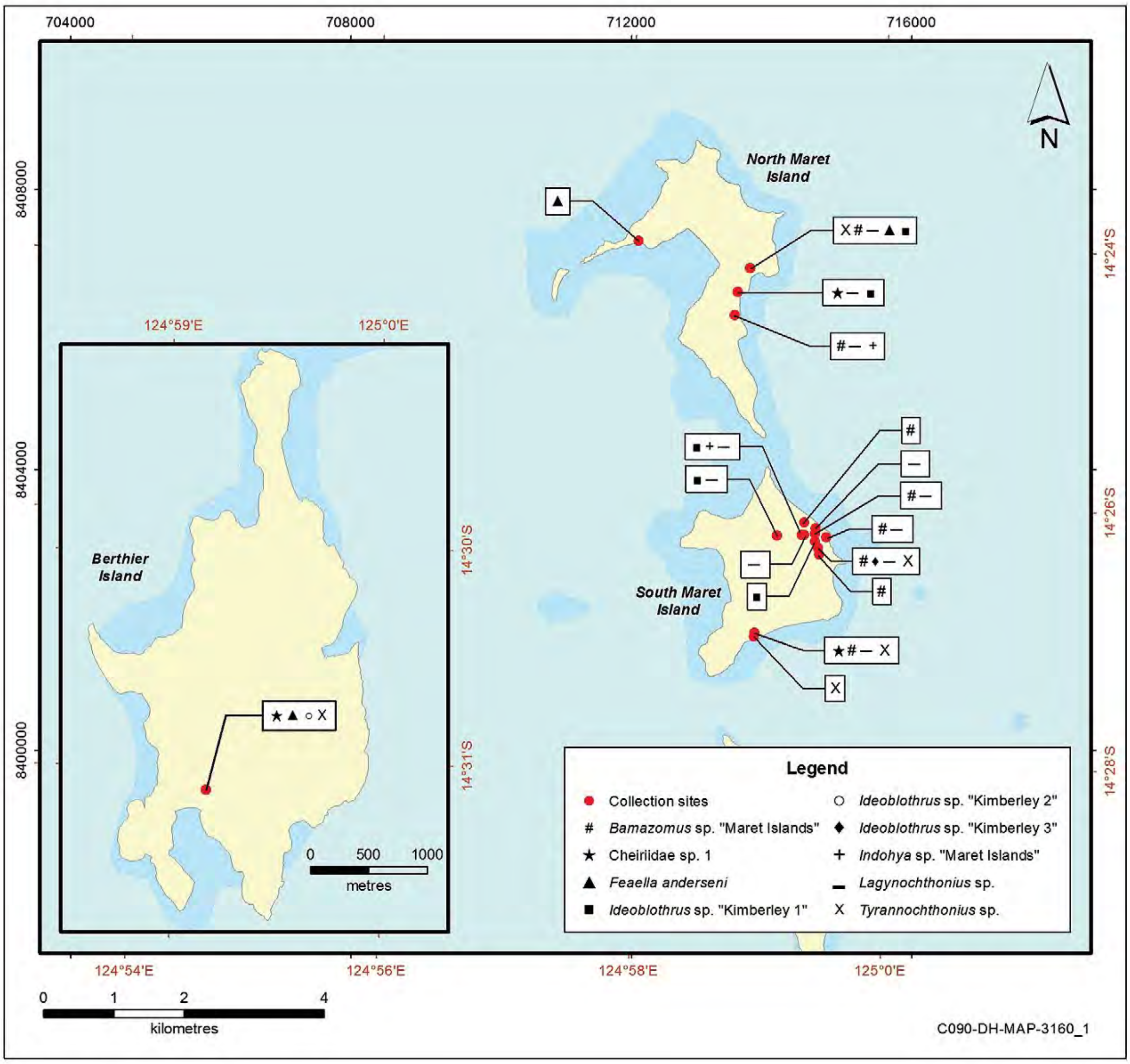


Figure 4-42: Distribution of short-range-endemic terrestrial schizomids and pseudoscorpions on the Maret Islands and Berthier Island

4 TERRESTRIAL FAUNA

Order Schizomida—schizomids

Bamazomus sp. "Maret Islands" (family Hubbardiidae)

An undescribed terrestrial schizomid was collected from two sites on North Maret Island and from six sites on South Maret Island (Figure 4-42). All of the specimens were sieved from leaf litter within vine-thicket habitats (slope and plateau vine thicket). Adult males, which provide the most diagnostic morphological features for separating species in taxonomic keys, were collected from both islands. The adult male specimens were morphologically similar among sites. Many adult females and juveniles were also collected from both islands, and all appear to belong to the same species as the males.

The morphological features of the male specimens indicate that the species can be confidently assigned to the genus *Bamazomus*, first described by Harvey (Harvey 1992). It is a cosmopolitan genus comprising an unusual species from northern Queensland (the type species *B. bamaga*), a widespread Asian species (*B. siamensis*) and several species from northern Australia, Madagascar, the Seychelles and Asia. The group also includes troglobitic species from Cape Range (*B. subsolanus* and *B. vespertinus*) and the southern Kimberley region (*B. hunti*). However, the new species from the Maret Islands differs in morphology from all previously named species.

Possibly three undescribed species of troglobitic schizomid were collected from North Maret Island and South Maret Island during the survey. Two are in the genus *Bamazomus* and one is in the genus *Trithyreus*. These are discussed in more detail in Chapter 5 *Troglofauna*.

Order Scorpiones—scorpions

Hormurus sp. "WA1" (family Hormuridae)[11]

A hormurid scorpion, *Hormurus* sp. "WA1" (Figure 4-43), was collected at several sites on North Maret Island, South Maret Island, Berthier Island and Lamarck Island (figures 4-45, 4-46 and 4-47). Fourteen specimens were collected and sent to the Western Australian Museum for identification and to be added to the collection. Other specimens were observed but not collected. These scorpions typically live under basalt boulders within vine thickets on the island slopes or under boulders beneath trees on the plateau.

[11] At the time of the survey, these scorpions were placed in the genus *Liocheles* in the family Liochelidae. Monod, Harvey and Prendini (2013), however, refer all Australian species formerly in *Liocheles* to the genus *Hormurus* in the family Hormuridae.

Figure 4-43: *Hormurus* sp. "WA1" from North Maret Island

Hormurus scorpions occur throughout the Australasian region, including the Pacific Islands and much of south-eastern Asia (Koch 1977). Three distinct species of *Hormurus* are currently recognised for the Kimberley region of Western Australia (Monod, Harvey & Prendini 2013). *Hormurus* sp. "WA1" has also been found at one mainland location on the Kimberley coast opposite Bigge Island. This species is a highly restricted short-range endemic (Dr M.S. Harvey, Senior Curator and Head, Department of Terrestrial Zoology, Western Australian Museum, Perth, pers. comm. May 2007).

Urodacus sp. (family Urodacidae)

Three specimens of an unidentified species of the scorpion genus *Urodacus* (Figure 4-44) were collected, two from the plateau on South Maret Island during the March 2007 survey (Figure 4-46) and one from North Maret Island in July 2007 (Figure 4-45). However, adult male specimens have not been collected, hampering any further detailed taxonomic assessment. Previously, the genus *Urodacus* was thought to be restricted to mainland Australia (Koch 1977).

Figure 4-44: The *Urodacus* species collected on North Maret Island

On South Maret Island one specimen was found within *Corymbia* woodland while the other was found adjacent to a termite mound in more open vegetation (Figure 4-46). This is an undescribed species and its broader distribution is unknown.

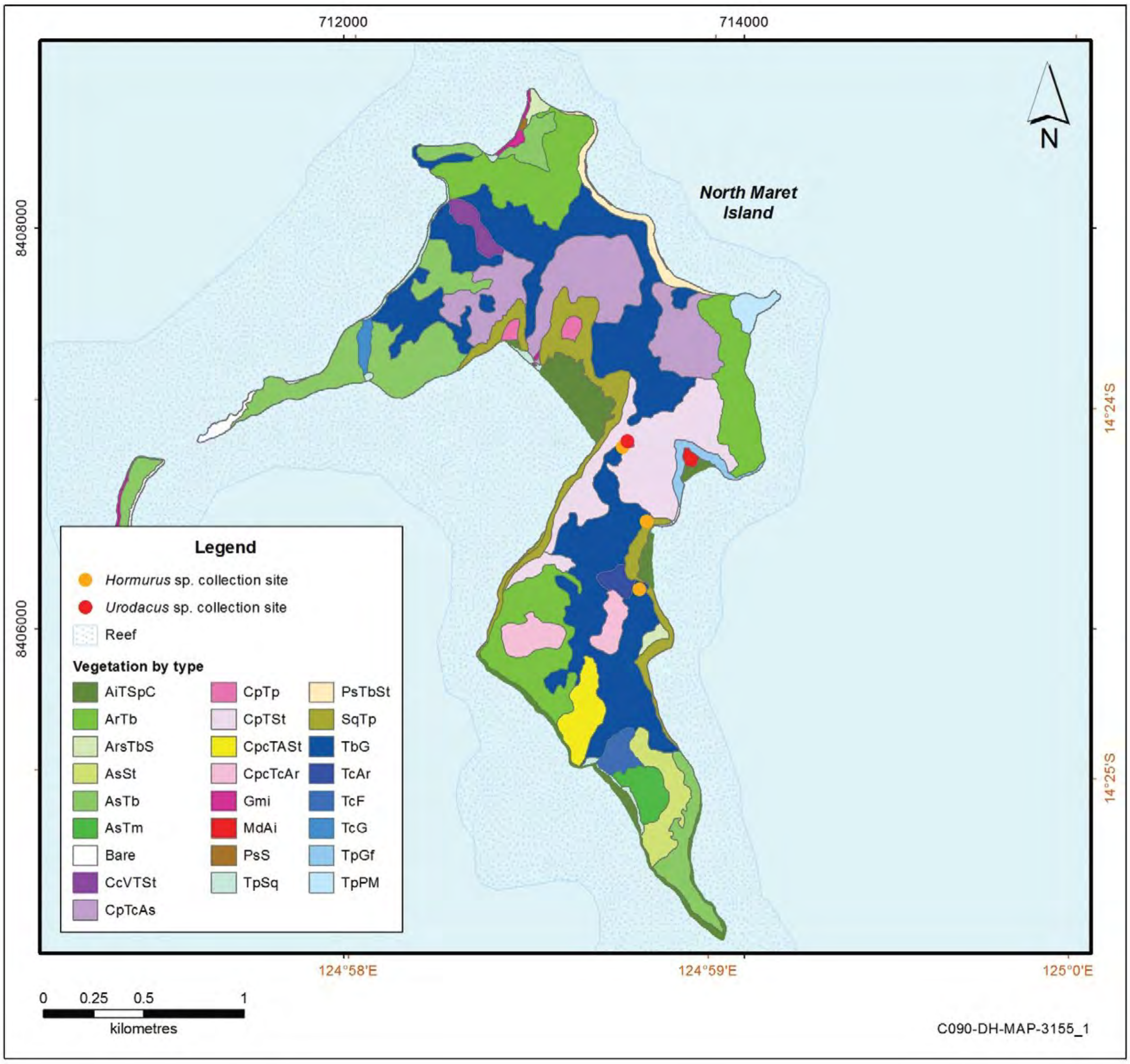


Figure 4-45: Collecting locations for the scorpions *Hormurus* sp. “WA1” and *Urodacus* sp. on North Maret Island (see Table 3-13 for descriptions of the vegetation units)

Class Chilopoda—centipedes

Several specimens of the giant centipede *Ethmostigmus rubripes* (family Scolopendridae) were collected from North Maret Island. This species is widespread across mainland Australia and is not a short-range endemic.

Class Diplopoda—millipedes

Several millipedes were recorded from leaf litter on South Maret Island. The sole male in the sample does not conform to the description of any known species from Australia. Investigations into this specimen are continuing and while it is possible that it is an introduced species, it is taken here as a possibly undescribed native. However, as the tropical millipede fauna is poorly collected and poorly understood its identification may not be possible for some time.

Thirty-four possibly troglobitic polyxenid millipedes were collected from three borehole sites on North Maret Island and from two borehole sites on South Maret Island during the survey.

This is also an undescribed species but identification to family and genus level was not possible as the majority of the collected specimens were juvenile. This species is discussed in more detail in Chapter 5 *Troglofauna*.

Class Insecta—insects

Order Thysanura—thysanurans

A single troglobitic thysanuran was collected from South Maret Island during the troglofauna survey and was identified as a currently undescribed species of the family Nicoletiidae. This specimen is discussed in more detail in Chapter 5 *Troglofauna*.

Conservation significance—arthropods

- Conservation significance 1: no arthropod species of conservation significance 1 were recorded from any of the surveyed islands.
- Conservation significance 2: during the course of this survey, the team collected 22 arthropod species that are believed to be as yet undescribed.

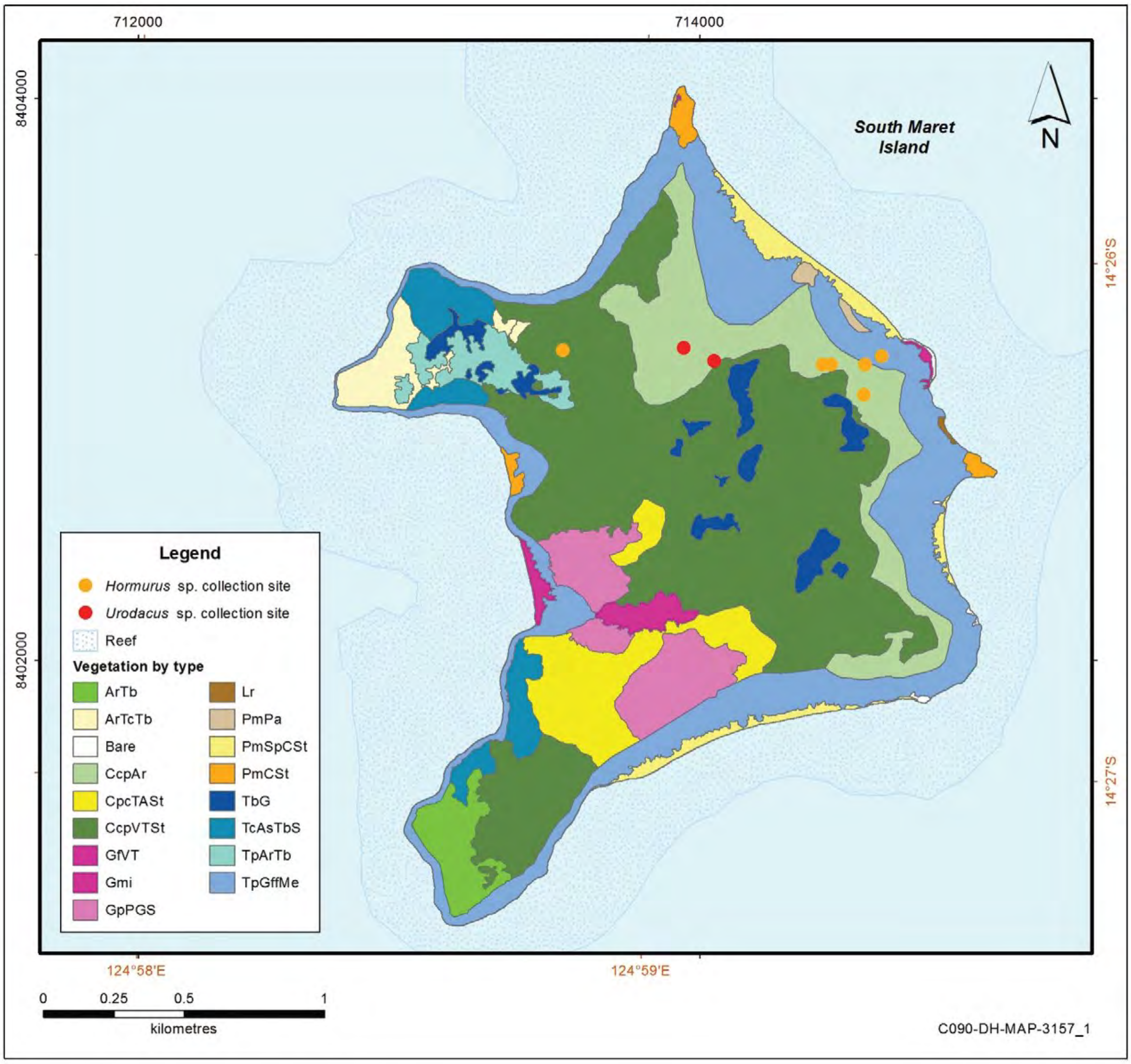


Figure 4-46: Collecting locations for the scorpions *Hormurus* sp. "WA1" and *Urodacus* sp. on South Maret Island (see Table 3-13 for descriptions of the vegetation units)

Although most could not be identified to species level because their groups are still relatively poorly understood taxonomically or because insufficient material was collected to permit a formal description to be prepared, such taxa are classifiable as being of conservation significance 2 and are listed below:

- A mygalomorph spider of the family Nemesiidae was collected on Berthier Island and is possibly an undescribed species.
- A mygalomorph spider of the family Theraphosidae was collected on Berthier Island and is possibly an undescribed species.
- A mygalomorph spider of the family Theraphosidae was collected on East Montalivet Island and is possibly an undescribed species.
- An undescribed chthoniid pseudoscorpion, *Lagynochthonius* sp. 1, was recorded at three sites on North Maret Island and eight sites on South Maret Island.
- An undescribed chthoniid pseudoscorpion, *Paraliochthonius* sp. 1, was collected on Berthier Island.
- An undescribed chthoniid pseudoscorpion, *Tyrannochthonius* sp. 1, was collected from one site on North Maret Island, three sites on South Maret Island and one site on Berthier Island.
- An undescribed hyid pseudoscorpion, *Indohya* sp. "Maret Islands", was collected from one site on North Maret Island and one site on South Maret Island.
- An undescribed syarinid pseudoscorpion, *Ideoblothrus* sp. "Kimberley 1", was collected from two sites on North Maret Island and three sites on South Maret Island.
- An undescribed syarinid pseudoscorpion, *Ideoblothrus* sp. "Kimberley 2", was collected from one site on Berthier Island.

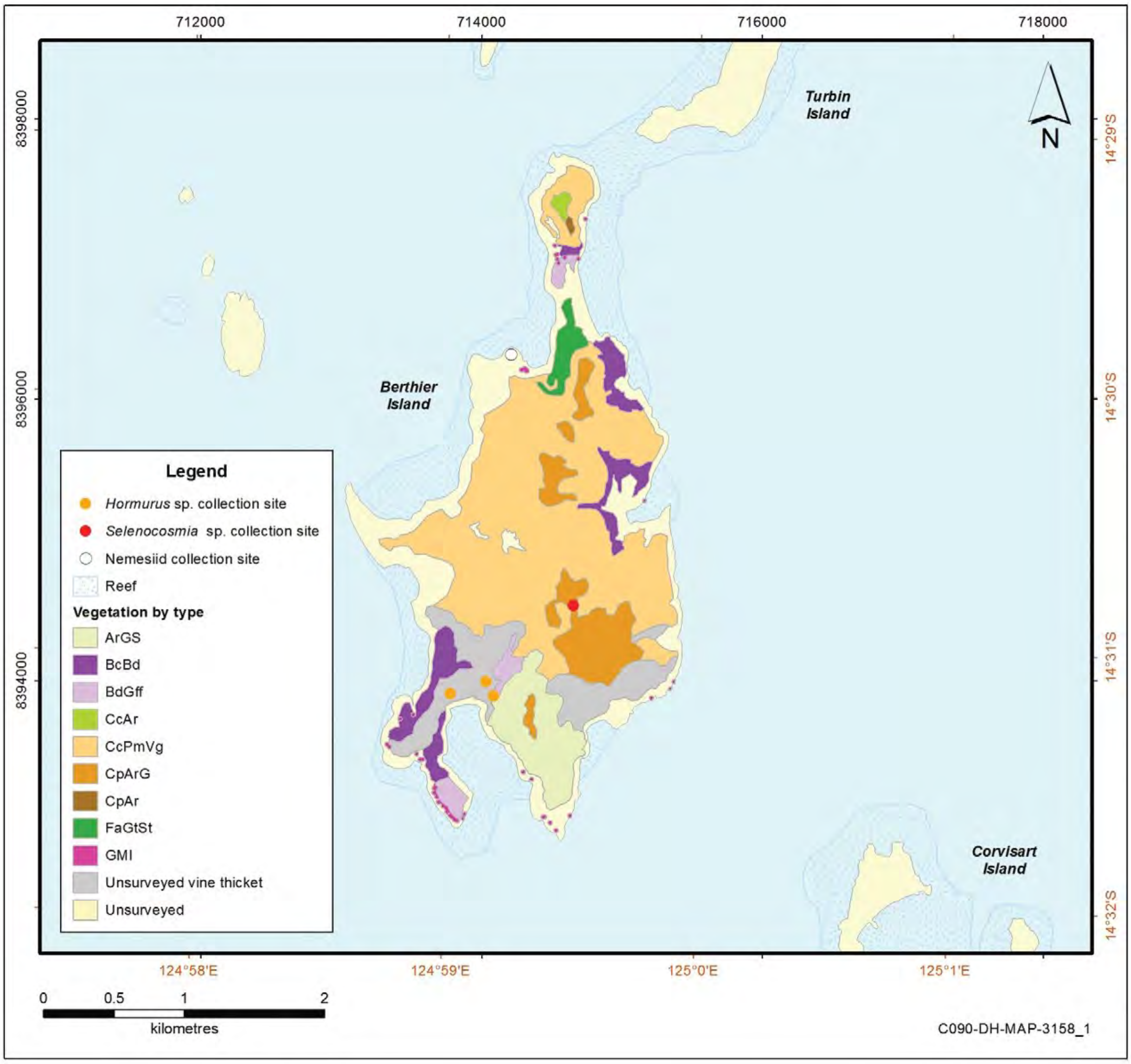


Figure 4-47: Collecting locations for the scorpion *Hormurus* sp. "WA1", the nemesiid spider and the theraphosid spider *Selenocosmia* sp. found on Berthier Island (see Table 3-13 for descriptions of the vegetation units)

- An undescribed syarinid pseudoscorpion, *Ideoblothrus* sp. "Kimberley 3", was collected from one site on South Maret Island.
- A cheiridiid pseudoscorpion of uncertain genus (the classification of this family is taxonomically unreliable) was collected from one site on North Maret Island, one site on South Maret Island and one site on Berthier Island. It is possible that it is an undescribed species.
- A possibly undescribed sternophorid pseudoscorpion, *Afrosternophorus* sp. 1, was collected from one site on South Maret Island. (The same species or a similar species occurs on the Kimberley mainland.)
- A possibly undescribed cheliferid pseudoscorpion, *Lissochelifer* sp. 1, was collected from one site on Lamarck Island.
- An undescribed terrestrial schizomid of the genus *Bamazomus* was collected from two sites on North Maret Island and from six sites on South Maret Island.
- Specimens of one and possibly two undescribed species of troglobitic schizomids of the genus *Bamazomus* were collected from boreholes on North Maret Island and South Maret Island during the troglofauna survey. (See Chapter 5 *Troglofauna*.)
- An undescribed species of troglobitic schizomid of the genus *Trithyreus* was collected from a borehole on South Maret Island during the troglofauna survey. (See Chapter 5 *Troglofauna*.)
- An undescribed hormurid scorpion, *Hormurus* sp. "WA1", was collected at several sites on North Maret Island, South Maret Island, Berthier Island and Lamarck Island.

  - An undescribed urodacid scorpion, *Urodacus* sp., was collected from two localities on South Maret Island and one locality on North Maret Island.
  - An undescribed millipede (class Diplopoda) was recorded from leaf litter on South Maret Island.
  - An undescribed millipede of the order Polyxenida (class Diplopoda) was collected on North Maret Island and South Maret Island during the troglofauna survey. (See Chapter 5 *Troglofauna*.)
  - An undescribed troglobitic thysanuran (silverfish) of the family Nicoletiidae was collected from a borehole on South Maret Island during the troglofauna survey. (See Chapter 5 *Troglofauna*.)
- Conservation significance 3: it is possible that some of the arthropods collected on this survey (including some of those listed above as being likely to be of conservation significance 2) would be classifiable as being of conservation significance 3.

DISCUSSION

Species diversity and distribution

The 2006–2007 study reported on in this chapter represents the most comprehensive survey and trapping program carried out on the Maret Islands and their neighbouring islands to date.

During the surveys, 141 vertebrate species were recorded: 4 amphibians, 33 reptiles, 51 landbirds, 47 shorebirds and seabirds (including records south to Pender Bay), and 6 mammals (5 bats and the Kimberley rock-rat). Resident colonies of bats were found only on West Montalivet Island (two species).

Approximately 43 species of invertebrates were recorded: 15 land snails, 2 earthworms, 3 spiders, 13 pseudoscorpions, possibly 4 species of schizomid (3 of them troglobitic), 2 scorpions, 1 centipede, 2 millipedes (1 possibly troglobitic) and 1 troglobitic thysanuran (silverfish).

Over the whole terrestrial fauna survey program, 31 species thought to be new to science were discovered: 1 gecko (the only vertebrate), 6 land snails, 2 earthworms, 3 spiders, 10 pseudoscorpions, 4 schizomids, 2 scorpions, 2 millipedes and 1 thysanuran (silverfish). Most if not all of these species are short-range endemics.

The troglobitic arthropods are discussed in more detail in Chapter 5 *Troglofauna*.

Amphibians

Three amphibian species were collected on Bigge Island in July and August 2006. An unidentified frog of the myobatrachid genus *Uperoleia* was heard calling on East Montalivet Island and West Montalivet Island; these records were of frogs calling from beneath boulders alongside a stream (East Montalivet Island) and from beneath the overhanging bank of a pool (West Montalivet Island). The call recorded on East Montalivet Island does not match the known calls of *Uperoleia* species in the west Kimberley, but it should be noted that the calls of some species of the genus are as yet undescribed. The frog calls on the two islands were similar and it is likely that both frogs were of the same species.

Reptiles

During the survey period, 33 terrestrial reptile species were recorded. Of the six islands intensively investigated in 2007, Prudhoe Island and South Maret Island had the highest species richness with 21 species each, and North Maret island and Lamarck Island had the lowest with 13 species each. These differences may indicate real differences in species richness between the islands, but may also be an artefact of sampling, especially in the case of cryptic species or species unlikely to be susceptible to trapping.

The herpetofauna of all islands was generally dominated by the same five species: the bar-shouldered skink (*Ctenotus inornatus*), the rough brown rainbow-skink (*Carlia johnstonei*), the northern bar-lipped skink (*Eremiascincus isolepis*), the lined firetail skink (*Morethia ruficauda*), and Bynoe's gecko (*Heteronotia binoei*). The most commonly recorded reptile species on all of the islands surveyed was *Ctenotus inornatus*, although it should be noted that this skink is relatively easy to trap.

Thirteen reptile species on the islands had not previously been reported or collected from the Bonaparte Archipelago. Of these new records, 12 were expected to be found on the basis of their broader distribution, while the thirteenth, a gecko, was found to be a new species and was later described by Bauer and Doughty (2012) as *Cyrtodactylus kimberleyensis*. Four species recorded in the literature as being present in this region were not detected during the surveys.

Reptile numbers and species richness did not appear to be affected by wet-season versus dry-season sampling, nor were they affected by the geology of the island. Species richness was however higher on sandstone substrates than on lateritic substrates, which is a similar pattern to the distribution of reptiles on the Kimberley mainland (Kendrick & Rolfe 1991).

The number of reptile species recorded varied between the islands. While the sampling effort was roughly equivalent between the six islands, cryptic species such as the Kimberley shallow-soil blind snake (*Ramphotyphlops kimberleyensis*) (two specimens found on South Maret Island and two on Prudhoe Island) and the common tree snake (*Dendrelaphis punctulatus*) (one specimen found on South Maret Island and one on Berthier Island) are difficult to sample effectively and their absence from trap returns is not a good indication that they are not present. In contrast, the absence from traps of conspicuous species such as the crocodile-faced dtella (*Gehyra xenopus*), the giant slender blue-tongue (*Cyclodomorphus maximus*) and the Kimberley rock monitor (*Varanus glauerti*) from North Maret Island, for example, is a good indication that these species are not present on that island.

Agamid lizards were noticeably absent from all of the islands surveyed during this study and as they are large, conspicuous and generally diurnal species it is likely that they are not present on the islands.

A number of "mulga snakes", at the time of the survey believed to be the species *Pseudechis australis*, were trapped in plateau habitats on the Maret Islands but were not detected on Berthier Island or East Montalivet Island. They appeared to be smaller than mulga snake specimens from the Kimberley mainland and it had also been noted during a previous survey that the skin patterns of the island snakes differed from those found in mainland populations (How et al. 2006). It was later determined that the island "mulga snakes" were in fact Weigel's black snakes (*Pseudechis weigeli*).

Several olive whipsnakes (*Demansia olivacea*) were also trapped and also appeared to be slightly smaller than their mainland counterparts (Mike Bamford, Principal Scientist, Bamford Consulting Ecologists, pers. comm. June 2007). As the evolution of dwarfism in island populations following geographic isolation from mainland populations is relatively common (Mills, Moro & Spencer 2004), lower mean size in these island populations may indicate genetic divergence from the mainland populations.

Landbirds

A total of 51 landbird species were recorded across all of the islands surveyed. Birds were most abundant on East Montalivet Island and least abundant on Prudhoe Island, with the greatest density per hectare being recorded on Lamarck Island. Twenty-two species of landbird were recorded on Lamarck Island, giving it the highest landbird count for any of the islands surveyed during the 2006–2007 study.

The landbird assemblages on the islands were small compared with that of the adjacent mainland, with only 16 to 20 species recorded on each of the four main laterite islands. Differences in the suite of species among the islands were attributable in the main to a few uncommon species being seen on only some islands. Each island had virtually the same suite of abundant species and these consisted almost entirely of species associated with vine-thicket vegetation.

Most birds were recorded in the slope vine-thicket vegetation or in upland woodland habitats that contained vine-thicket plants. These habitats provide the best shelter and for the many frugivorous vine-thicket bird species they offer the best foraging habitat.

The populations of vine-thicket birds on the study islands are significant in the context of the West Kimberley. The densities of vine-thicket specialists on the islands, particularly South Maret Island and East Montalivet Island, were similar to or higher than densities reported from vine thickets on the mainland (Higgins & Davies 1996). The high densities of these birds may be attributable to the lack of mammalian competitors for food and the long periods which have elapsed since the last occurrence of fire. It should be noted, however, that some of the densities recorded may be overestimates because of reliance on calls in the thickets rather than sightings, but any such overestimates would likely have been consistent between islands and at least moderately consistent between species.

Shorebirds and seabirds

A total of 47 shorebird and seabird species were recording during the survey. Thirty-three of these were recorded around 36 islands and their associated rocks and reefs in the Bonaparte Archipelago. A further 14 species were recorded in the course of cetacean surveys south to Pender Bay.

The numbers of shorebirds recorded around the Maret Islands were very low in comparison with other regions within Western Australia, probably because tidal environments are narrow and there is a lack of tidal mudflats. However, the breeding of bridled terns on the islands of the Albert Islands group is regionally significant.

The waters surrounding Berthier Island, Albert Island and Browse Island appear to be important feeding grounds for a number of seabird species including brown boobies, roseate terns, several other species of tern, and the lesser frigatebird, all of which are listed as marine and migratory under the EPBC Act.

Mammals

Trapping and observations from the survey support the conclusion of How et al. (2006) that there are no resident mammals on the Maret Islands, the principal focus of the survey. The only mammals likely to forage on the islands are some of the bats recorded across the archipelago during this survey: the black flying-fox (*Pteropus alecto*), the little red flying-fox (*Pteropus scapulatus*), the common sheathtail-bat (*Taphozous georgianus*), the northern cave bat (*Vespadelus caurinus*) and the ghost bat (*Macroderma gigas*).

The only other terrestrial mammal observed on the islands surveyed for the study was the Kimberley rock-rat (*Zyzomys woodwardi*), which occurs on East Montalivet Island and Prudhoe Island.

Land snails

The land snail fauna comprised a total of 15 nominal species (not all could be identified) from eight families, with between two and nine species occurring at each site. None of the snails encountered during this survey appear to be introduced species, even though the Maret Islands and the other surveyed islands have been frequently visited by tourists and traders over the years. It is also of interest that the snail fauna on Lamarck Island contains two species not encountered elsewhere in the survey area. This island is further south and closer to the mainland than the others surveyed and has elements in common with the snail fauna of the Prince Regent River Nature Reserve.

Following the completion of the survey, a genetic study was carried out on the *Amplirhagada* species. This revealed four distinct clades which correspond with three geographically separate island groups, 10 to 160 km apart. The high degree of genetic divergence among these populations is consistent with a long history of isolation. The divergence times between the main clades found in *Amplirhagada* have been calculated to date back at least 1.5 to 2 million years (Johnson, O'Brien & Fitzpatrick 2010), meaning that the snail faunas of the island groups have been reproductively isolated since long before rises in sea level separated the islands.

Earthworms

Earthworm surveys were conducted across North Maret Island, South Maret Island, Berthier Island and East Montalivet Island during the wet season in 2007, and opportunistically on Prudhoe Island and Lamarck Island in the dry season. The few specimens captured, however, were all from South Maret Island and Berthier Island. Although they were sexually immature and thus not identifiable to species level, they appear to be assignable to the genus *Diplotrema*, with each island having its own species.

Arthropods

During the terrestrial invertebrate surveys two mygalomorph spiders from the families Nemesiidae and Theraphosidae were collected from Berthier Island. The theraphosid was a single adult male of the genus *Selenocosmia* and the nemesiid was a juvenile and unidentifiable at genus level. A third mygalomorph spider was collected from East Montalivet Island; it too was a juvenile, however, and could not be identified.

Eleven genera from nine families of pseudoscorpion were collected in vine-thicket habitats from the Maret Islands, Berthier Island and Lamarck Island. Ten of the pseudoscorpions are likely to be described as new species.

One previously unknown species of terrestrial schizomid, *Bamazomus* sp. "Maret Islands", was collected on North Maret Island and South Maret Island, and two and possibly three undescribed species of troglobitic schizomid of the genera *Bamazomus* and *Trithyreus* were collected from North Maret Island and South Maret Island during the survey.

Two undescribed species of scorpion of the genera *Hormurus* and *Urodacus* were collected. Fourteen specimens of the hormurid scorpion were collected at several sites on North Maret Island, South Maret Island, Berthier Island and Lamarck Island under boulders in vine thickets on the island slopes or under boulders beneath trees on the plateau. The habitat requirements of *Urodacus* scorpions are largely unknown; however, they are more widely distributed in the arid and semiarid areas of Australia and appear to be more adapted to xeric conditions. Only two specimens were found on South Maret Island and one specimen from North Maret Island. Previously, the genus *Urodacus* was thought to be restricted to mainland Australia.

Two undescribed species of millipede were recorded from the Maret Islands, one of which was a terrestrial species collected from leaf litter. Thirty-four mostly juvenile specimens of an undescribed hypogean species of polyxenid millipede were also collected from boreholes on North Maret Island and South Maret Island, but although the species lives underground it is unlikely to be a true troglobite.

A single thysanuran was collected from a borehole on South Maret Island. The specimen was strongly troglomorphic, with no eyes, no pigment, and elongate antennae. It was identified as belonging to the family Nicoletiidae.

Faunal habitats

The habitats of greatest ecological importance on the Maret Islands, Berthier Island and East Montalivet Island are the vine thickets or the vegetation communities that contain vine-thicket elements. These communities cover not only the scree slopes of all four laterite islands and areas of Lamarck Island, but also substantial areas of the upland plateau on South Maret Island and Berthier Island. They offer a moist, sheltered habitat for both vertebrates and invertebrates and valuable foraging areas for frugivorous birds and fruit-bats.

The extensive upland vine-thicket elements on South Maret Island may also be regionally important habitat for geckos and pythons and for a number of invertebrate species. These habitats are extensive on the South Maret Island plateau but not on the North Maret Island plateau and are absent or limited in extent on the nearby sandstone islands. The grasslands and open woodlands appeared to support higher abundances of some reptile species than did adjacent vine thickets.

Amphibians

While the west Kimberley has a rich amphibian fauna, with 24 species so far recorded, few species have been recorded on islands of the Bonaparte Archipelago, presumably because most lack permanent fresh water or adequate mesic refugia. Bigge Island is an exception: four species from this island are held by the Western Australian Museum and one of these and two additional species were recorded during the July–August 2006 survey for this study.

No frogs were recorded on the Maret Islands and they are unlikely to occur there because there is no permanent fresh water and there are no wetlands.

An unidentified species of the genus *Uperoleia* was heard calling on East Montalivet Island and West Montalivet Island. Watercourses and wetlands on the Montalivet Islands, while small, are near-permanent. The watercourses on East Montalivet Island are associated with broad shields of basalt, while the wetland on West Montalivet Island lies in a soil-filled valley between sandstone ridges, but probably underlain by basalt. This wetland is artificial, and was probably created by excavation when the island had a small radio-tracking base on it during World War II.

There is also a near-permanent stream on the eastern side of Berthier Island, where basalt lies at the surface of the landscape. It is possible that the same frog may also be present at this site despite not being detected during the surveys.

No amphibians were detected on Prudhoe Island or Lamarck Island. This may have been attributable in part to the fact that the survey took place during the dry season when amphibians are less active.

Reptiles

Most of the reptile species encountered were found to occur widely across different vegetation and landform types, although where sample sizes were large some habitat preferences became apparent. For example, the very abundant *Ctenotus inornatus* occurred in almost every vegetated habitat but was more abundant in grasslands.

The grassland and woodland areas on the Maret Islands are important for reptile species such as *Ctenotus inornatus*, *Notoscincus ornatus*, *Ramphotyphlops kimberleyensis*, *Carlia triacantha* and *Pseudechis weigeli*, which were more abundant in or were restricted to the open grasslands or woodland areas on the upland plateaux.

Some species also exhibited preferences for certain substrate types; *Gehyra xenopus*, for example, was recorded only on basalt rocks. Species that were abundant and conspicuous within vine-thicket habitats on the Maret Islands included *Carlia johnstonei*, a small skink which is presumably capable of exploiting the small patches of canopy-filtered sunlight for thermoregulation.

Species that were recorded on only a few islands also tended to be infrequently caught, making it difficult to rule out their occurrence on islands where they have not been trapped. Low capture rates in each of the vegetation groups also make it difficult to draw any conclusions regarding their possible habitat associations.

Birds

Vine-thicket communities are an important component of the vegetation of the islands. The Maret Island vine thickets in particular appear to constitute a regionally significant bird habitat; this is attributable to the relatively large size and interconnectivity of the patches. The largest vine-thicket patches on the Kimberley mainland occur at Prince Regent Nature Reserve, the Mitchell Plateau and Cape Bougainville. While these patches are up 100 ha in extent, the vine-thicket communities on the mainland are mostly made up of small isolated patches less than 5 ha in extent (Price, Woinarski & Robinson 1999; Russell-Smith & Bowman 1992). The slope vine thicket on South Maret Island alone covers a nearly continuous area of approximately 70 ha.

Adjacent upland vine thickets further increase the effective size of these habitats. These large vine-thicket communities appear to provide a year-round source of fruit because of the diversity of fruiting plants they contain. This allows frugivorous bird species to thrive and remain on the islands for most if not all of the year. This contrasts with the situation on the Kimberley mainland where frugivorous birds have to travel between smaller and more isolated vine-thicket patches in search of fruit, rather than remaining year-round in one patch (Price 2004).

Those plant species that are seasonally fruiting and characteristic of the vine thickets on the Maret Islands, Berthier Island and East Montalivet Island are *Flueggea virosa* subsp. *melanthesoides*, *Vitex glabrata*, *Diospyros maritima*, *Croton habrophyllus*, *Premna acuminata*, *Pavetta muelleri*, *Celtis philippensis*, *Drypetes deplanchei*, *Sterculia quadrifida*, *Mimusops elengi*, *Grewia breviflora*, *Grewia glabra*, *Garuga floribunda* var. *floribunda*, *Ganophyllum falcatum* and *Glycosmis trifoliata*.

Earthworms

On South Maret Island earthworms have been found only on the lateritic plateau in vine thicket and in *Corymbia* and *Acacia* woodland habitats. The earthworm specimens from South Maret Island were all found within the same widely distributed soil unit. This suggests that earthworm habitat is widely distributed across South Maret Island and North Maret Island.

The specimen captured on Berthier Island in April 2007 was captured in soil under vine-thicket vegetation on a hill slope under basalt rocks.

The presence of earthworms in woodlands and vine-thicket on the lateritic plateau of South Maret Island and in vine thicket on Berthier Island has significance for the regional biodiversity of earthworms both on the mainland and on other islands in the Bonaparte Archipelago. On the Kimberley mainland, the only systematic sampling of earthworms that has been carried out was on remnant vine-thicket patches in 1988 and 1989 (McKenzie & Dyne 1991). These authors suggested that although each of the 11 widely separated vine-thicket patches that they sampled (out of a total of 15) had its own, apparently unique, species of *Diplotrema*, this did not necessarily mean that most of the hundreds of other vine-thicket patches in the Kimberley would also have their own unique species. Gene flow, for example, could still occur between discrete vine-thicket patches within the same drainage system or along the same watercourse and so several patches could share the same species.

Gene flow between the earthworm populations on neighbouring islands of the Bonaparte Archipelago is a far less plausible scenario, however, and the *Diplotrema* earthworms of the Maret Islands are likely to be of a different species from those of Berthier Island and from those of the nearest population on the Kimberley mainland.

Arthropods

The pseudoscorpions reported on here were found in three principal habitat types: along the shoreline in the intertidal zone, under the bark of trees, or in especially the leaf litter of the vine thickets. While all of these habitats are widespread on the Maret Islands, the vine-thicket patches, at least on North Maret Island, are fragmented and disjunct. It is therefore likely that the several species of pseudoscorpion that were found on the Maret Islands during this study are short-range endemic species.

Spiders from two mygalomorph families, the Theraphosidae and the Nemesiidae, were recorded during the surveys. The theraphosid was captured in open *Corymbia* woodland with *Grevillea* and *Acacia* shrubs, vine thicket and low grasses on a lateritic substrate on top of Berthier Island. The nemesiid was captured in slope vine-thicket vegetation over basalt rocks, also on Berthier Island.

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Troglofauna

5

Garth Humphreys

Humphreys, G. 2014. Troglofauna. pp. 187–201 in Comrie-Greig, J. and Abdo, L.J. (eds), *Ecological studies of the Bonaparte Archipelago and Browse Basin*. INPEX Operations Australia Pty Ltd, Perth, Western Australia.

ABSTRACT

This chapter presents the results of a survey carried out on the subterranean fauna of the Maret Islands in the Bonaparte Archipelago in north-western Australia in 2007 and 2008.

Seven boreholes were drilled on North Maret Island and seven on South Maret Island, primarily for geotechnical purposes in support of a proposal (later abandoned) to establish onshore infrastructure for a liquefied natural gas project on the islands.

The heavy-duty polyvinyl chloride casings used in the boreholes by the hydrogeologists were modified to facilitate their use in the sampling of subterranean fauna by cutting slots for troglobite access at regular intervals along their lengths.

No stygobites were collected from any of the boreholes sampled. This appears to be attributable to a lack of suitable stygobite habitat. The below-watertable geology of the islands is made up of a saprolitic clay layer which has low transmissivity and lacks the interstitial spaces which characterise stygobite habitat.

The troglofauna survey yielded a total of 17 063 invertebrate specimens, representing 20 higher-order taxonomic groups. The great majority of these specimens were surface or soil invertebrates that were not troglomorphic. However, a total of 50 troglobitic and potentially troglobitic specimens were collected, representing three invertebrate orders (Schizomida, Thysanura and Polyxenida).

Fifteen troglobitic schizomid specimens were collected during the study from five sample sites, five individuals from North Maret Island and ten from South Maret Island. Fourteen of these were of the genus *Bamazomus* and DNA data suggest the presence of at least two clades which are potentially equivalent to two undescribed species. A single specimen from South Maret Island was identified as belonging to another undescribed species which is referable to the genus *Trithyreus*.

A single thysanuran was collected from South Maret Island. It was strongly troglomorphic, with no eyes, a complete loss of pigment, and elongate antennae. The specimen was identified as a currently undescribed species of the family Nicoletiidae.

A total of 34 polyxenid millipede specimens were collected from the two islands. This is a taxonomically poorly defined group and the majority of the collected specimens were juvenile. As a result, identification to species level was not possible. The specimens collected from the islands lack eyes and have diminished pigment, both troglomorphic characteristics. However, recent molecular analyses have demonstrated that subterranean polyxenid millipedes show little evidence of short-range endemism at regional scales, and are therefore unlikely to be true troglobites. However, until further molecular analyses are carried out, this new species from the Maret Islands has been conservatively treated as a troglobite.

INTRODUCTION

This chapter presents the methodology and results of a subterranean fauna survey conducted on the Maret Islands in the Bonaparte Archipelago in the Kimberley region of Western Australia in 2007 and 2008. It is based on an unpublished report by environmental consultants Biota Environmental Sciences Pty Ltd (Biota 2009).

The studies were carried out to provide baseline environmental data for a proposal by INPEX Browse, Ltd. to establish an onshore natural-gas processing plant on the Maret Islands as part of its Ichthys Gas Field Development Project. However, in 2008 INPEX selected Darwin in the Northern Territory as the preferred site for the plant and INPEX now has no plans to develop the Maret Islands for industrial use.

The purpose of the study was to determine if the geology of the Maret Islands provided habitat for subterranean animal life and, if so, whether any taxa found would prove to be endemic to the islands and thus at risk of extinction if any development should be permitted to take place.

Two broad categories of animals are generally considered to make up the true (obligate) subterranean fauna:

- **Stygofauna**: the obligate groundwater-dwelling aquatic animals of a region taken collectively; individuals or species are known as stygobites.
- **Troglofauna**: the obligate cave- or karst-dwelling subterranean animals of a region taken collectively; individuals or species are known as troglobites.

Stygobites inhabit groundwater, sometimes occurring close to the surface. They are highly specialised obligate dwellers in subterranean groundwater habitats (Humphreys 2000). They are known to be present in a variety of rock types including karst (limestones), fissured rock (e.g. granite) and porous rock (e.g. alluvium) (Marmonier et al. 1993).

Stygal animals known from Western Australia include a range of crustaceans (often the most abundant and diverse), platyhelminths, oligochaete worms, mites and beetles (Eberhard, Halse & Humphreys 2005; Humphreys 1999; Watts & Humphreys 1999).

Troglobites occur in the strata between the superficial soil layer and the water table, where suitable habitat space is available. Troglobitic animals have been collected primarily from karstic limestone systems in northern Western Australia: at Cape Range near Exmouth, on Barrow Island off the Pilbara coast, and in the Kimberley region (Biota 2002, 2005, 2011; Harvey 1988; Humphreys 2002). Survey work in the Robe River area in the Pilbara region, however, has also yielded troglobites from strata with vugs and small-scale cavities in pisolitic mesa formations (Biota 2006, 2007, 2010). Troglobites have also since been recorded from a variety of other rock types in the Kimberley and Pilbara regions, including sandstone, calcrete and the Brockman Iron Formation, all of which have subterranean habitat space.

Troglobitic species commonly have restricted distributions and, as a result, short-range endemism (sensu Harvey 2002) is common in this fauna. In the arid zone, the troglobitic fauna is generally considered to be a relictual rainforest litter fauna, having arisen from tropical lineages that descended into subterranean environments during the aridification of Australia in the late Miocene (Humphreys 1993). This is inferred from the affinities of the taxonomic groups represented amongst the troglofauna with other extant taxa of the same groups in tropical climates. These groups include the Schizomida, Pseudoscorpiones, Araneae, Scolopendrida, Polydesmida, Diplura, Thysanura, Coleoptera and Blattodea (Biota 2006; Humphreys 2002).

METHODOLOGY

Troglofauna

Sampling effort

Fourteen boreholes were drilled in the study area primarily for hydrogeological and geotechnical purposes (RPS 2007), seven on North Maret Island and seven on South Maret Island (see tables 5-1 and 5-2). By agreement with the hydrogeological and geotechnical surveyors, the heavy-duty polyvinyl chloride (PVC) casings for the boreholes were modified to facilitate their use in the sampling of subterranean fauna by cutting slots for troglobite access at regular intervals along their lengths.

Four additional sampling sites were also located opportunistically in eroded areas on the margins of the islands, two on each island. All four were natural fractures and holes: OPP1 and OPP2 on South Maret Island and OPP3 and OPP4 on North Maret Island. The 14 geotechnical boreholes were able to be sampled for troglobites and with the opportunistically discovered fractures and holes there was a total of 18 sampling sites. The distribution of the sampling sites is shown in Figure 5-1.

Table 5-1: Troglofauna sampling locations on the Maret Islands (coordinates relative to GDA94, MGA zone 51)

Location	Site	Easting	Northing	Date drilled	Depth below ground level (m)	Notes
North Maret Island	BH01	712418	8407543	07-08-2007	10.0	Blocked at ~5 m
	BH02	712966	8408169	04-08-2007	10.0	Blocked at ~8 m
	BH03	712945	8407734	02-08-2007	30.0	–
	BH04	713682	8407642	09-08-2007	10.0	Groundwater at ~10 m
	BH05	713316	8406716	13-08-2007	10.0	Groundwater at ~8 m
	BH06	712893	8405822	14-08-2007	10.0	Groundwater at ~12 m
	BH07	713574	8405223	15-08-2007	10.0	–
	OPP3	713224	8408188	–	<5.0	–
	OPP4	713565	8407778	–	<5.0	–
South Maret Island	BH08	713975	8402097	03-09-2007	61.5	–
	BH09	713669	8402328	09-09-2007	56.0	–
	BH11	714140	8403010	16-10-2007	35.0	–
	BH12	714378	8402324	04-10-2007	48.2	–
	BH13	714536	8402798	27-09-2007	46.9	–
	BH14	713920	8402759	10-10-2007	54.0	–
	BH15	713013	8403318	18-09-2007	51.2	–
	OPP1	712999	8403392	–	<5.0	–
	OPP2	713056	8403406	–	<5.0	–

Table 5-2: Construction details of sampled boreholes

Hole designation	Slotted top and gravel-filled annulus	Slotted bottom	Metal cover	Top cap	Bottom cap	Cement top	Notes	Installation type
BH01	6 m	1 m	No	Yes	Yes	No	–	PVC casing only
BH02	5 m	1 m	No	Yes	Yes	Yes	Unable to case bottom 1 m because of cave-in	PVC casing only
BH03	8 m	1 m	No	Yes	Yes	No	–	PVC casing only
BH04	4.5 m	1 m	No	Yes	Yes	Yes	Unable to case bottom 1.5 m because of cave-in	PVC casing only
BH05	5 m	1 m	No	Yes	Yes	Yes	Unable to case bottom 1 m because of cave-in	PVC casing only
BH06	7 m	–	No	Yes	Yes	No	–	PVC casing only
BH07	8 m	2 m	Yes	No	Yes	Yes	–	Monitoring of groundwater at laterite boundary
BH08	4.5 m	2 m	No	Yes	No	Yes	–	Unknown
BH09	8.5 m	2 m	No	Yes	No	Yes	–	Unknown
BH11	8 m	2 m	Yes	No	Yes	Yes	Hole bridged during annulus fill; PVC fully installed	Groundwater monitoring only
BH12	9 m	–	Yes	No	Yes	Yes	Bottom 6 m not cased owing to buoyancy of PVC, because PVC not slotted at bottom	Monitoring of groundwater at laterite boundary
BH13	5 m	2 m	No	Yes	Yes	Yes	–	Unknown
BH14	8 m	4 m	Yes	No	Yes	Yes	–	Groundwater monitoring piezometer
BH15	8 m	4 m	Yes	No	Yes	Yes	–	Groundwater monitoring piezometer

Sampling for troglobitic fauna was conducted over three phases during 2007 and 2008 (Table 5-3). The number of traps that could be installed was limited by both the number of boreholes available and the condition of the holes. In total, 99 traps were installed over the three survey phases, with sampling effort roughly equivalent between the islands.

Table 5-3: Troglofauna sampling effort and phases on the Maret Islands

Phase	Date recovered	Location	Sample sites	Subtotal of traps	Total number of traps
1	06-02-2008	North Maret Island	BH01–BH07	14	29
		South Maret Island	BH08–BH09, BH11–BH15	15	
2	14-04-2008	North Maret Island	BH01–BH07, OPP3, OPP4	16	35
		South Maret Island	BH08–BH09, BH11–BH15, OPP1, OPP2	19	
3	06-08-2008	North Maret Island	BH01–BH07, OPP3, OPP4	16	35
		South Maret Island	BH08–BH09, BH11–BH15, OPP1, OPP2	19	

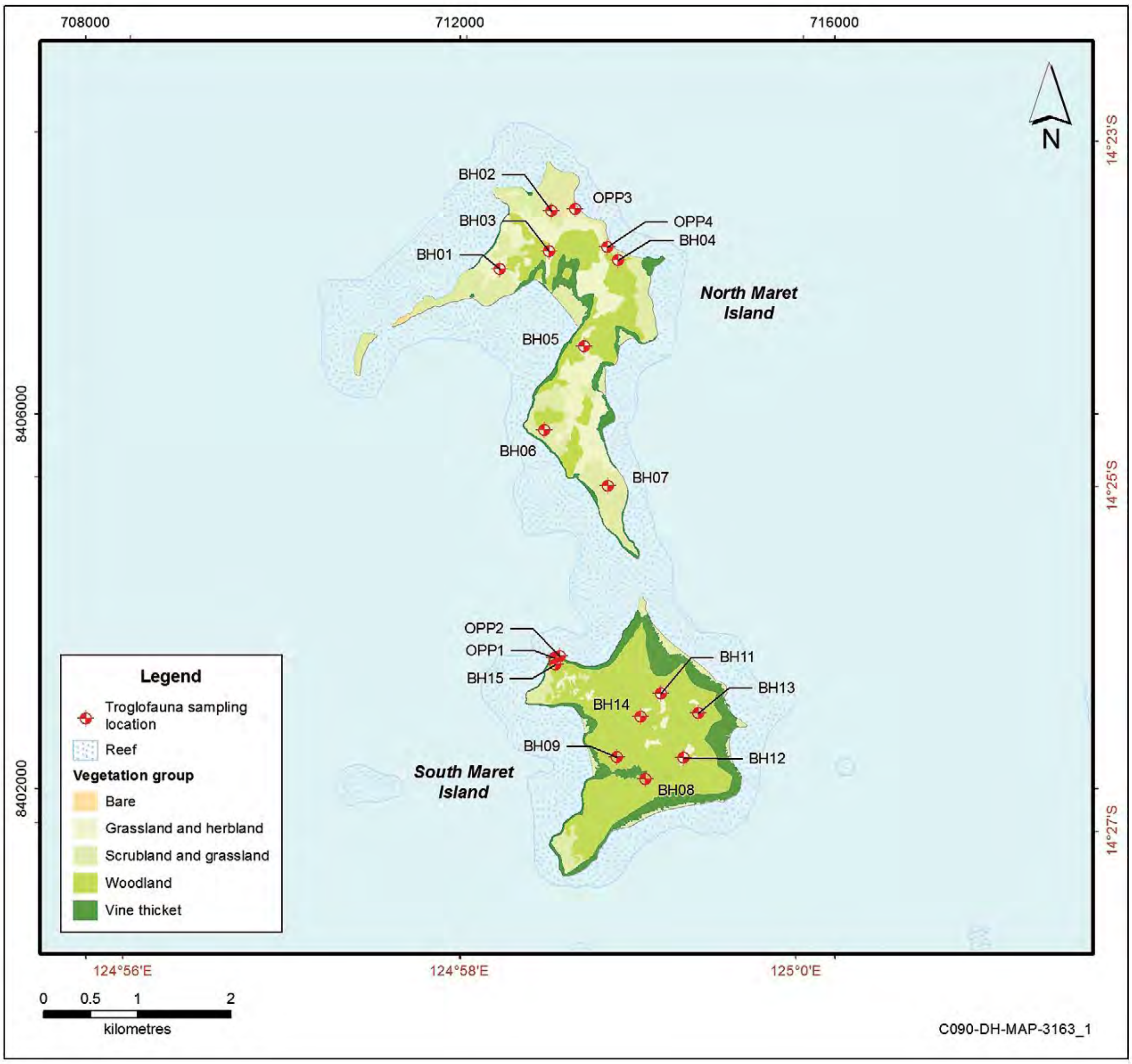

Figure 5-1: Locations of the 14 boreholes ("BH" labels) and 4 natural fractures ("OPP" labels) on the Maret Islands used for sampling for troglofauna

Sampling methods

The troglofauna was sampled by means of custom-built litter traps suspended inside the boreholes. Drill logs were reviewed to identify areas where fracture zones or cavities occurred in the profile. Traps were suspended in each hole sampled, and arranged to align with these potentially more prospective zones.

The traps were constructed from PVC irrigation pipe of 50 mm internal diameter, cut to a length of 180 mm. Each trap had a series of 20 mm holes drilled in the side and was left open at the upper end. They were installed in such a way that they were in contact with the interior of the sampled borehole once in place.

Leaf-litter material was gathered locally from the ground surface. The collected litter was soaked in water and irradiated in a microwave oven on maximum power setting to kill any surface invertebrates present and to assist in breakdown.

The wet litter was added to the traps and kept in sealed plastic bags until immediately prior to insertion into the boreholes. The traps were left in the ground for a minimum period of six weeks to allow sufficient time for colonisation by any troglobites present. The traps were then recovered and stored in zip-locked plastic bags for return to a laboratory in Perth, Western Australia, for sorting.

Specimen sorting, curation and data management

Animal specimens were recovered from the traps using specially designed Tullgren funnel units. Leaf litter from each trap was placed in a sieve over which an aluminium lamp containing a 25 W bulb was directed. This created a temperature of approximately 30 °C at the leaf-litter surface. A funnel was positioned below the sieve and a collecting vessel containing 100% ethanol was attached to it. Leaf litter was left to dry in the sieves for a period of 24 hours.

Animal specimens collected through the funnels were identified in Perth to ordinal or family level using dissecting microscopes (Olympus SZ40 and SZ61). Each specimen collected was assigned a unique number based on borehole location and then tracked using customised data sheets. Specimens were preserved in 100% ethanol to allow for DNA analyses.

Stygofauna

Stygofauna sampling effort and techniques

Stygofauna sampling at the Maret Islands followed a similar format to other stygofauna sampling projects undertaken previously in Western Australia for various environmental impact assessment projects. The methodologies and approach were consistent with those outlined in Western Australia's Environmental Protection Authority (EPA) guidance statements 54 (EPA 2003) and 54a (EPA 2007).

Boreholes were sampled only on South Maret Island during this study, as preliminary hydrogeological work had indicated that the boreholes on North Maret Island were all either dry or contained only a very small amount of groundwater (Carl Davies, Principal Hydrogeologist, RPS, Perth, Western Australia, pers. comm. 2007). Seven boreholes on South Maret Island were therefore sampled for stygofauna during a single survey phase in February 2008.

Groundwater sampling was undertaken using modified plankton haul nets. These sampling nets are constructed from 70 µm plankton mesh, with a 50 mm aperture attached to a weighted catch jar. Each borehole was dragged a minimum of five times. On the final haul, the net was agitated gently, which acts to stir the benthos layer for more effective specimen-collecting. On the surface, the net was flushed thoroughly with water and the resulting sample placed in a marked container and into a shaded insulated container (an "Esky") for storage before sorting.

After the sampling of a borehole, the nets were thoroughly rinsed with water and, where possible, left to dry before being used in another hole. This was done to prevent possible cross-contamination between aquifers and boreholes.

Molecular analysis

Objectives

DNA analysis was carried out only for the collected schizomid specimens, as this group has an existing phylogenetic framework and sufficient individuals had been collected to allow a meaningful analysis of the Maret Islands subterranean fauna. As terrestrial surface-dwelling schizomids had also been collected from both islands by staff of the Western Australian Museum, molecular analysis was also used as a tool to compare the surface forms with the subterranean forms.

DNA extraction

DNA was extracted from the schizomid specimens using a simple Qiagen DNeasy kit following the prescribed protocol, with the exception of the final elution of extracted DNA in a volume of 60 µL. DNA was extracted from several legs or from whole specimens depending upon the size of the specimen.

Polymerase chain reaction

The polymerase chain reaction (PCR) procedure was used to amplify the cytochrome oxidase *c* subunit one (COI) mitochondrial gene. This gene was chosen because of the known useful levels of variability of this region in many other phylogenetic investigations, and its reliability for inferring phylogenetic information (Biota 2005, 2006; Bond 2004; Bond & Sierwald 2003; Farrell 2001; Hart & Podolsky 2005; Hebert et al. 2003; Hebert et al. 2004; Holland & Hadfield 2002; Kojima et al. 1995; Paquin & Hedin 2004; Steinke, Albrecht & Pfenninger 2004; Stothard et al. 2002). The gene has also been found to be reliable for "DNA barcoding" (Hebert et al. 2003).

The PCR amplification of the double-stranded DNA product was performed using a PTC-200 Peltier thermal cycler. Successful reactions for the COI gene involved an initial denaturation at 94 °C for 2 minutes. The reaction was then cycled through denaturation at 94 °C for 30 seconds, followed by annealing at 48 °C for 20 seconds and then elongation at 74 °C for 15 seconds. These steps were repeated for 35 cycles, followed by a final elongation at 72 °C for 2 minutes.

For each PCR reaction, positive and negative controls were used. The positive control (the standard) consisted of the same PCR mix with extracted schizomid DNA that had previously been shown to work with the primers. This control was used to test that PCR conditions were correct. If the positive control did not produce a band of the desired size, then a problem with the PCR conditions was apparent. Alternatively, if the positive control did produce a band of the correct size, and no band was produced for the desired species, then there was a problem with the DNA template. The negative control (the blank) consisted of the same mixture of chemicals, except that distilled water (dH_2O) replaced the DNA template. This control was used to ensure that there was no contamination in the dH_2O used in the reactions.

PCR products were run on a 1% agarose gel in 0.5× TBE buffer using a constant voltage of 100 V (400 mA) for 20 minutes. The gels were then treated with Sybr Safe DNA gel stain for approximately 40 minutes. After staining, the gel was exposed to ultraviolet light and photographed in order to visualise the PCR products. Photographs were viewed using AlphaDigiDoc.

The PCR products were verified against an appropriately sized marker, a GeneRuler 100 bp Plus DNA Ladder. The blank and the standard were also run out on the gel to check for contaminants and to verify that PCR conditions were stable. The PCR products were then purified using an UltraClean PCR clean-up DNA purification kit (from MO BIO Laboratories Inc.). PCR products were sequenced using ABI BigDye chemistry by the Macrogen Inc. facility.

Sequence editing and analysis

Sequences were checked and edited and chromatograms were visualised using Gene Codes Corporation's Sequencher software. Sequences were then aligned using ClustalW and gaps were adjusted by eye.

Phylogenetic and molecular evolutionary analyses were conducted using the molecular evolutionary genetics analysis tool MEGA version 3.1 (Kumar, Tamura & Nei 2004). Kimura's two-parameter model of genetic distance was used to generate a distance matrix in this program (Kimura 1980; Kumar, Tamura & Nei 2004). The model accounts for the difference in the ratio of transitions to transversions. A transition is the substitution of a purine for another purine or the substitution of a pyrimidine for another pyrimidine. Transversions are all other types of nucleotide substitutions. In most DNA segments, transitional nucleotide substitutions are known to occur more frequently than transversions (Forstner, Davis & Arévalo 1995; Nei & Kumar 2000).

A "neighbour-joining tree" was constructed using all individuals in MEGA version 3.1 (Kumar, Tamura & Nei 2004). A "bootstrap" routine with 100 pseudo-replicates was performed to determine the internal support for the individual nodes. Samples sequenced in this study were analysed together with previously sequenced schizomids from the Pilbara (Berry 2005; Biota 2006), thus providing context for the observed levels of sequence divergence of the Maret Islands specimens.

Limitations

The field sampling completed for this study was also subject to limitations, principally in relation to the boreholes available for the survey. There were, for example, some concerns with the adequacy of the gravel-pack installation in some holes. This might have resulted in air spaces occurring in the annulus of some boreholes, potentially limiting the ability for any troglobites that might have been present to access the interior of the casing where the traps were situated. Although attempts were made to remedy this situation prior to the field survey, the extent to which these issues might have ultimately affected the results of the pilot study is not clear.

The logistic difficulties associated with drilling on the Maret Islands meant that relatively few boreholes were available for the survey. Several of these subsequently became blocked, further reducing the number of sample points. The remaining affected boreholes were blocked at deeper points and sampling of at least the upper strata of potential habitat was still possible. This has probably limited the adequacy of the sampling of the troglofauna of the islands.

RESULTS

Stygofauna

No stygobites were collected from any of the boreholes sampled on South Maret Island. The boreholes on North Maret Island were not sampled as preliminary hydrogeological work had indicated that the boreholes there were all either dry or contained only a very small amount of groundwater.

Troglofauna

The three-phase troglofauna survey yielded a total of 17 063 invertebrate specimens, representing 20 higher-order taxonomic groups. The great majority of these specimens were surface or soil invertebrates that were not troglomorphic.

Reviews and identification of troglobitic groups have previously been carried out as part of studies carried out at Mesa A (an iron-ore minesite in the Pilbara region of north-western Western Australia) and for other related programs (Biota 2006, 2007). This identification work was completed in collaboration with the Western Australian Museum and it distinguished groups that may be troglobitic (and therefore potentially restricted in geographical range) from deep-soil and surface animals. This framework was used as the basis for specific examination of the Maret Islands fauna to identify a total of 50 troglobitic and potentially troglobitic specimens, representing three orders across the three sampling phases (tables 5-4 and 5-5). Eight specimens were collected from North Maret Island and 42 specimens were collected from South Maret Island.

Table 5-4: Summary of the distribution and abundance of troglobitic and potentially troglobitic specimens recorded from the Maret Islands

Island	Borehole	Troglobitic and potentially troglobitic taxa*			Borehole totals
		Polyxenida	Schizomida	Thysanura	
North Maret Island	BH02	1	–	–	1
	BH03	1	–	–	1
	BH04	–	2	–	2
	BH07	1	3	–	4
South Maret Island	BH08	26	–	–	26
	BH09	–	2	–	2
	BH13	–	2	1	3
	BH15	–	6	–	6
	OPP1	5	–	–	5
	Total	**34**	**15**	**1**	**50**

* It is pointed out below that recent molecular analyses of subterranean polyxenid millipedes have shown little evidence of short-range endemism at regional scales. It is therefore unlikely that the Maret Islands polyxenids are true troglobites. However, as no sequencing has yet been carried out on these specimens, the conservative position, that they are potentially troglobitic, is still maintained in this chapter.

Detailed records of the troglobitic and potentially troglobitic specimens collected during the survey are summarised in Table 5-5.

Table 5-5: Detailed records of all troglobitic and potentially troglobitic specimens collected during the survey

Phase	Date	Site	Sample identification number	Higher-order taxonomic group	No. of specimens	Litter condition	Notes
1	06-02-2008	BH03	BH3P1T2-2	Polyxenida	1	Dry	–
1	06-02-2008	BH07	BH7P1T2-3	Polyxenida	1	Damp	–
1	06-02-2008	BH15	BH15P1T2-3	Schizomida	2	Damp	–
2	14-05-2008	BH07	BH7P2T1-2	Schizomida	2	Wet	Juveniles
2	15-05-2008	BH08	BH8P2T1-5	Polyxenida	13	Moist	–
2	15-05-2008	BH08	BH8P2T2-4	Polyxenida	2	Wet	–
2	15-05-2008	BH09	BH9P2T1-3	Schizomida	1	Moist	Juvenile
2	15-05-2008	BH13	BH13P2T1-3	Thysanura	1	Moist	–
2	15-05-2008	BH15	BH15P2T1-1	Schizomida	3	Moist	–
3	06-08-2008	BH09	BH09P3T1-1	Schizomida	1	Wet	–
3	06-08-2008	BH15	BH15P3T2-1	Schizomida	1	Wet	–
3	06-08-2008	OPP1	BHOPP1P3T1-2	Polyxenida	5	Dry	–
3	06-08-2008	BH13	BH13P3T1-1	Schizomida	2	Moist	–
3	06-08-2008	BH08	BH08P3T1-5	Polyxenida	1	Moist	–
3	06-08-2008	BH08	BH08P3T2-1	Polyxenida	10	Moist	–
3	06-08-2008	BH07	BH07P3T1-1	Schizomida	1	Wet	–
3	06-08-2008	BH02	BH02P3T1-3	Polyxenida	1	Moist	–
3	06-08-2008	BH04	BH04P3T1-2	Schizomida	1	Wet	–
3	06-08-2008	BH04	BH04P3T2-2	Schizomida	1	Wet	–

No further consideration is given here to the remainder of the specimens collected, as most clearly represented epigean (surface) forms. At the time of the surveys, the polyxenid millipedes were considered to be of uncertain troglobitic status and had been conservatively treated as troglobitic in contemporaneous assessments (Biota 2007, 2010). More recent molecular analyses have demonstrated that subterranean polyxenid millipedes show little evidence of short-range endemism at regional scales, and are therefore unlikely to be true troglobites (Biota & Helix 2012). Nevertheless, until sequencing has been carried out on the Maret Islands specimens, they must be considered to be potentially troglobitic.

The collection sites for the confirmed troglobites (the schizomids and the thysanuran) were boreholes BH04, BH07, BH09, BH13 and BH15 and the collection sites for the potential troglobites (the polyxenids) were boreholes BH02, BH03, BH07, BH08 and OPP1.

Account of the troglobitic and potentially troglobitic fauna

A summary of the troglobitic fauna identifications completed as part of this study is provided for higher-order taxonomic groups below. As noted above, only those taxonomic groups that contained troglobitic or potentially troglobitic specimens have been considered in detail.

Order Schizomida (schizomids)

Schizomids are fast-moving predatory arachnids that mostly live in tropical climates (Harvey 2000). They superficially resemble spiders but have a tail-like structure at the end of the abdomen (the flagellum) and long sensory front legs (Harvey & Yen 1989) (Figure 5-2). At the time of this study there were 53 species of schizomids described from Australia, all of which belong to a single family, the Hubbardiidae (Harvey 1992, 2001).

Fifteen troglobitic schizomid specimens were collected during the study from five sample sites: five individuals from North Maret Island and ten from South Maret Island (Table 5-4). The distribution of these records suggests that schizomids are widespread throughout the sampling areas on both islands.

Most of the mature specimens collected were identified from morphological examination as belonging to at least one undescribed species of the genus *Bamazomus* (Schizomida: Hubbardiidae). Two morphologically distinct forms were collected from the islands; the differences in flagellum structure at the end of the abdomen are visible from figures 5-2 and 5-3. As discussed below, molecular analysis of DNA samples from the collected material indicates that three distinct clades may be distinguished on the two islands, possibly justifying subdivision at species level.

The schizomid DNA data indicate the presence of two *Bamazomus* clades in sympatry on South Maret Island. One of those clades is more closely related to the clade from North Maret Island than to the other clade from South Maret Island. There is a 3.8% sequence divergence between the two South Maret Island clades, only a 2% divergence between the northern and southern clades that are closely related, and a 3.5% divergence between the northern and southern clades that are more distantly related. A neighbour-joining tree for schizomids collected from the Maret Islands is presented in Figure 5-4, showing their relationships with other regional collections; the blue and green labels represent North Maret Island and South Maret Island collections respectively, while the scale bar indicates the degree of genetic divergence.

Figure 5-2: Schizomid (genus *Bamazomus*) collected from borehole BH7 on North Maret Island

Figure 5-3: Schizomid (genus *Bamazomus*) collected from borehole BH15 on South Maret Island

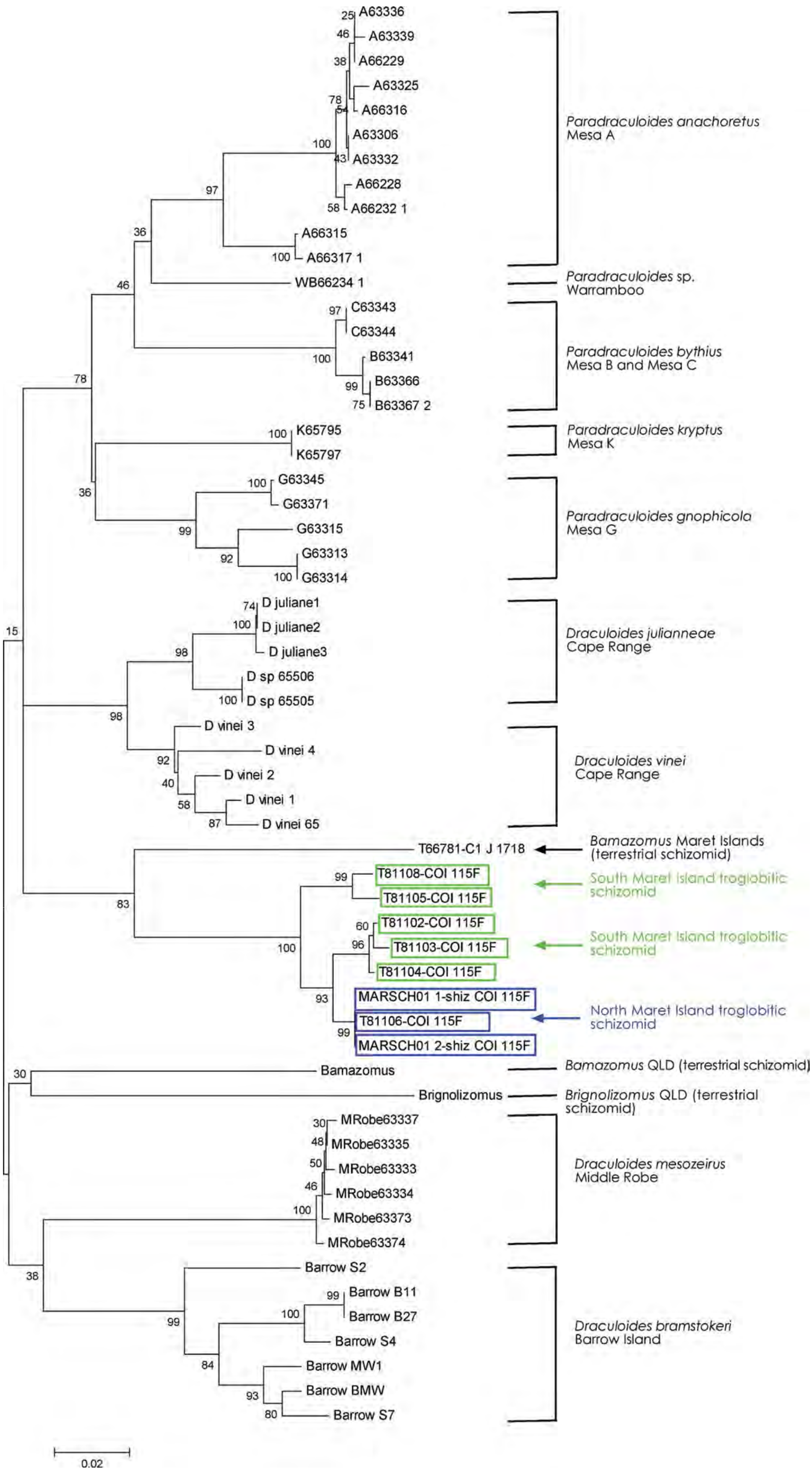

Figure 5-4: Neighbour-joining tree for schizomids collected from the Maret Islands showing their relationships with other regional collections

The troglobitic schizomids of the genus *Bamazomus* collected on the Maret Islands appear to be more closely related to the terrestrial schizomid from the Maret Islands collected by staff of the Western Australian Museum[1] than to other troglobitic schizomids from Cape Range, Barrow Island, and the Mesa and Robe Valley areas in the Pilbara region. However, the divergence between the terrestrial and troglobitic schizomids from the Maret Islands is around 14%, indicating clearly that they are different taxa and that the subterranean specimens were not epigean individuals that had fallen into the boreholes.

These DNA data suggest the presence of at least two clades of troglobitic schizomids on the Maret Islands that are potentially equivalent to two undescribed species. The level of divergence is not, however, as substantial as that observed between described species of troglobitic schizomids from mesa landforms in the Robe Valley in the Pilbara region of Western Australia, where populations from each of the mesas examined exhibited unique and highly divergent mtDNA lineages (Harvey et al. 2008). Further surveys and mtDNA analyses would be required to clarify the schizomid diversity in the Maret Islands, and to put it into context with regional patterns of genetic diversity.

The data strongly suggest a genetic division between the North Maret Island and South Maret Island schizomid populations, although this may not warrant taxonomic distinction.

A single specimen from borehole BH15 was identified by Dr Mark Harvey of the Western Australian Museum as belonging to a second undescribed species which is referable to the genus *Trithyreus*. This is the first record of this genus in Australia, the closest previous records having been from South-East Asia (Dr Mark Harvey, Head of the Department of Terrestrial Zoology, Western Australian Museum, pers. comm. 2008). Borehole BH15 on South Maret Island has therefore yielded the only known specimen of the species *Trithyreus* sp. nov. 1.

Order Thysanura (silverfish)

A single thysanuran was collected from borehole BH13 on South Maret Island during the second phase of sampling. The specimen was strongly troglomorphic; it had no eyes, no pigment, and elongate antennae. The specimen was identified as belonging to the family Nicoletiidae, which has previously been collected in the Pilbara region of Western Australia (Biota 2006).

The single specimen of Nicoletiidae sp. nov. 1 from South Maret Island is sufficiently morphologically divergent from the Pilbara specimens that it appears to be another undescribed species.

Figure 5-5: Troglobitic thysanuran collected from borehole BH13 on South Maret Island

Order Polyxenida (pincushion millipedes)

Pincushion millipedes are a primitive diplopod group, seldom achieving a length of 5 mm (Harvey & Yen 1989). A total of 34 polyxenid millipede specimens were collected from three sites on North Maret Island (BH02, BH03 and BH07) and from two on South Maret Island (BH08 and OPP1) during the survey. This is a taxonomically poorly defined group and the majority of the collected specimens were juvenile. As a result, identification to species level was not possible.

The specimens collected from the islands lack eyes and have less pigment than epigean forms, both troglobitic characteristics. However, there is some uncertainty as to whether this group is truly troglobitic. It is possible that the Maret Islands species is instead edaphobitic (a deep-soil inhabitant) or troglophilic (a facultative troglobite). This is perhaps borne out by the record of polyxenids from site OPP1 on South Maret Island, which was relatively shallow and exposed to the surface.

As noted earlier, molecular analyses have demonstrated that subterranean polyxenid millipedes show little evidence of short-range endemism at regional scales, and are therefore unlikely to be true troglobites. Molecular analysis is needed to better determine the level of genetic divergence between surface and subterranean populations of this taxon. Until this is complete, this new species from the Maret Islands, designated as Polyxenida sp. nov. 1, has been conservatively treated here as a troglobite.

[1] *Bamazomus* sp. "Maret Islands" held in the Western Australian Museum, Perth, Western Australia.

DISCUSSION AND CONCLUSIONS

Summary of findings

The survey work on the Maret Islands yielded no stygobites. This appears to be attributable to a lack of suitable stygobite habitat. The below-watertable geology of the islands is made up of a saprolitic clay layer, which has low transmissivity and lacks the interstitial spaces which characterise stygobite habitat (Carl Davies, Principal Hydrogeologist, RPS, pers. comm. 2007). As previously noted, only the boreholes on South Maret Island were sampled as hydrogeological work had indicated that the boreholes on North Maret Island were all either dry or contained only a very small amount of groundwater.

The surveys, however, did document the presence of several troglobitic taxa on the Maret Islands.

None of the troglobitic taxa collected from the Maret Islands appear to belong to currently described troglobite species and it is likely that they all represent new species. This is not surprising given the lack of sampling for troglobites on offshore islands in the region and the geographical separation of the Maret Islands from the mainland and other islands.

Given the geographical barriers to genetic interchange between troglobitic communities on adjacent islands of the Bonaparte Archipelago, it is possible that each island with suitable subterranean habitat supports a unique troglofauna.

While two of the taxa, *Trithyreus* sp. nov. 1 and Nicoletiidae sp. nov. 1, are currently only known from single collection locations on South Maret Island (Table 5-6), there is likely to be a wider troglobitic community on the islands that is yet to be fully documented.

Potential distribution of troglobites and habitat extent on the Maret Islands

The findings of this study, taken together with geological information collected by RPS (2007), indicate that the recorded troglofauna is probably associated with the ironstone conglomerate stratum that occurs on both North Maret Island and South Maret Island. This geological unit is weathered and vuggy and extends to a depth of approximately 10 m, while the units underlying it are dominated by stiff and sandy clays down to the water table, with minimal habitat space for troglobites.

The extent of potential troglofauna habitat can be inferred from borehole geological information (Figure 5-6). Geological bore logs from the 14 boreholes drilled over the two islands indicated that the ironstone conglomerate stratum occurs across the islands but appears to be relatively superficial (down to around 10 m below ground level). The widespread occurrence of troglofauna in sampling boreholes across the islands suggests that troglobitic habitat occurs across the greater part of both of the Maret Islands (Table 5-4).

The molecular data for the schizomids indicate that there may be two or three discrete species amongst the specimens collected from the Maret Islands. However, the COI sequence divergence of 3–4% between clades is perhaps not sufficient to warrant separation at species level.

The prevailing model is that troglobitic ecosystems are driven by surface inputs of water, nutrients, and energy (Biota 2006; Humphreys 1991). It is possible that the distributions of some species will be more localised within each island, reflecting small-scale habitat heterogeneity relating to patchiness in surface inputs. The genetic distance between the two schizomid clades on South Maret Island (Figure 5-4) may reflect genetic isolation between troglobitic communities in different habitat patches on this island.

Table 5-6: Distribution of confirmed and potential troglobites from the Maret Islands

Taxon	Island	Sites	Number of specimens
Schizomida			
Bamazomus sp. nov. 1*	North	BH04, BH07	5
	South	BH09, BH13, BH15	9
Trithyreus sp. nov. 1	South	BH15	1
Thysanura			
Nicoletiidae sp. nov. 1	South	BH13	1
Polyxenida			
Polyxenida sp. nov. 1	North	BH02, BH03, BH07	3
	South	BH08, OPP1	31

* Molecular data indicate that three different *Bamazomus* clades are present on the two islands, so further division of this taxon may be warranted.

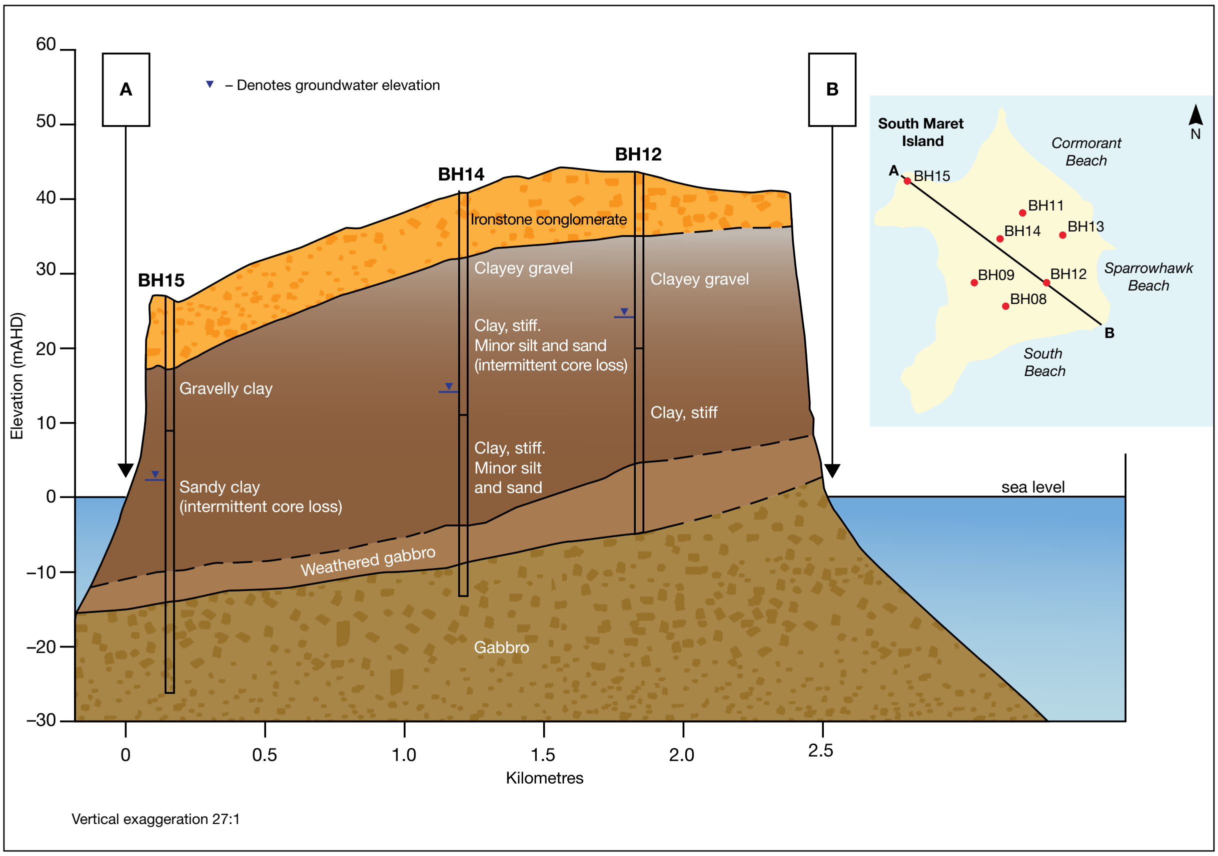

Figure 5-6: Geological cross-section of South Maret Island (RPS 2007)

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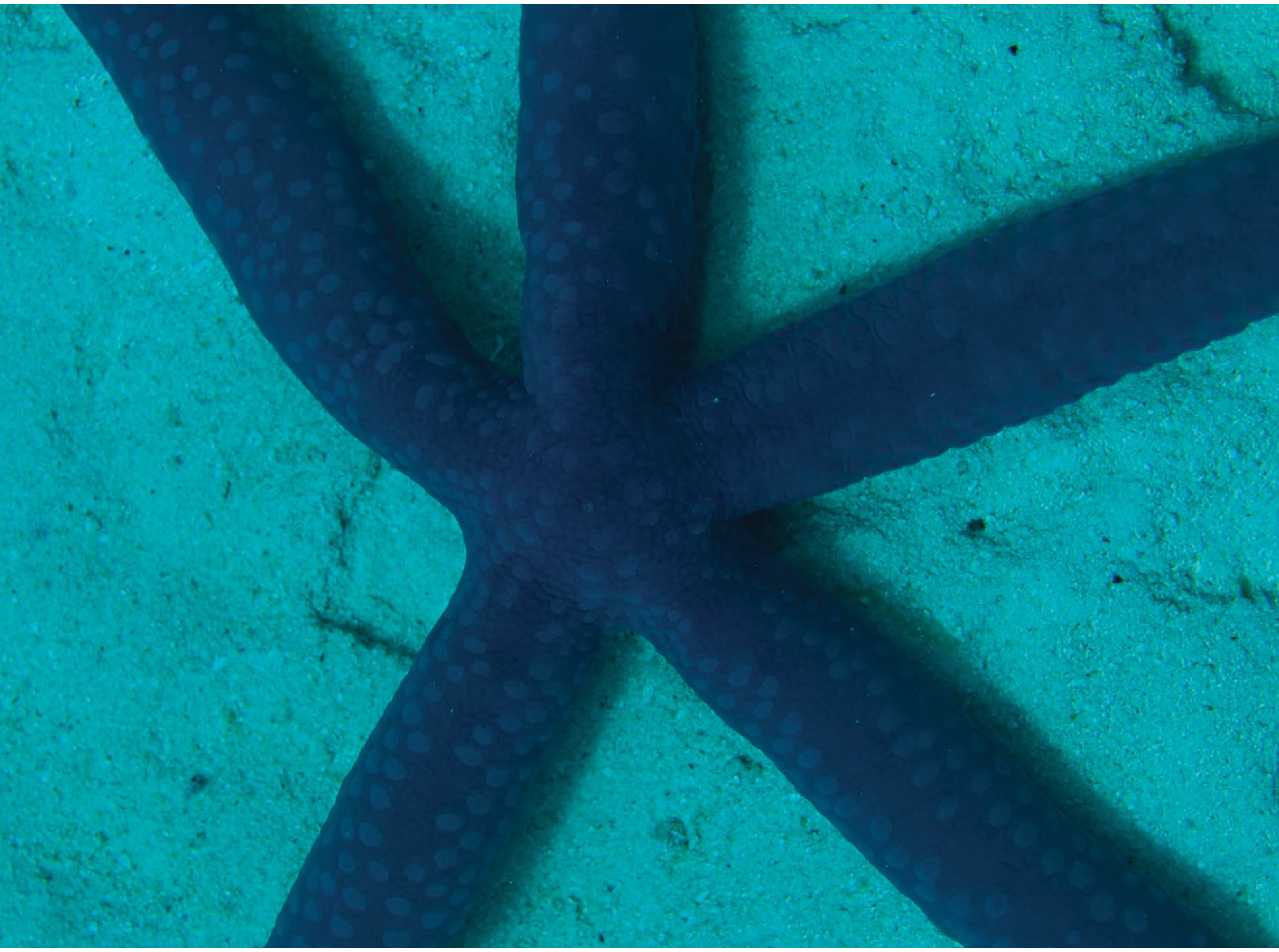
Marine



Photograph courtesy of David Abdo
(The blue sea star *Linckia laevigata*)

6

Introduction to the marine environment

The coastal waters of the Kimberley region of Western Australia possess a wealth of marine life. The marine biodiversity is remarkable, with the many hundreds of islands within the region supporting fringing reefs and an abundance of sponges, decapods, molluscs and other invertebrates, and including the highest coral species diversity in Western Australia.

GEOLOGY AND SEDIMENTS

The continental shelf off the coast of the Kimberley has two principal geological structures. The slope, outer shelf and middle shelf lie over the Browse Basin where the surface sediments are marine carbonates and, apart from some relict Quaternary strand-line terraces, the seabed is dominated by soft-substrate benthic habitats.

In contrast, the inner continental shelf (to a depth of approximately 50 m) lies over the submerged margin of the Kimberley Basin where shallow sediments of mainly terrigenous origin lie over Proterozoic metamorphosed sandstone and igneous rocks. The inner-shelf seabed topography is complex, reflecting the long subaerial erosional history of the terrestrial Kimberley Plateau prior to inundation. Consequently, the inner shelf has high and irregular relief with exposures of the basement rocks and shallow surficial sediments, generally reworked by marine depositional processes (Figure 6-1).

CURRENTS AND WATER FLOW

The characteristically clear, oligotrophic offshore waters of the Kimberley region are dominated by the Indonesian Throughflow and Holloway currents. These currents bring warm tropical waters and their associated marine life from Indonesia down along the Western Australian coast.

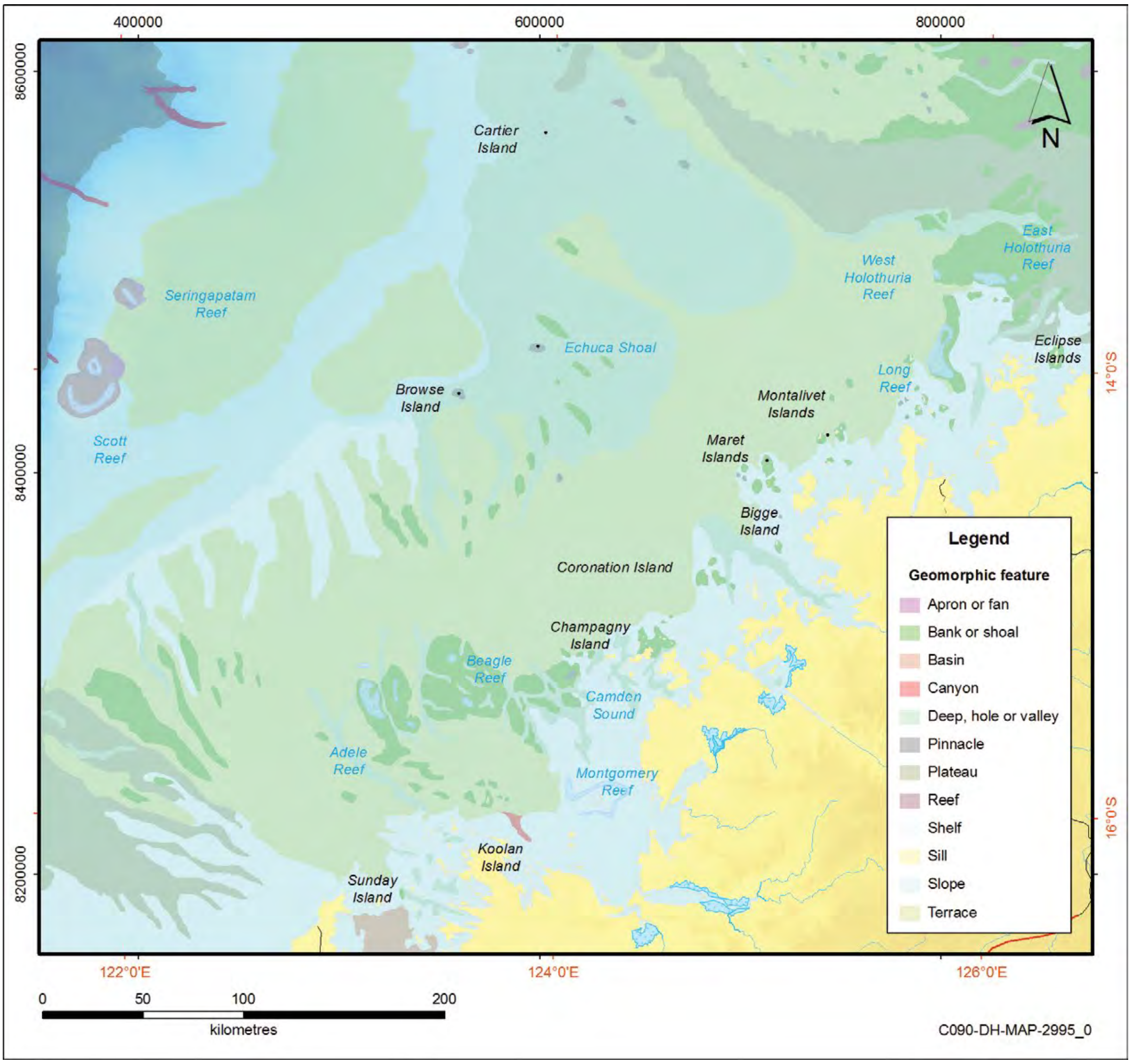


Figure 6-1: The geomorphic features of the Browse Basin, based on the geomorphic units of Australia's exclusive economic zone (Geoscience Australia 2013)

Photograph courtesy of Christine Lamont

Figure 6-2: The Kimberley coastline is notable for its tidal ranges of 10–12 m, shown clearly by the high-water mark in this inlet in King Hall Island west of Koolan Island in the Buccaneer Archipelago

The region's coastal waters are typically turbid, being influenced by large tides and the influx of water from streams and rivers. The shorelines of the Kimberley mainland and islands are characterised by rocky shore, fringing reef, mangrove and mudflat habitats (Waples 2007; Wilson 2013), and there are approximately 30 major rivers with numerous tributaries and tidal creeks. The largest is the Fitzroy River which discharges into King Sound north-east of Broome.

This shoreline is usually exposed to relatively low wave energy but can experience larger ocean swells from the south-west to north-west as well as seasonal storm-driven local waves. The regional macrotidal conditions, with amplitudes of up to 11 m in some places (Figure 6-2), produce pronounced tidal currents which contribute to moderate-to-high turbidity in the coastal waters.

REEFS AND ROCKY SHORES

The shores of the Kimberley region are formed along the north-western margin of the highly metamorphosed Kimberley Plateau and the igneous King Leopold Orogen. A large proportion of the region's shoreline is composed of Proterozoic metamorphic and igneous rocks. There are many species of molluscs and barnacles that inhabit upper intertidal rock surfaces, where they normally form distinctive zones relative to mean sea level and to their degree of exposure to waves and sun.

The rocky shores of the region also support a variety of coral species without the development of reef structures; these are often exposed at extreme low tide. The corals grow directly on Proterozoic basement rocks with little or no coralgal framework construction.

Figure 6-3: Limestone platform and fringing reef edge dominated by corals of the family Faviidae on the western side of the isthmus between North Maret Island and South Maret Island

Seaward from the rocky shores lie many fringing reefs. Examples of this type of reef may be seen at the Slate Islands and at Cassini, Prudhoe, Lamarck, Hedley, East Montalivet, North Maret and Berthier islands. Wilson (2013) has described two main fringing-reef types in the Bonaparte Archipelago. On shores exposed to the prevailing westerly swell, fringing reefs have grown to form wide limestone rock platforms with diverse coral communities along the reef-front edge that are dominated by rounded massive corals, especially of the family Faviidae (Figure 6-3). On more sheltered shores, limestone rock platforms are poorly developed and fringing reefs are made up mainly of corals of the genus *Acropora* growing on coral rubble (Figure 6-4). This pattern of fringing-reef development seems to be consistent throughout the archipelago. Many authors have also noted the presence of massive corals such as those of the genera *Porites* and *Goniastrea* on the outer parts of reef flats (e.g. Bassett-Smith 1899 and Blakeway 1997).

The distribution of coral species across the fringing terraced or ramped reefs is highly varied. One of the main factors affecting coral distribution is the degree of exposure to ocean swell of the reef flat above the low-water mark, further influenced by the development of reef-flat terraces, pools, and lagoons at relatively high levels in the middle and upper intertidal zones.

The impounded water behind the terraces remains as wide pools that may be several metres deep; these provide protection for marine plants, invertebrates, fish and turtles. Pools behind reef terraces are frequently populated by species of *Acropora*, *Montipora*, *Porites* and other coral genera, despite their often considerable elevation above the low-water mark. Shallow lagoons are also developed along the landward margins of many reef flats backed by cliffs, with or without a mangrove fringe. These lagoons may also contain seagrasses (e.g. *Enhalus acoroides*) and coral communities at elevations relatively high above the low-water mark.

SEAGRASSES AND ALGAE

Western Australia has the highest diversity of seagrasses in the world, with about 25 species represented (see, for example, Kirkman 1997). Seagrasses are significant components of marine ecosystems and their contribution to total primary carbon production is critical to regionally important dugong and turtle populations. Ten seagrass species have been recorded from the Kimberley region, although Kimberley seagrass meadows are not as well developed as those in the Canning, Pilbara and West Coast bioregions (Walker 1992, 1996, 1997). *Thalassia hemprichii* is common in rock pools within the intertidal reef flats of the Maret and other Bonaparte Archipelago islands. *Halophila ovalis* is also common around these islands, usually occurring as sparse assemblages in sandy lagoons and sheltered bays.

Walker (1996, 1997) found that the diversity and abundance of the algal flora of the region is generally low, probably a consequence of the extreme tidal exposure and the highly turbid waters. However, a large number of *Sargassum* species are found on Kimberley reefs and rhizobenthic algae of genera such as *Halimeda*, *Avrainvillea* and *Udotea* are common on reefs with pockets of sediment.

VERTEBRATE FAUNA

The waters of the Kimberley region are home to an abundance of resident and migratory marine species, including sharks, turtles, dugongs and cetaceans.

The region supports over 800 fish species, the majority of which are widespread and found across the Indo-Pacific region (Fox & Beckley 2005). Hutchins (2001) found that the fish faunas of the inshore and offshore areas of the Kimberley were mostly made up of non-endemic taxa, with the inshore areas (including the Bonaparte Archipelago) dominated by pomacentrids, labrids, lutjanids, chaetodontids and acanthurids, and the offshore areas (including Scott Reef) dominated by pomacentrids, labrids and acanthurids.

Six species of marine turtle are known to occur in Kimberley waters, all of them protected species under Western Australian and Commonwealth legislation. These are the green turtle (*Chelonia mydas*), the flatback turtle (*Natator depressus*), the hawksbill turtle (*Eretmochelys imbricata*), the loggerhead turtle (*Caretta caretta*), the leatherback turtle (*Dermochelys coriacea*) and the olive ridley turtle (*Lepidochelys olivacea*). The region also supports extensive turtle foraging grounds and there are nesting beaches on many of the islands.

Figure 6-4: An *Acropora* reef on the eastern side of the isthmus between North Maret Island and South Maret Island

Photograph courtesy of David Abdo

Figure 6-5: A loggerhead turtle in the waters of the Kimberley

A large number of cetacean species have been recorded in the Kimberley region, both toothed whales of the suborder Odontoceti (such as dolphins, beaked whales, pilot whales and sperm whales) and baleen whales of the suborder Mysticeti (such as the humpback, pygmy blue, Bryde's, Antarctic minke and dwarf minke whales) (Jenner, Jenner & McCabe 2001; Jenner, Jenner & Pirzl 2009).

ENDEMISM

The extent to which offshore coral reefs in the Kimberley region are interconnected and interrelated in terms of larval recruitment is unknown. The reefs and banks along the continental shelf edge lie in the path of the south-westerly flowing Indonesian Throughflow and Holloway currents. It has been suggested that these reefs may be dependent on larval recruits carried by currents from upstream reefs. However, seasonal reversals of current direction on the shelf associated with changes in the direction of the prevailing wind have been noted (Cresswell et al. 1993). Interconnectedness is likely to be a complex matter, depending on each reef's position relative to the seasonal current patterns and the breeding behaviours and seasonality of the many species living in this environment.

Most species inhabiting the offshore areas of the Kimberley region are widespread throughout the Indo-Pacific, but are not found in the adjacent coastal zone.

However, significant regional endemism is found among the species of the inshore coastal zone. This is a manifestation of the water circulation associated with the Indonesian Throughflow and the differences in the nature and diversity of the habitats between the clearer offshore oceanic waters and the turbid, macrotidal coastal waters. The Indonesian Throughflow delivers tropical water and propagules of corals and other species with extended pelagic larval stages to the edge of the Sahul Shelf (DEWHA 2007; Wijffels & Meyers 2004). It does not make direct contact with the coastal area and the pelagic larvae that it usually transports are primarily oceanic species that are not well adapted to the muddy habitats and turbid waters of the inshore coastal area.

ANTHROPOGENIC PRESSURES

The body of scientific knowledge on the Kimberley marine environment is still relatively small compared with what is known of other areas of Australia, particularly the tropical areas of the east coast (Masini, Sim & Simpson 2009). However, because of the remoteness of the region, the marine environment is thought to be still relatively pristine. Halpern et al. (2008) categorised the Kimberley as being under "very low impact" of anthropogenic influence. This category includes only 3.7% of the world's oceans, most of which are in polar regions.

Nevertheless, with the growing economic interest in the region, both recreational and industrial, a greater understanding of its biota is necessary to ensure effective management and sustainable use into the future. This publication represents the Ichthys LNG Project's contribution to the body of knowledge on the island and marine ecosystems of the Kimberley region. It is intended as a source reference for future research, monitoring and management.

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Marine turtles

7

David Waayers

Waayers, D.A. 2014. Marine turtles. pp. 213–271 in Comrie-Greig, J. and Abdo, L.J. (eds), *Ecological studies of the Bonaparte Archipelago and Browse Basin*. INPEX Operations Australia Pty Ltd, Perth, Western Australia.

ABSTRACT

Although marine turtles are known to be widespread along the northern Western Australian coast, it is only in recent years that there has been any concerted effort to acquire knowledge relating to their abundance and distribution in this region and to understand their genetic affiliations with other regional populations. Six species of turtle have been identified in the Kimberley region: the green turtle (*Chelonia mydas*), the flatback turtle (*Natator depressus*), the hawksbill turtle (*Eretmochelys imbricata*), the loggerhead turtle (*Caretta caretta*), the leatherback turtle (*Dermochelys coriacea*) and the olive ridley turtle (*Lepidochelys olivacea*).

This chapter presents the results of marine turtle baseline studies undertaken in the Kimberley region of northern Western Australia between June 2006 and April 2008. The main purpose of the surveys was to gain an understanding of the distribution, abundance and genetic affinities of green and flatback turtles at the Maret Islands and other islands in the Bonaparte Archipelago, and to identify regionally significant nesting populations in the Kimberley region. The studies also addressed aspects of breeding biology, breeding success, population dynamics and habitat use.

A regional aerial survey of nesting beaches along the north-west Kimberley coast was conducted in late January and early February 2007, a period presumed to coincide with turtle nesting activity. The survey indicated that turtle nesting is largely restricted to the offshore islands of this section of the coast. The largest turtle rookeries were found at the Lacepede Islands (723 fresh tracks from female turtles on the night preceding the survey), the Maret Islands (198 tracks) and Cassini Island (70 tracks).

Detailed beach surveys in the Bonaparte Archipelago revealed that green, flatback and hawksbill turtles nested in the area in 2006–2008. Most of the nesting turtles were green turtles which contributed 87% of the nesting effort during this period, while flatback turtles contributed most of the remaining 13% and hawksbill turtles were rare. Although olive ridley turtles have been recorded nesting in the archipelago, they were not observed during this survey. Loggerhead and leatherback turtles have also been recorded in the waters of the archipelago, but are not known to nest in the region. The studies were therefore focused on green and flatback turtles.

Green and flatback turtle nesting activity peaked over summer, with most of the turtles nesting between November and April and hatchlings emerging between December and May. There was high interannual variability in green turtle nesting activity with, for example, 60% fewer green turtles nesting at the Maret Islands in the 2007–2008 season compared with the 2006–2007 season. In contrast, there was little interannual variation in the numbers of nesting flatback turtles over these two seasons.

The results of this survey indicate that the Maret Islands constitute one of the more significant regional rookeries. The nearshore habitats surrounding the Maret Islands are also important for inter-nesting, foraging and mating turtles. Satellite telemetry studies showed that 12 out of 16 tagged inter-nesting green turtles stayed within 13 km of their nesting beaches on the Maret Islands in water less than 30 m deep. However, these studies also revealed that the other four green turtles and all four of the tracked inter-nesting flatback turtles travelled relatively long distances (up to 90 km) to other areas within the Bonaparte Archipelago.

Aerial surveys in November 2007 found large numbers of male and female turtles in the nearshore waters around Cassini Island, the Holothuria Banks and Long Reef, suggesting that these areas are regionally significant foraging areas for turtles. While sample sizes were small, satellite telemetry also provided evidence for foraging habitats at Long Reef and Eighty Mile Beach in Western Australia and at Bathurst and Melville islands north of Darwin in the Northern Territory. The majority of flatback turtles showed a relatively well-defined northward migration pathway to the Holothuria Banks foraging area north of Long Reef. One green turtle migrated from South Maret Island over a distance of 1898 km to Prince of Wales (Muralug) Island in northern Queensland.

Analysis of differences in mitochondrial DNA haplotype frequencies among regional nesting populations found that the green turtles nesting in the Bonaparte Archipelago are part of the large North West Shelf Management Unit. In contrast, the genetic analyses indicate that the flatback turtle population of the Maret Islands and surrounding islands constitutes a breeding stock partially isolated from the North West Shelf stock and the West Arnhem Land Management Unit, and may represent a "Bonaparte Archipelago Management Unit". Additional studies are required to confirm this, however, as there is evidence of some genetic exchange between the flatback turtles nesting in the Bonaparte Archipelago and the main flatback turtle population of the North West Shelf Management Unit and the sample sizes in this study were small.

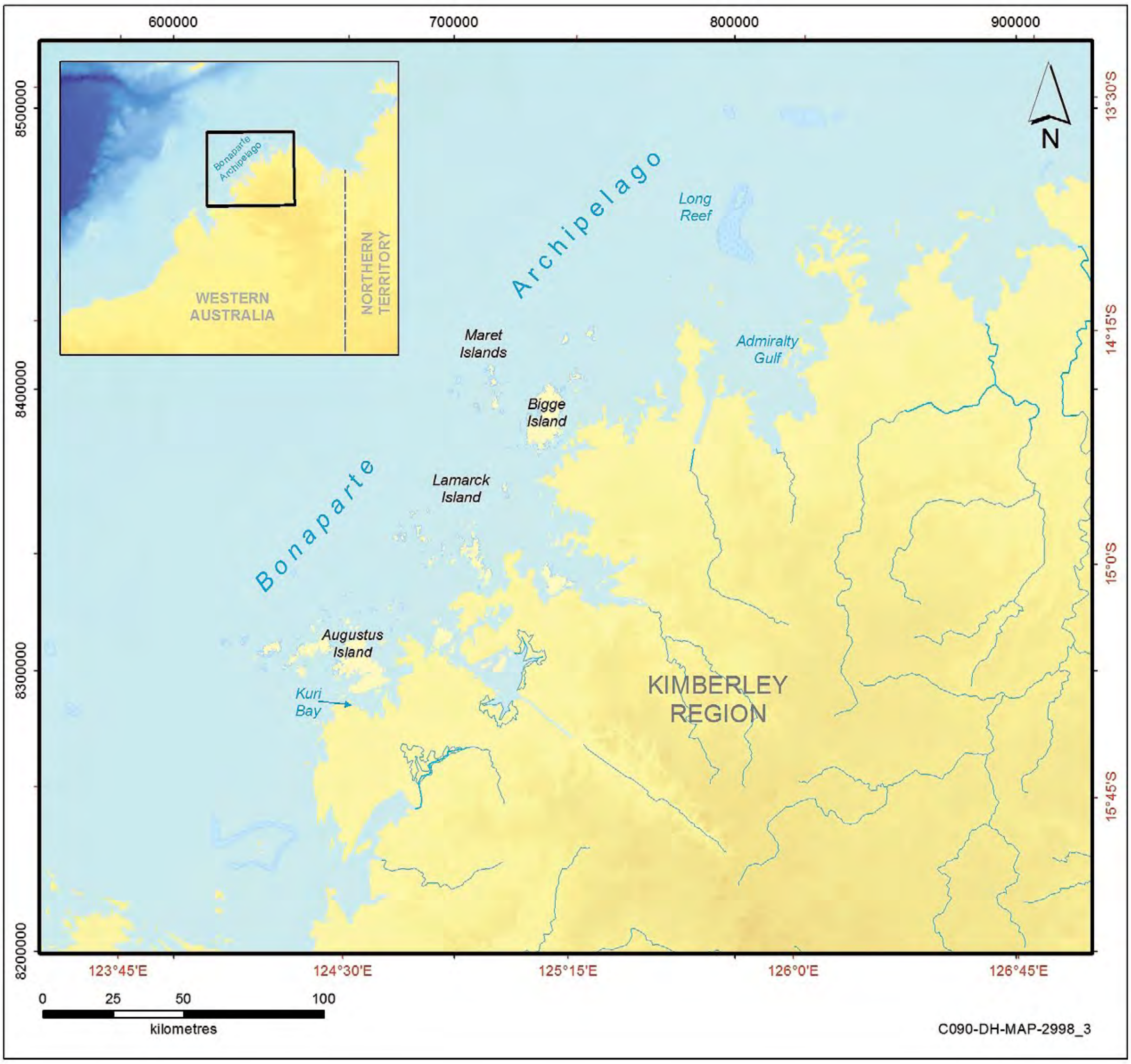


Figure 7-1: The Maret Islands and Bonaparte Archipelago in the Kimberley region

INTRODUCTION

While the broader distribution of marine turtle species across northern Australia is known (Limpus 2009a; Whiting et al. 2008), there is relatively little information available relating to marine turtle populations in the Kimberley region. Satellite telemetry studies have been undertaken on green and flatback turtles in the Kimberley in recent years (Waayers & Fitzpatrick 2013; Waayers, Smith & Malseed 2011); however, little is known about the location of nesting sites, mating aggregations, inter-nesting areas, foraging areas, the genetic affinities of turtles with neighbouring management units, and the ecology and population dynamics of marine turtles breeding in the Bonaparte Archipelago. These distinct and often spatially separated life stages show that turtles depend on five broad types of habitats during their life: mating areas, nesting beaches, inter-nesting habitat, feeding areas, and pelagic waters. In the *Recovery plan for marine turtles in Australia* (Environment Australia 2003) it is recognised that knowledge of these critical habitats in northern Australia is scanty and deficient.

The aim of this study was to gather baseline information on marine turtles in the Kimberley region, with a focus on the Maret Islands and surrounding islands of the Bonaparte Archipelago (Figure 7-1). Because of the paucity of data on turtles in this area, the primary focus of the study was to identify important habitats that would subsequently provide the basis for setting up more complex surveys for a monitoring program.
The study was undertaken over two years during the 2006–2007 and 2007–2008 nesting seasons. The study team collected genetic samples from green and flatback turtles to determine which of several recognised turtle management units they belonged to and focused on identifying important habitats used by marine turtles,

including nearshore habitats, significant rookeries and inter-nesting habitats surrounding the Maret Islands. Satellite tracking was also used to determine migratory pathways and potential foraging grounds.

The objectives of the study were as follows:

- to determine the genetic affinities of the female green and flatback turtles nesting at the Maret Islands
- to identify important turtle rookeries in the north-west Kimberley region
- to identify critical habitats (e.g. nearshore aggregation areas, inter-nesting areas and probable foraging grounds) within the Bonaparte Archipelago
- to determine the hatchling productivity at the Maret Islands and surrounding islands
- to determine the variability in sand temperature at the average nest depth in the Bonaparte Archipelago
- to describe the inter-nesting distribution of marine turtles around the Maret Islands
- to determine the post-nesting migration pathways of green and flatback turtles nesting at the Maret Islands.

Conservation status of marine turtles

Six species of marine turtle are known to occur in northern Western Australia: the green turtle (*Chelonia mydas*), the flatback turtle (*Natator depressus*), the hawksbill turtle (*Eretmochelys imbricata*), the loggerhead turtle (*Caretta caretta*), the leatherback turtle (*Dermochelys coriacea*) and the olive ridley turtle (*Lepidochelys olivacea*) (DSEWPaC 2011).

In Western Australia all six species are listed under the Wildlife Conservation Regulations 1970 (WA) and are further protected under Commonwealth law by the *Environment Protection and Biodiversity Conservation Act 1999* (Cwlth) (EPBC Act). They are also listed under international laws, including the Convention on the Conservation of Migratory Species of Wild Animals (the "Bonn Convention") (UNEP 1979), the Convention on International Trade in Endangered Species of Wild Fauna and Flora ("CITES") (UNEP 1973) and the Red List of Threatened Species of the International Union for Conservation of Nature and Natural Resources (IUCN 2013). The conservation status of each species is summarised in Table 7-1.

Life cycle of marine turtles

In general, marine turtle eggs incubate in the nest for between 50 and 60 days (Limpus 2009a). Nest temperature, humidity, salinity and oxygen levels must remain within a narrow range for embryonic development to be successful and therefore any disturbance of the nest during the incubation period can change the microclimate of the nest and hinder embryonic development (Ackerman 1996). Sand temperature within the nest influences the length of the incubation period and also determines the sex of the hatchlings through the phenomenon known as temperature-dependent sex determination. The thermal tolerance range of turtle embryos incubated at constant temperatures is between 25 °C and 37 °C (Bustard 1972; Miller 1996). Warmer nest conditions tend to produce a higher percentage of females, with cooler conditions tending to produce proportionately more males.

Table 7-1: Marine turtle conservation status in Australia

Common name	Threatened species status				
	EPBC Act	Wildlife Conservation Regulations 1970 (WA)	Bonn Convention Appendix	CITES Appendix	IUCN Red List status
Green turtle	Marine; Migratory; Vulnerable	Animal is rare or is likely to become extinct	I and II	I only	Endangered
Flatback turtle	Marine; Migratory; Vulnerable	Animal is rare or is likely to become extinct	II only	I only	Not yet assessed
Hawksbill turtle	Marine; Migratory; Vulnerable	Animal is rare or is likely to become extinct	I and II	I only	Critically endangered
Loggerhead turtle	Marine; Migratory; Endangered	Animal is rare or is likely to become extinct	I and II	I only	Endangered
Leatherback turtle	Marine; Migratory; Endangered	Animal is rare or is likely to become extinct	I and II	I only	Critically endangered
Olive ridley turtle	Marine; Migratory; Endangered	Animal is rare or is likely to become extinct	I and II	I only	Vulnerable

Small groups of hatchlings usually emerge in the early evening over consecutive nights. Hatchlings find their way to the sea by crawling towards the brighter, lower oceanic horizon and away from the elevated silhouettes of vegetation and dunes (Salmon & Witherington 1995; Salmon et al. 1992; Witherington & Martin 2003). When they enter the water, they appear to use the shore wave action as a directional cue to make their way offshore.

The early developmental years are often termed "the lost years" because very little is known about the juveniles of any marine turtle species during this time. However, it is believed that juvenile turtles of species with a pelagic stage aggregate at oceanic convergences where they feed on accumulated buoyant biota such as seaweed and small crustaceans (Walker & Parmenter 1990) (Figure 7-2).

It is not known if all marine turtle species have a pelagic phase; Walker and Parmenter (1990), for example, suggest that the flatback turtle could possibly be unique among marine turtles in not having a pelagic phase in its life cycle.

Once they reach adulthood, the turtles move into shallow-water continental shelf habitats. These habitats may differ between species, life stages, regions and seasons (Bjorndal 1996; Eckert et al. 2006).

Foraging areas may host individuals from a range of different breeding stocks (Luke et al. 2004) and turtles may often travel large distances (>1000 km) from their foraging habitats to return to their breeding areas (Ross 1985).

Marine turtles generally reach sexual maturity between 30 and 50 years of age. All species exhibit similar mating and nesting characteristics, with nesting-beach habitat requirements being broadly similar for all species of turtle. Miller (1996) characterised suitable turtle nesting beaches as having clear access from the sea, adequate elevation to prevent inundation of the eggs either by tides or by an underlying water table, a sandy substrate which facilitates gas diffusion, and sand that is moist and fine enough to prevent collapse of the egg chamber during construction.

Turtles usually deposit eggs above the high-water mark on exposed sandy beaches. Successful nesting involves several discrete stages: beaching, selecting a nest site, digging an egg chamber, laying eggs, covering the egg chamber, and returning to the water. Since the tracks of turtles are recognisable for each species, it is relatively easy to monitor the relative abundance of different turtle species emerging on to a beach to nest on a particular night.

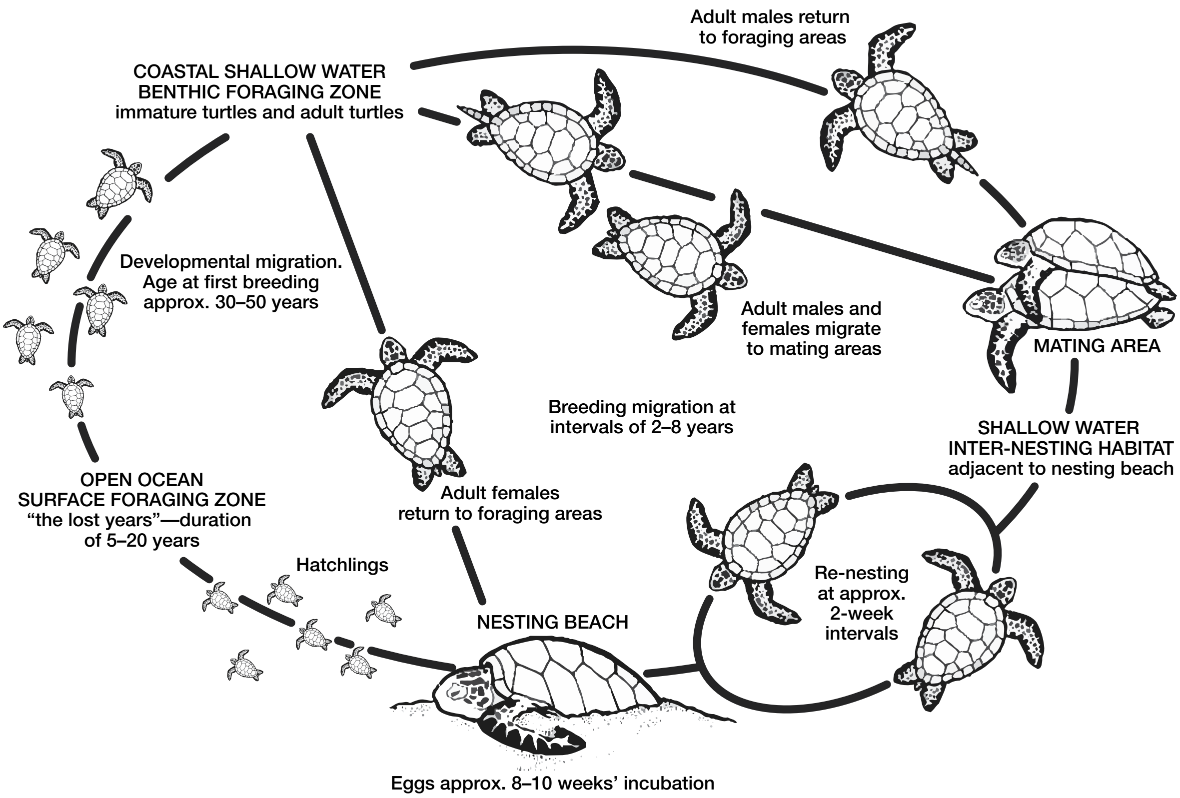


Figure 7-2: The basic life cycle of marine turtles (adapted from Lutz & Musick 1996, p. 53)

7 MARINE TURTLES

Photographs A to F in Figure 7-3 illustrate how tracks can be used for identification:

- A: a line across the beach marking adult and hatchling tracks
- B: a successful nest of a green turtle
- C: the emerging and returning track of a green turtle
- D: the emerging track of a flatback turtle
- E: the returning track of a hawksbill turtle
- F: a green turtle hatchling track.

Figure 7-3: Examples of tracks from three different turtle species at the Maret Islands

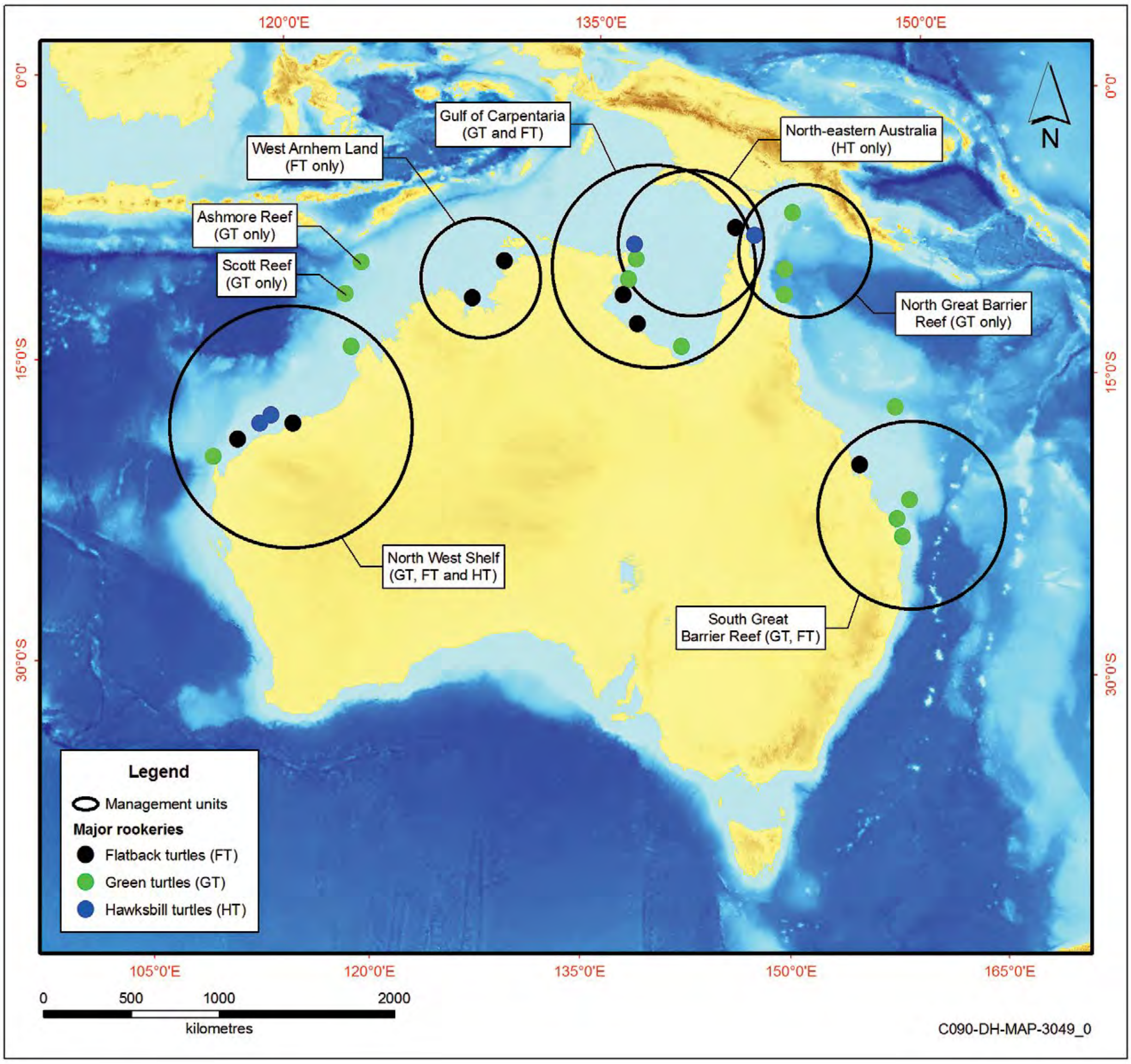


Figure 7-4: Key breeding areas and management units for green, flatback and hawksbill turtles in Australia

Marine turtles in Western Australia

The major rookeries for green, flatback and hawksbill turtles in Australia are shown in Figure 7-4 above (based on Dutton, Broderick & FitzSimmons 2002; Limpus 2007, 2008, 2009b; Limpus & Chatto 2004). The distribution of turtle rookeries in the Kimberley region is largely unknown apart from the green and flatback turtle rookery on the Lacepede Islands (Prince 1994). This is the closest known large rookery to the Maret Islands. The main hawksbill and loggerhead turtle rookeries in Western Australia are much further to the south, in the Dampier Archipelago and the Ningaloo region respectively.

Green turtles

Six management units have been recognised for green turtles in Australia, based on genetically distinguishable populations: these have been designated as the northern Great Barrier Reef (nGBR), southern Great Barrier Reef (sGBR), Gulf of Carpentaria (GoCgr[1]), North West Shelf (NWSgr), Ashmore Reef (AR) and Scott Reef (SR) units. The NWSgr population has been reported to include rookeries from the North West Cape in the south to the Lacepede Islands in the north (Dutton, Broderick & FitzSimmons 2002), encompassing the coastal areas of the Gascoyne, Pilbara and Kimberley regions of Western Australia. The Maret Islands lie between the NWSgr Management Unit and the AR, SR and GoC management units.

[1] The suffix "gr" (for green turtle) is used as there is also a Gulf of Carpentaria flatback turtle management unit, which is distinguished by the suffix "fl". In similar fashion, the North West Shelf management unit for the green turtle is designated as NWSgr.

Dethmers et al. (2006) estimated the population of female green turtles in the North West Shelf Management Unit to be approximately 125 300 individuals, which is considered to be one of the largest green turtle populations remaining in the world (Limpus 2008). The Gascoyne region (between Carnarvon and the Muiron Islands) supports between 3000 and 43 000 female turtles (Prince 1994; UNEP 2007; Waayers 2003, 2010), while the Pilbara region (between Serrurier Island and the Dampier Archipelago) supports between 14 500 and 46 000 green turtle females (Pendoley 2005; Prince 1994; UNEP 2007).

In Western Australia, the green turtle breeding season typically occurs between November and March (Pendoley 2005; Prince 1994; Waayers 2010). The turtles may travel long distances from their foraging habitats to breeding areas (Godley et al. 2002; Hays et al. 2001; Plotkin 2003; Ross 1985). Another study, however, has shown non-migratory foraging–breeding area patterns by green turtles from the Cocos (Keeling) Islands in the Indian Ocean (Whiting et al. 2008). Adult male green turtles also migrate to spend approximately one month at their mating ground each year, during which time they mate with several females before returning to their foraging areas (Limpus 1993). Breeding green turtles show strong fidelity to particular mating areas in successive migrations and often aggregate in nearshore areas (Musick & Limpus 1996; National Academy of Sciences 1990). Breeding female turtles often return to nest on beaches within 5 km of their natal beach (Limpus 2006). They remain in the inter-nesting areas, that is, shallow (<20 m) nearshore habitats (Hays et al. 2001; Waayers, Smith & Malseed 2011), for several months, while the male turtles migrate back to their foraging grounds.

Although green turtles generally nest every five years, there is considerable variation in their remigration interval[2] (n = 2094, mean = 5.35, SD = 1.52, range = 1–8 years) (Limpus et al. 2003). When they move into shallow sublittoral habitats at approximately 10 years of age, they change from a carnivorous diet to a predominantly herbivorous diet, feeding principally on seagrasses, a wide range of algae, and mangrove fruits (Read & Limpus 2002; Whiting & Miller 1998).

Photograph courtesy of David Waayers

Figure 7-5: An adult female green turtle resting in the intertidal area after laying eggs on South Beach, South Maret Island, in December 2007

Flatback turtles

Four management units have been recognised for flatback turtles in Australia, based on genetically distinguishable populations: these have been designated as the Eastern Australia (EA), Gulf of Carpentaria (GoCfl[3]), West Arnhem Land (WAL), and North West Shelf (NWSfl) units (Dutton, Broderick & FitzSimmons 2002; Limpus 2007). The NWSfl stock is currently known to exist between the Muiron Islands and the Lacepede Islands (Limpus 2007) and includes the waters of the Pilbara and Kimberley regions.

Little is known about the mating behaviour of the flatback turtle. However, West Arnhem Land flatback turtles have been observed mating on the shore of Bare Sand Island and at Roche Reef which is about 10 to 15 km from the nesting beach on Bare Sand Island (Dr Michael Guinea, Faculty of Engineering, Health, Science and the Environment, Charles Darwin University, Darwin, Northern Territory, pers. comm. 2007). This suggests that flatback turtles may mate near their rookeries, but that mating is not restricted to the immediate vicinity of the nesting beaches.

Flatback turtles nest mainly between November and February in Western Australia (Pendoley 2005) and between June and August in the Northern Territory (Chatto 1998). Although most turtles nest at night, flatback turtles may also occasionally nest during daylight hours (Spotila 2004). Studies on flatback turtles at the Lacepede Islands in the Kimberley region have identified a broad inter-nesting area extending up to 60 km from the rookery (Waayers, Smith & Malseed 2011).

[2] The remigration interval for an individual turtle is defined as the number of years between successive breeding seasons.

[3] The suffix "fl" (for flatback turtle) is used as there is also a Gulf of Carpentaria green turtle management unit, which is designated as GoCgr. In similar fashion, the North West Shelf management unit for the flatback turtle is designated as NWSfl.

Although numerous satellite transmitters have been attached to flatback turtles in Western Australia (Waayers, Fitzpatrick & Smith 2012), there is little published work available for identifying foraging habitats of the NWSfl population (Thums et al. in prep.). Recent satellite tracking data from the Lacepede Islands (Waayers, Smith & Malseed 2011), Eco Beach south of Broome (CVA 2011) and Barrow Island (Chevron 2009) suggest that flatback turtles migrate over great distances along the northern Western Australian coast to foraging grounds in the northern Kimberley area. Some data from satellite and flipper tags indicate that Western Australian flatback turtles may migrate as far as the Northern Territory (Prince 1998; Waayers, Smith & Malseed 2011). Studies from eastern Australia have established the remigration period of flatback turtles as ranging between 1 and 5 years (n = 40, mean = 2.7, SD = 0.92) (Limpus, Fleay & Baker 1984).

Photograph courtesy of David Waayers

Figure 7-6: An adult flatback turtle returning to the water after having had an identity tag attached to its right front flipper, South Beach, South Maret Island, December 2007

Hawksbill turtles

Three genetically distinct populations of hawksbill turtles have been identified and two management units are recognised in Australia: these have been designated as the north-eastern Australia (NEA) and North West Shelf (NWShb[4]) units (Dutton, Broderick & FitzSimmons 2002; Moritz et al. 2002). The NEA Management Unit includes rookeries in the Torres Strait, the northern Great Barrier Reef and Arnhem Land, while the NWShb Management Unit ranges from the North West Cape to the Dampier Archipelago.

Hawksbill turtles nest all year round, but the peak nesting period is typically between July and September in northern Australia (DSEWPaC 2011; Limpus 1992).

The major rookeries for hawksbill turtles in Western Australia are in the Dampier Archipelago, the Montebello Islands and the Lowendal Islands (Limpus 2009b); however, no reliable nesting statistics are available.

Studies conducted in eastern Australia have shown that hawksbill turtles are highly migratory (Parmenter 1983). The remigration interval of hawksbill turtles in Western Australia ranges between 1 and 8 years (n = 49, mean = 3.7, SD = 1.2) (Limpus 2009b). They feed on planktonic animals and plants during their pelagic early juvenile phase (Meylan 1984), while older juvenile and adult turtles generally forage in benthic habitats such as coral and rocky reefs. Adult turtles are omnivorous, feeding on sponges, cephalopods (squid, cuttlefish, and octopus), gastropods (marine snails), cnidarians (jellyfish), seagrass and seaweed (Carr & Stancyk 1975; Limpus 1992; Whiting 2000; Witzell 1983).

Loggerhead turtles

Two management units have been identified for loggerhead turtles in Australia: these have been designated as the Eastern Australia (EAlh) and Western Australia (WAlh) units (Dutton, Broderick & FitzSimmons 2002). They are based on rookeries in the southern Great Barrier Reef in Queensland and between Shark Bay and Ningaloo Reef in Western Australia respectively. No mating or nesting has been recorded in the Kimberley region. Young juvenile loggerhead turtles forage among floating rafts of brown macroalgae (*Sargassum* spp.), and feed on seagrass, algae, crustaceans, molluscs, insects, jellyfish, fish and some anthropogenic debris. Large juveniles and adults mostly forage in the hard- and soft-bottom habitats of the continental shelf on gastropod molluscs, clams, sea cucumbers, jellyfish, starfish, corals, crabs and fish (Limpus, Fleay & Guinea 1984; Limpus, Miller & Chatto 2008).

Olive ridley turtles

Olive ridley turtles are rarely encountered along the Kimberley coast. Since 2007, only four have been recorded nesting in the Kimberley region: one in 2008 near Cape Leveque, two on Darcy Island in 2008 in the Bonaparte Archipelago, and one on the coast near Langgi in Camden Sound in 2009. Genetic analyses suggest that they are associated with the northern Australian populations at Melville and Bathurst islands near Darwin in the Northern Territory, and at Flinders Beach on the western Cape York Peninsula in Queensland (Prince et al. 2010).

[4] The suffix “hb” (for hawksbill turtle) is used as there is also a North West Shelf green turtle management unit, designated as NWSgr and a North West Shelf flatback turtle management unit designated as NWSfl.

Leatherback turtles

Studies on the nesting habits of leatherback turtles in south-eastern Queensland have found that the season commences in mid-December, reaches a peak in January, and ends in February (Limpus, Fleay & Guinea 1984). Leatherback turtles are presumed to migrate to Australian waters from nesting populations in Indonesia, Papua New Guinea and the Solomon Islands (Limpus 1997, 2009c). These turtles have been recorded as nesting sporadically in south-eastern Queensland and there have also been unconfirmed reports of nesting attempts near Cape Leveque in the Kimberley region in Western Australia (Dr Robert Prince, Senior Research Scientist, Conservation Science Centre, Department of Environment and Conservation, Perth, Western Australia, pers. comm. 2007).

MATERIALS AND METHODS

Prior to the commencement of field-based surveys, a desktop review was undertaken of previous turtle research in northern Australia and general biological information on the turtle species expected to occur in the Kimberley region. The broad distribution information provided by the EPBC *Protected matters search tool* (DSEWPaC 2013) and the *Marine turtle interactive mapping system* (UNEP 2007) were also used to determine the likelihood of occurrence of each turtle species within the study area. This information was then corroborated, where possible, from scientific literature or through personal communication with experienced turtle researchers.

On 29 June 2006, a beach-based reconnaissance survey was carried out at Browse Island and from 30 June to 3 July a vessel-based reconnaissance survey was conducted to identify potential nesting sites at the Maret Islands and a number of the neighbouring islands of the Bonaparte Archipelago. Evidence of nesting activity from previous seasons (e.g. body pits and egg shells) was recorded to identify potential sampling sites for the main study. In addition, regional aerial surveys were undertaken in late January and early February 2007 to identify rookeries in the Kimberley region between Broome and the Anjo Peninsula. The information from the reconnaissance survey in 2006 and the regional aerial surveys in early 2007 was used to select the study sites listed in Table 7-2 for surveying in more detail. These surveys were scheduled around the expected timing of the reproductive activities of green and flatback turtles in Western Australia (Pendoley 2005; Prince 1998). They were also scheduled to capture the mating period (September to January), the nesting period (November to March) and the hatching period (December to May). Surveys were also conducted during the non-nesting period from June to August; these captured the foraging periods for green, flatback and hawksbill turtles.

Genetic studies

Genetic analyses were conducted to elucidate the broader regional affinities and associated management units of the green and flatback turtles in the Bonaparte Archipelago. Tissue samples from turtles of both species were taken from those nesting at the Maret Islands, East Montalivet Island and Cassini Island. The samples were collected from the turtles' shoulders (Dutton & Balazs 1995) while they were returning to the water following a nesting attempt and were also taken on an opportunistic basis from hatchlings that had been dead for no more than one week (FitzSimmons, Moritz & Bowen 1999).

Each tissue sample was placed in a labelled specimen jar containing 20% dimethyl sulfoxide ($(CH_3)_2SO$) in saturated sodium chloride (NaCl) solution. All instruments were thoroughly cleaned with alcohol swabs following each sampling to avoid DNA cross-contamination.

A total of 42 tissue samples were collected from green turtles in the Bonaparte Archipelago during the 2006–2007 season. Mitochondrial DNA (mtDNA) sequencing was used to determine whether the turtles nesting in the Bonaparte Archipelago were part of the offshore Timor Sea stock (including Ashmore and Scott reefs) or the North West Shelf stock. The mitochondrial genome, which is maternally inherited and therefore gives information on female lineages within a species, contains a range of genes and regions that are useful for defining regional groups. The “control” (or “D-loop”) region of the DNA strand accumulates polymorphisms (mutations in the DNA sequence). The frequency of various contributions of polymorphisms (haplotypes) is then used as a measure of genetic connectedness between populations. Samples of mtDNA extracted from the somatic tissues of green turtles nesting in the Bonaparte Archipelago were compared with published mtDNA sequences and data from the National Centre for Biotechnology Information’s GenBank (2008), for the Ashmore Reef, Scott Reef and North West Shelf green turtle management units.

A total of 28 tissue samples were collected from flatback turtles nesting on the Maret Islands, Lamarck Island and East Montalivet Island during the 2007–2008 season. Because of the lack of publicly available data relating to genetic markers for flatback turtles, the genetic analysis of this species was carried out using samples from different regions in northern Australia, including Barrow Island (west of Dampier), Delambre Island (offshore Karratha), Mundabullangana (near Port Hedland) and Cape Domett[5] (FitzSimmons 2008). Both mtDNA sequencing and nuclear microsatellite markers were used to determine the genetic affinities of flatback turtles in the Bonaparte Archipelago.

[5] Cape Domett is on the Kimberley mainland near the Northern Territory border, north of Wyndham.

Table 7-2: Target period, schedule, study sites and scope for the 2006–2008 turtle surveys

Target period of survey	Survey period	Days surveyed	Survey scope	Study sites
Off-peak nesting period and resident foraging activity	29 June 2006	1	Beach-based reconnaissance survey (including track-count surveys).	Browse Island
Off-peak nesting period and resident foraging activity	30 June 2006 to 3 July 2006	4	Vessel-based reconnaissance survey.	North Maret, South Maret, Browse, Berthier, Prudhoe, Bigge, Albert[6], Lamarck, East Montalivet and West Montalivet islands
Mating period	7 November 2006 to 8 November 2006	2	Nearshore aerial surveys.	Bonaparte Archipelago: Lamarck Island to East Montalivet Island
Peak nesting period	6 December 2006 to 19 December 2006	14	Track-count surveys; satellite telemetry studies.	South Beach on South Maret Island
Peak nesting and hatching period	11 January 2007 to 24 January 2007	14	Track-count surveys; clutch surveys; satellite telemetry studies.	North Maret, South Maret, Lamarck, East Montalivet and West Montalivet islands
Peak nesting and hatching period	31 January 2007 to 2 February 2007	3	Regional aerial surveys.	Kimberley region: Broome to Anjo Peninsula
Peak hatching period and end of nesting season	17 February 2007 to 2 March 2007	14	Track-count surveys; clutch surveys; satellite telemetry studies.	North Maret, South Maret, Lamarck, East Montalivet and West Montalivet islands
Peak hatching period	18 March 2007 to 21 March 2007	4	Track-count surveys; clutch surveys.	South Beach on South Maret Island
Off-peak nesting period	2 May 2007 to 5 May 2007	4	Track-count surveys.	Cassini Island
Off-peak nesting period (winter nesting)	17 July 2007 to 30 July 2007	14	Track-count surveys.	North Maret, South Maret, Albert and Turbin islands
Off-peak nesting period and resident foraging activity	29 September 2007 to 15 October 2007	17	Track counts; nearshore vessel surveys (line-transect and point surveys).	East and West Montalivet, North and South Maret, Berthier, Albert, Prudhoe and Bigge islands
Start of nesting season and expected hawksbill nesting period	29 September 2007 to 15 October 2007	17	Track-count surveys.	North Maret, South Maret, Albert and Turbin islands
Mating period	6 November 2007 to 8 November 2007	3	Nearshore aerial surveys.	Bonaparte Archipelago: Coronation Islands to Long Reef
Peak nesting and mating period	9 November 2007 to 23 November 2007	14	Genetic studies (collection of tissue samples); track-count surveys; sand temperature studies (installation of loggers at South Maret, East Montalivet and Lamarck islands); satellite telemetry studies.	North Maret, South Maret, Lamarck, East Montalivet, West Montalivet, Albert and Turbin islands
Peak nesting period	6 December 2007 to 19 December 2007	14	Genetic studies (collection of tissue samples); track-count surveys; satellite telemetry studies.	North Maret, South Maret, Lamarck, East Montalivet, West Montalivet, Albert and Turbin islands
Peak nesting and hatching period	17 January 2008 to 30 January 2008	14	Genetic studies (collection of tissue samples); track-count surveys; clutch surveys.	North Maret, South Maret, Lamarck, East Montalivet, West Montalivet, Albert, Turbin and Berthier islands
Peak hatching period and end of nesting season	25 March 2008 to 12 April 2008	19	Genetic studies (collection of tissue samples), track-count surveys; satellite telemetry studies; removal of sand temperature loggers (South Maret, East Montalivet and Lamarck islands).	North Maret, South Maret, Lamarck, East Montalivet, West Montalivet, Albert, Turbin and Berthier islands

[6] The Albert Islands group lies south-west of the Maret Islands and is made up of seven islands. The largest island is unnamed but is unofficially called “Albert Island” and was so called during this survey. The southernmost and second-largest island is officially known as Suffren Island. Two (or three) of the islands are very small and are better described as islets.

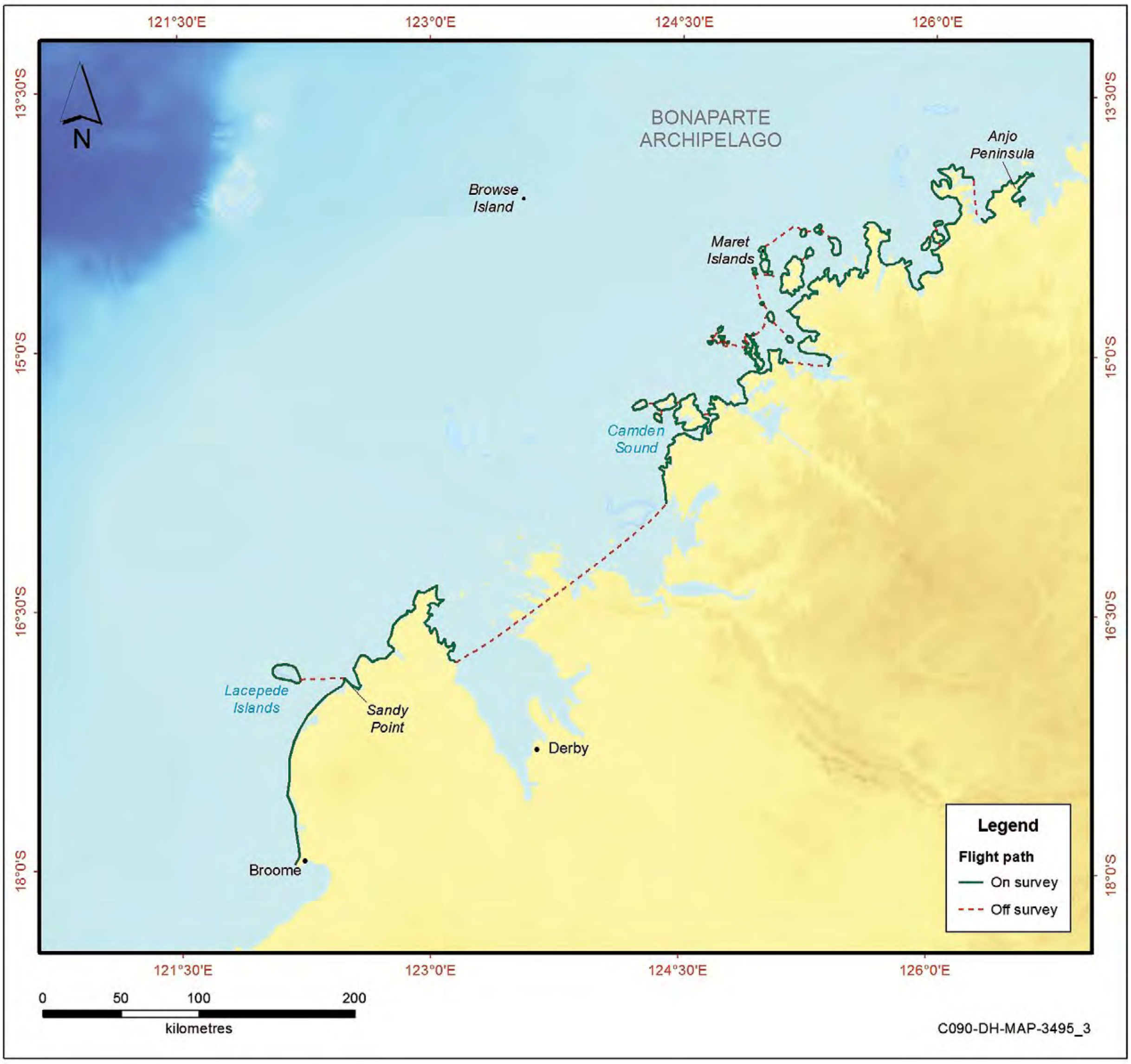


Figure 7-7: Flight paths of regional aerial surveys in the Kimberley region in January and February 2007

Regional aerial surveys

Aerial surveys of sandy beaches on islands and the mainland coast of the Kimberley region were conducted on 31 January, 1 February and 2 February 2007 to provide a "snapshot" of turtle nesting activity. Prior to the surveys, principal areas of interest were determined by examining satellite imagery, and all sandy beaches that were more than 200 m long on the coastal islands and the mainland between Broome and the Anjo Peninsula were surveyed. Approximately 80% of all the sandy beaches between these locations were included. The flight paths of the regional aerial surveys are shown in Figure 7-7.

The team for the regional survey in early 2007 used a Kawasaki BK117 helicopter, which was flown at an angle of 45° from the high-water mark on the seaward side of the beaches at an altitude of 80–100 m. The most effective aircraft survey speed to detect turtle tracks and cover the distance required was between 60 and 80 knots, depending on the density of turtle tracks and the speed and direction of the wind.

The surveys followed flooding spring tides occurring before nightfall. This specific tidal condition cleared all old turtle-nesting tracks during the night, exposing only the newly formed tracks the following morning. This allowed the observers to attribute any new tracks between the high-water mark and the low-water mark to turtle activity from the previous night.

Each flight commenced at 6 a.m. and lasted approximately four hours, to take advantage of the low angle of the sun. At low angles, the sun casts shadows across the tracks and makes them more visible from the air. The early morning surveys also enabled the team to take advantage of lighter winds, which meant that there was minimal erosion of the tracks.

The methods for recording the turtle tracks were modified from other aerial surveys undertaken in Australia (Chatto 1998; Waayers 2010) and America (LeBuff Jr & Hagan 1978; Schroeder & Murphy 1999; Shoop, Ruckdeschel & Thompson 1985).

Tracks were first identified with the naked eye and then recorded on a high-definition digital video camera for quantitative analysis. Global positioning system (GPS) coordinates and corresponding times were recorded at the start of each beach transect. Where possible, still images taken from the video footage (Figure 7-8) were analysed to determine the species that had made each track, based on identification methods described by Waayers (2010). For each beach, records were kept of the number of fresh tracks, the species present and the length of the beach. The abundance of tracks was divided into three categories: low (<10 tracks), medium (10–100 tracks), and high (>100 tracks). Densities of fresh tracks were calculated by dividing the total number of fresh tracks per day by the length of the beach in kilometres.

Nearshore aerial surveys

Snapshot aerial surveys were conducted over the nearshore areas of the Bonaparte Archipelago at the commencement of the nesting periods in November 2006 and 2007. Their purpose was to determine the distribution of turtles within the nearshore waters of islands and reefs between Lamarck Island and East Montalivet Island (7–8 November 2006), and between the Coronation Islands area and Long Reef (6–8 November 2007).

The Bonaparte Archipelago was divided into five main areas (Figure 7-9):

- the Coronation Island group—including Coronation, Keraudren, Colbert and Lamarck islands
- the Maret Islands group—including North Maret, South Maret, Turbin, Albert, Corvisart and Berthier islands, and the Robroy Reefs
- the Montalivet Islands group—West Montalivet, East Montalivet, Don, Patricia and Walker islands
- the Bigge Island group—Prudhoe and Bigge islands and the adjacent mainland Kimberley coast
- Cassini Island and Long Reef.

A combination of shoreline (Preen 2001) and line-transect surveys (Marsh & Sinclair 1989; Marsh et al. 1994; Prince 2001) was used to record the distribution of turtles. Sightings of turtles at the surface, within the water column, and on the seafloor (only in shallow areas) were recorded.

In November 2006, a twin-engined Britten-Norman Islander FM/40 aircraft was used in the survey, flying at an altitude of 150 m and at ground speeds of 90–100 knots. Shoreline surveys covered waters up to 520 m from the shore by scanning strips 260 m wide on each side of the aircraft, while line-transect surveys were conducted over the waters between Bigge Island and the mainland coast at a spacing of 2.5 km to avoid double-counting.

In November 2007, the BK117 helicopter was again used, flying at a lower altitude of 30 m and at ground speeds of 60–70 knots. These surveys covered waters up to 105 m from the shore, for 52 m on either side of the aircraft.

Figure 7-8: Green turtle tracks photographed from the helicopter at South Maret Island in February 2007

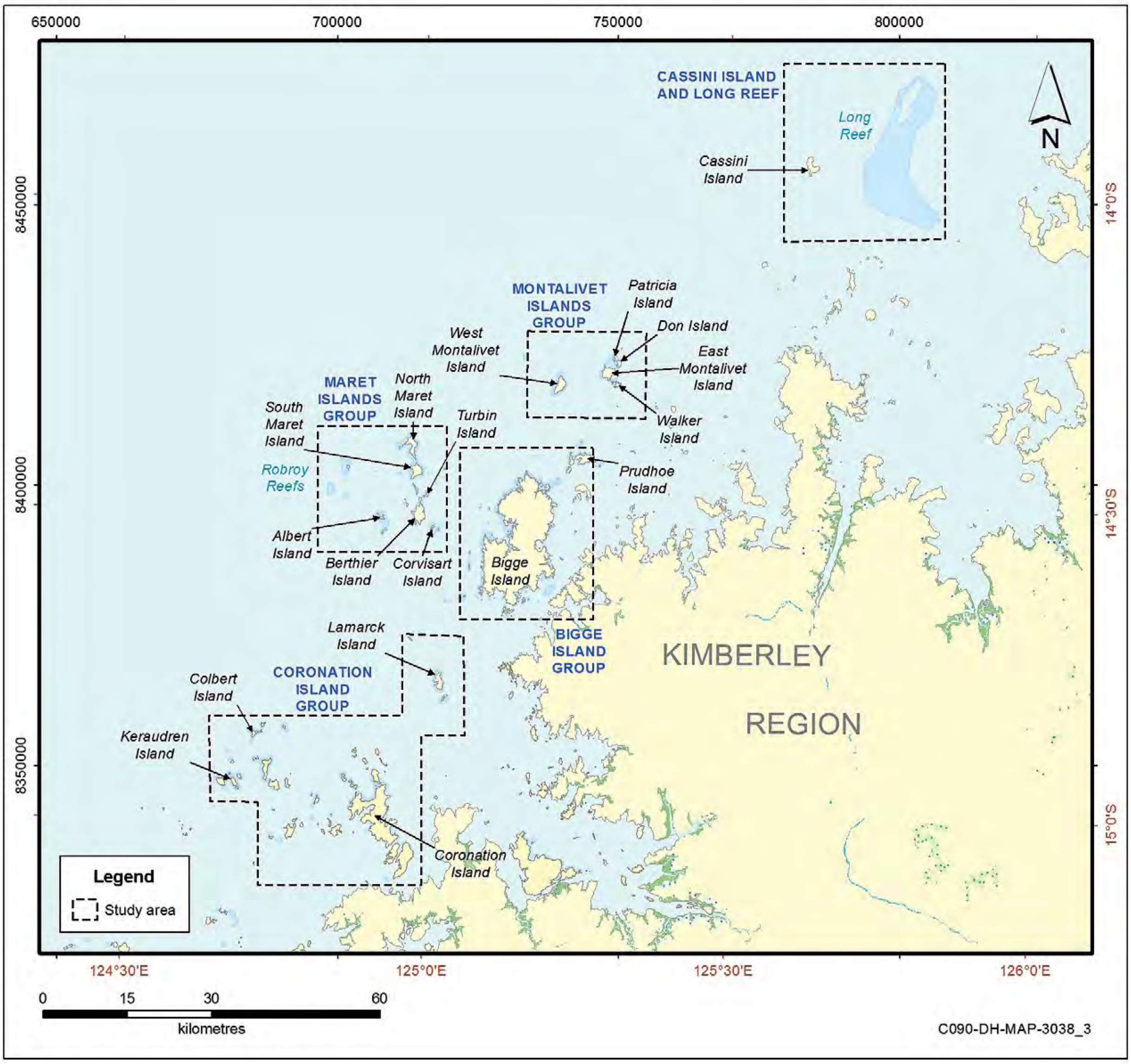


Figure 7-9: Locations of the nearshore areas surveyed for turtles in November 2006 and November 2007

Line-transect surveys were also conducted at the Robroy Reefs and Long Reef. Two observers were used to record turtles, one on the starboard and the other on the port side of the aircraft. The surveys were conducted between 10 a.m. and 2 p.m., with a break at noon, to avoid surface glare from the sun and to take advantage of enhanced light penetration through the water column. Sea-surface conditions were below Beaufort sea state 3 (winds of 7–10 knots), and the cloud cover was less than 4 oktas[7] (sky half cloudy) for all survey days. Observers recorded the location, species, sex, age class and behaviour of turtles where possible.

The spatial distribution of turtles was analysed and presented using ArcMap 10.1. The numbers of turtles were tallied and their densities were calculated for each area. These densities were then compared between areas and years. The different aerial survey sampling methods, however, meant that the abundance of turtles could not be compared between years.

Nearshore vessel surveys

A nearshore vessel study, comprising a combination of line-transect and point surveys, was undertaken in the Bonaparte Archipelago between 29 September and 15 October 2007. The purpose of the vessel surveys was to cover a variety of different habitats that might support marine turtles and to identify areas utilised by turtles. The vessel surveys also provided a means for identifying the different species using different habitats.

[7] In meteorology, an okta is a unit of measurement used to describe the amount of cloud cover at any given location. Sky conditions are estimated in terms of how many eighths of the sky are covered in cloud, ranging from 0 oktas (completely clear sky) through to 8 oktas (completely overcast).

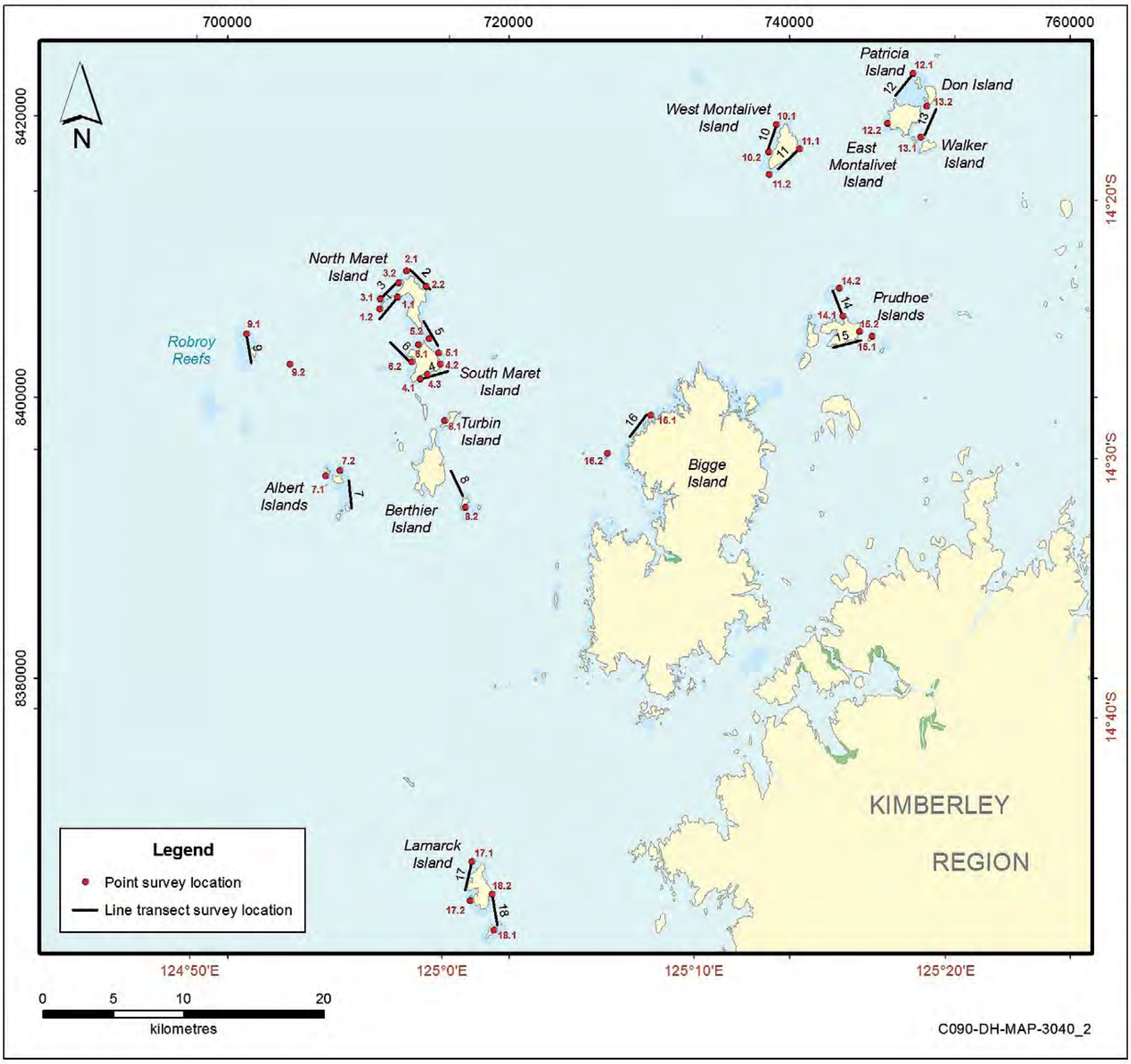


Figure 7-10: Locations of the point and line-transect surveys in October 2007

Line transects (vessel-based)

The locations of the transect lines were selected based on a range of different habitats to identify important mating or probable foraging areas[8]. The important nearshore areas included the Maret Islands group, the Montalivet Islands group, the Lamarck Islands, the Prudhoe Islands and western Bigge Island as shown in Figure 7-10. The strip widths along the 2 km transects were approximately 100 m wide, with each transect covering 200 000 m^2. The survey was conducted from a small vessel that maintained a constant speed of 3 knots. Turtles were recorded at the surface and under the water during the survey. No correction factors were used to account for changes in the environmental conditions. The numbers of turtle sightings within the strip width were tallied for each transect.

Where possible, the species, sex, behaviour (e.g. swimming, diving, surfacing to breathe, or mating), location (as a GPS position), water depth and time of sighting of the turtles were recorded. Turtles were placed into three age classes based on carapace length: juvenile (<50 cm), subadult (50–70 cm) and adult (>70 cm).

Environmental conditions were recorded during the point and line-transect surveys, including the Beaufort sea state number, the cloud cover in oktas, geological features, water temperature, water depth and tide height from local tide charts.

[8] Note that for the purposes of this study, likely foraging areas were identified from the behaviour of turtles and an assessment of the particular environments in which they were observed; however it is not possible to confirm foraging areas without viewing turtles feeding consistently in a particular area.

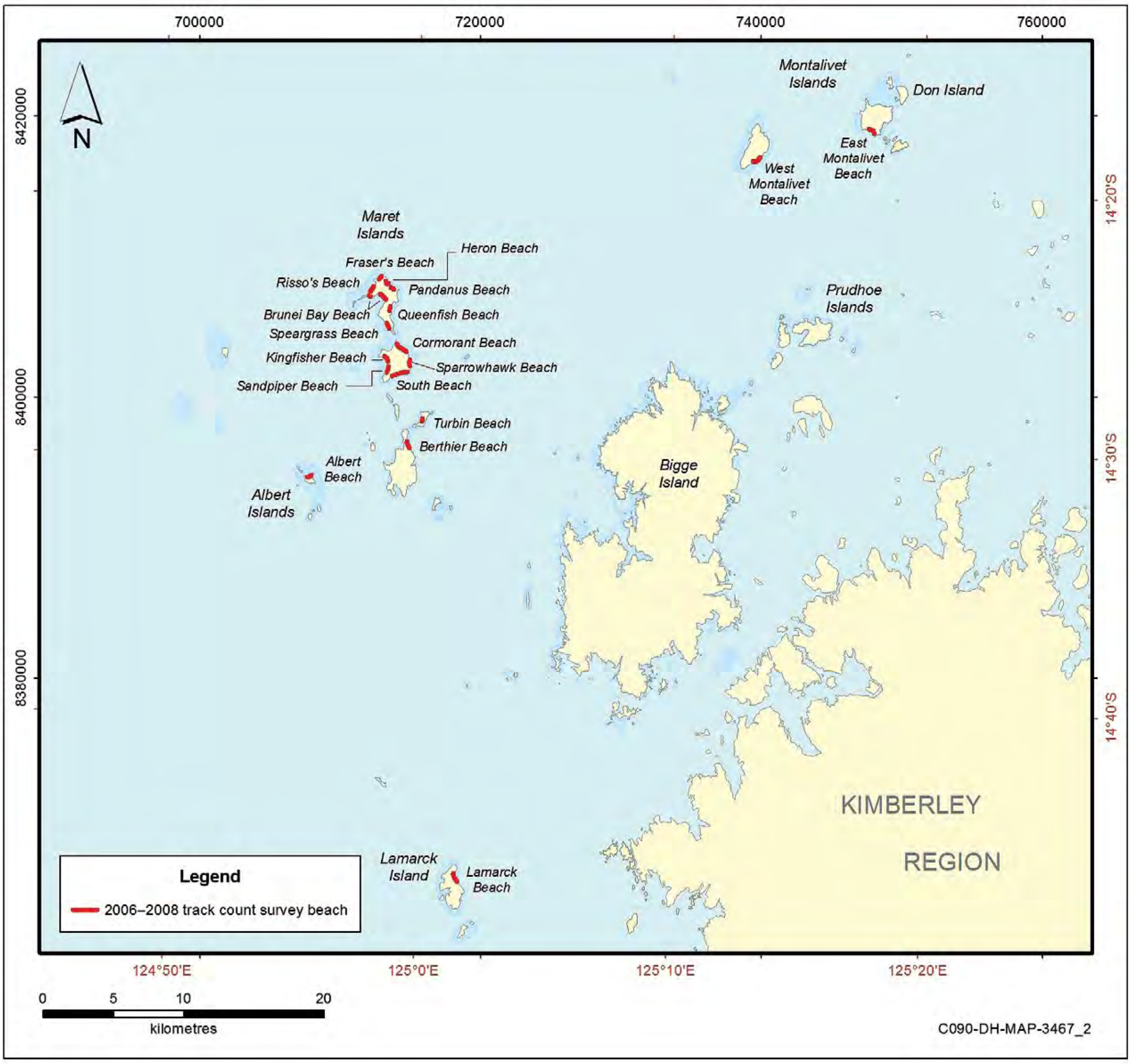


Figure 7-11: Track-count survey sites in 2006–2007 and 2007–2008

Point surveys (vessel-based)

Each point survey was conducted from a stationary vessel in potential foraging habitats at both ends of a line transect. Four observers were positioned on the vessel, with each observer being allocated a 90° quadrant to ensure a 360° view of the survey area. All turtles observed within 50 m of the vessel were recorded and the data recorded included species, sex, age class and behaviour. The vessel was anchored for 30 minutes in order to account for at least one instance of a turtle surfacing (Lutcavage & Lutz 1996). The vessel approached the survey area slowly and drifted for 10 minutes to avoid disturbing the turtles. Possible resightings of turtles were taken into account to minimise double-counting. Binoculars were used to identify distinguishing features of the turtles wherever possible. Observers also recorded whether their sightings were of groups of turtles or of individuals.

Opportunistic sightings

Opportunistic observations of turtles in nearshore waters were recorded during the 2006–2007 and 2007–2008 track-count surveys and while team members were in transit between beaches around the Maret Islands. Uncommon events or species were also recorded by scientists engaged in other types of work during the baseline data collection phase for the surveys. The same parameters, as described above, were recorded for each sighting during the opportunistic observations.

Track-count surveys

Track-count surveys were conducted during the expected green and flatback turtle nesting period to establish the distribution and abundance of turtles within the survey area. South Beach at the south end of South Maret Island was selected as an index beach to detect changes in nesting activity during and between seasons. In 2006–2007, track counts were undertaken each month between December 2006 and March 2007. In 2007–2008, track counts were undertaken between October 2007 and April 2008. Each survey was generally conducted over 14 consecutive days, although surveys in March 2007 were undertaken over four consecutive days. Mid-year surveys were also conducted in July 2007 to record winter nesting activity.

Tracks were recorded on selected beaches of eight islands of the Bonaparte Archipelago (Figure 7-11):

- South Maret Island
  - 2006–2007: South Beach (index beach), Sparrowhawk Beach, Cormorant Beach
  - 2007–2008: South Beach (index beach), Sparrowhawk Beach, Cormorant Beach, Kingfisher Beach and Sandpiper Beach
- North Maret Island
  - 2006–2007: Queenfish Beach, Brunei Bay Beach, Pandanus Beach
  - 2007–2008: Queenfish Beach, Brunei Bay Beach, Pandanus Beach, Speargrass Beach, Risso's Beach, Heron Beach and Fraser's Beach
- Turbin Island (northern beach)—both surveys
- Albert Island (northern beach)—both surveys
- East Montalivet Island (southern beach)—both surveys
- West Montalivet Island (eastern beach)—both surveys
- Lamarck Island (eastern beach)—both surveys
- Berthier Island (north-eastern beach)—2007–2008 survey only.

Track-count surveys were conducted on foot in the early morning, based on methods described in Schroeder and Murphy (1999) and Waayers (2010). All turtle tracks were identified by trained personnel and verified using field guides. Successful nests were distinguished from non-nesting "false crawls"[9] by examining the track and any nesting attempts made by the turtle while on the beach. Characteristics of successful nests include an "escarpment" around a primary body pit, a shallow secondary body pit, and high moisture content in the covering sand (see Figure 7-3 B). It was assumed that in "successful" nesting attempts, the turtle had laid a clutch of eggs. A false crawl involves little or no evidence of digging, in which case the track may simply form an arc-shaped track, or considerable sand disturbance from digging a body pit or egg chamber without evidence of covering.

[9] A "false crawl" is where a female attempts to nest but returns to the sea without laying any eggs.

It was assumed that in false crawls the turtle had not laid a clutch of eggs. After each track was recorded, it was marked with a line in the sand above the high-water mark to prevent double-counting. If the entire beach was completed in one day, the beach was marked. All fresh tracks left by the turtles that had attempted to nest during the previous night were recorded. Track patterns were also recorded, as these are distinctive for each species known to be nesting in the area and allow the turtles to be identified.

The nesting abundance (i.e. the number of nests per night) for each turtle species was compared between beaches to identify important rookeries within the Bonaparte Archipelago. The distributions of nests were presented using contour densities in Esri's ArcMap Spatial Analyst software (ArcView 9.2). The mean number of nests per night was calculated for South Beach on South Maret Island to determine the temporal changes in nesting activity during the nesting season. Nesting success was defined as the proportion of female tracks on the beach that resulted in a successful nesting event. It provides a measure of the proportion of actual nests resulting from the tracks counted during the regional aerial surveys and it is an indicator of the suitability of different beaches for nesting (e.g. acceptable sand moisture content and temperature range). Beaches with fewer than 10 tracks were excluded from the study to avoid biasing results.

Clutch surveys

Clutch surveys were undertaken during the night on the beaches that had been covered in the track-count surveys during the peak hatching period (January to March). Hatchling emergences were detected by patrolling the beaches for hatchling tracks along the high-water mark between 5.30 p.m. and 3.00 a.m. Clutches were identified by following hatchling emergences back to the nest. All nests were marked with a stake and then excavated four days after the first emergence. Clutch contents were categorised as follows (Miller 1999):

- hatched eggs (an eggshell was only counted if more than 50% of the shell was intact)
- live hatchlings remaining in the clutch
- dead hatchlings that had hatched
- unhatched eggs with no embryo
- unhatched eggs with undeveloped embryos
- unhatched eggs with full-term embryos.

Hatching success

Hatching success was measured as the proportion of eggs that successfully hatched (Glen et al. 2005). It was calculated by dividing the number of successfully hatched eggs (empty shells) by the total number of eggs laid in the clutch (empty shells together with undeveloped embryos and dead hatchlings).

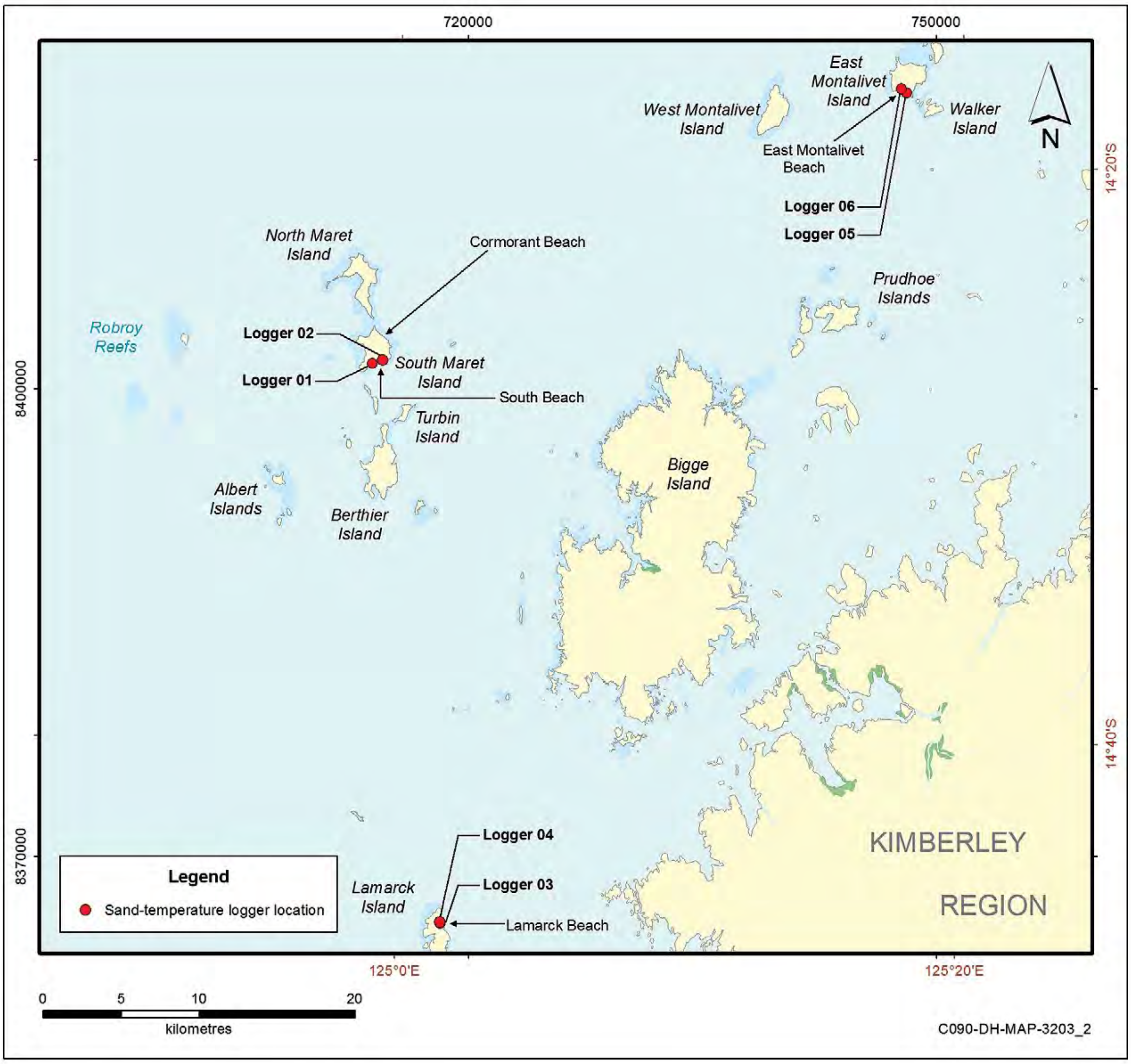


Figure 7-12: The locations of the sand-temperature loggers

Nest depths measured from the sand surface to the top of the egg chamber and from the top of the egg chamber to the bottom of the egg chamber were also recorded.

After the hatching success assessment, hatchling tracks were marked with a line in the sand to prevent duplication of counting and to enable the detection of fresh tracks made by further hatchling emergences from the same nest.

Egg size

During the night surveys, a random sample of 10 eggs was removed from the egg chamber of green and flatback turtle nests during egg-laying. The longest and shortest diameters of the eggs were measured using callipers (Miller 1999). All eggs were returned to the chamber before the nests were covered by the turtles.

Sand temperature studies

Two sand-temperature loggers were installed at South Beach on South Maret Island, two at East Montalivet Beach and two at Lamarck Beach from November 2007 to May 2008 (Figure 7-12). The six iBCod 22L submersible loggers with 8 kB data memory (from Thermodata Pty Ltd, South Yarra, Victoria) were buried below the ground within the nesting zone at average nest depth (taken as 50 cm). The loggers sampled sand temperature every 128 minutes at a resolution of ±0.0625 °C and with a precision of ±0.5 °C. The loggers were retrieved in May 2008, after averaging 2134 readings per logger.

The data were downloaded using an iBClamp logger connection clamp (from Alpha Mach Inc., Mont-Saint-Hilaire, Quebec, Canada) and processed using temperature logging and reporting software from Thermodata Pty Ltd. The temperature range was examined both between islands and within the year.

Satellite telemetry studies

Satellite telemetry was employed in this survey to study turtle movements. A total of 28 satellite Fastloc platform transmitter terminals (PTTs) were attached to the carapaces of female green and flatback turtles from various beaches on the Maret Islands. The time of deployment was scheduled to coincide with the nesting season for these species.

The details recorded for each turtle were as follows:

- the minimum curved carapace length, measured from the anterior midpoint of the nuchal scute to the notch where the two hindmost marginal scutes meet (CCLmin)
- the curved carapace width, measured at the widest part of the carapace between the outer edges of the sixth marginal scutes (CCW)
- the tag number
- the PTT number and the time, date and location of its deployment.

Once the transmitter terminals had been deployed, turtle locations were determined when the turtle was on land or at the sea surface for long enough to permit the satellite to lock on to the signal transmitted by the PTT. A saltwater switch was fitted to the PTTs to extend battery life by turning the transmitter off when the turtle was underwater.

The analysis was divided into three behaviour modes: inter-nesting movements, post-nesting migration, and foraging. The end of the inter-nesting period was indicated by the last nesting event before a turtle immediately travelled away from the nesting area. The post-nesting migration was indicated by transiting behaviour between the last nesting event and a turtle's arrival at its foraging area. The change from a transiting to a foraging behaviour mode was indicated by the turtle adopting an "area-restricted search" pattern within a defined area as described by Kareiva and Odell (1987).

The data did not indicate that any of the deployed PTTs were washed up on shore or otherwise taken during transmission.

Green turtles

Six KiwiSat 101 PTTs were attached to nesting female green turtles on South Beach in December 2006. In March and April 2008, a further 15 KiwiSat 101 PTTs were attached to green turtles from various beaches in the Bonaparte Archipelago to focus on post-nesting migration patterns (see Table 7-11). The PTTs were glued to the second vertebral scute of the turtle's carapace as described in Godley et al. (2003) (Figure 7-13). The scute was scraped clean with a paint-scraper, scrubbed with steel wool, sanded, scored and then cleaned with acetone before the PTT was attached. The fixative used was a two-part epoxy resin, PowerFast Pro (from Powers Fasteners Australasia Pty Ltd, Victoria). The resin was carefully moulded into a hydrodynamic shape in keeping with the general contours of the carapace to help to reduce drag (Watson & Granger 1998). Longlife Antifouling Blue (from International, Coomera, Queensland) was used to prevent algal fouling on the PTT. Turtles were held in a wooden pen for approximately 3.5 hours to allow time for the glue to set.

Flatback turtles

Three Fastloc PTTs were attached to flatback turtles in 2006–2007 and four during 2007–2008 (see Table 7-12). The PTTs were attached to the turtles on the beach while they were returning to the water after nesting, using custom-built harnesses (Figure 7-13) based on a design developed by Sperling and Guinea (2004). The harnesses were designed to detach from the turtles after about a year as the metal crimps around each harness corroded from exposure to sea water.

Figure 7-13: PTT units attached to a green turtle (left) and to a flatback turtle (right) on South Maret Island

Both the Fastloc and the KiwiSat 101 PTTs were configured to operate continuously for the first 90 consecutive days and then to switch to an on–off duty cycle (a 12–72 hour cycle in period 1 and a 12–48 hour cycle in period 2) to prolong battery life. Fastloc PTTs have sensitive GPS receivers that record a positional range from a number of satellites. The data were downloaded from the transmitters via the Argos satellite system and were processed by Sirtrack Wildlife Tracking Solutions. Positioning was most effective when five or more satellites could be detected, with eight satellites providing the most accurate position.

The KiwiSat 101 PTT data were analysed using the Satellite Tracking and Analysis Tool (STAT) program made available by SEATURTLE.ORG (Coyne & Godley 2005). KiwiSat 101 PTTs are generally less accurate than Fastloc PTTs, but provide fixes that are adequate for determining the large-scale distribution of migrating turtles. The three most accurate location classes (1–3) were used to represent the data (Table 7-3).

Table 7-3: Accuracy of Argos and Fastloc GPS data

Accuracy (distance in metres)	Argos data* (class and distance)	Fastloc GPS† (number of satellites and distance)
20	3 (<150 m)	8–10 (19–25 m)
30	3 (<150 m)	7 (32 m)
60	3 (<150 m)	6 (61 m)
150	3 (<150 m)	5 (140 m)
350	2 (150–350m)	5 (140 m)
1000	1 (350–1000 m)	6 (810 m)

* Based on at least four messages during a satellite pass.

† Based on a CEP (circular error probability) of 95%.

The inter-nesting period was defined as the time between PTT deployment and the final nesting event for the season. It was not assumed that a turtle was nesting for the first time at the time of deployment. The inter-nesting analysis involved examining the movements of turtles during the inter-nesting period, estimating the inter-nesting interval (i.e. the number of days between nesting events), and estimating the number of clutches for each individual turtle during the inter-nesting period. The inter-nesting interval was obtained by identifying nesting events on the beach.

The criteria for identifying a nesting event are described below:

- The turtle was located within 150 m of the nesting beach, based on the accuracy of the Fastloc GPS (5–10 satellites) and Argos data (only Class 3).
- The signal of the PTT was strong (>5 satellites).
- The location was recorded at night.
- At least six days had passed before the next nesting event, which is the shortest inter-nesting interval physiologically possible for turtles (Miller 1996).

Post-nesting migration was taken to commence on the day the turtle departed from the nesting area after her final nesting event and continued until she reached an area that was thought to be a foraging ground, which was identified when the turtle remained in the same general area for at least 30 days.

RESULTS

Genetic analysis

Green turtles

The results of mtDNA analyses of tissue samples from green turtles nesting in the Bonaparte Archipelago were found to be similar to those obtained from populations from the NWSgr Management Unit. An analysis of molecular variance (AMOVA) test was run on haplotype frequency data from the Bonaparte Archipelago and published data from the NWSgr, SR, AR, and GoC management units as well as from other management units in the Western Pacific region. The AMOVA demonstrated significant differences between regions ($P < 0.0001$), as well as amongst management units within regions ($P < 0.0001$) and between rookeries within the management units ($P = 0.009$) (Table 7-4).

Population pairwise F_{ST} tests[10] showed that management units within the Australian region were all significantly different, except for the comparison of the Bonaparte Archipelago samples and the NWSgr samples ($F_{ST} = 0.008$, $P = 0.53$). Thus, the green turtles of the Bonaparte Archipelago can be considered to be part of the same management unit as those occurring along the Pilbara coast and at the Lacepede Islands, but distinct from all other management units including those at Ashmore Reef and Scott Reef.

Table 7-4: Hierarchical analysis of molecular variance (AMOVA) in green turtle samples from Australian management units

Comparison	Variance	Percentage total	Probability value	Φ statistics (fixation indices)
Between "regions"	0.055	11.72	<0.0001	$\Phi_{CT} = 0.12$
Among management units within "regions"	0.201	42.41	<0.0001	$\Phi_{SC} = 0.48$
Between rookeries within management units	0.217	45.86	0.009	$\Phi_{ST} = 0.54$

10 In population genetics, the fixation index (F_{ST}) is a measure of population differentiation attributable to genetic structure.

Average pairwise distances between the green turtle population in the Bonaparte Archipelago and populations in other recognised management units were also relatively high (and indicative of significant genetic differences with $P < 0.0001$), with the exception of the GoCgr and NWSgr populations. The genetic similarity between the Bonaparte Archipelago and NWSgr populations is depicted in Figure 7-14, where shorter horizontal bars indicate closer genetic similarity.

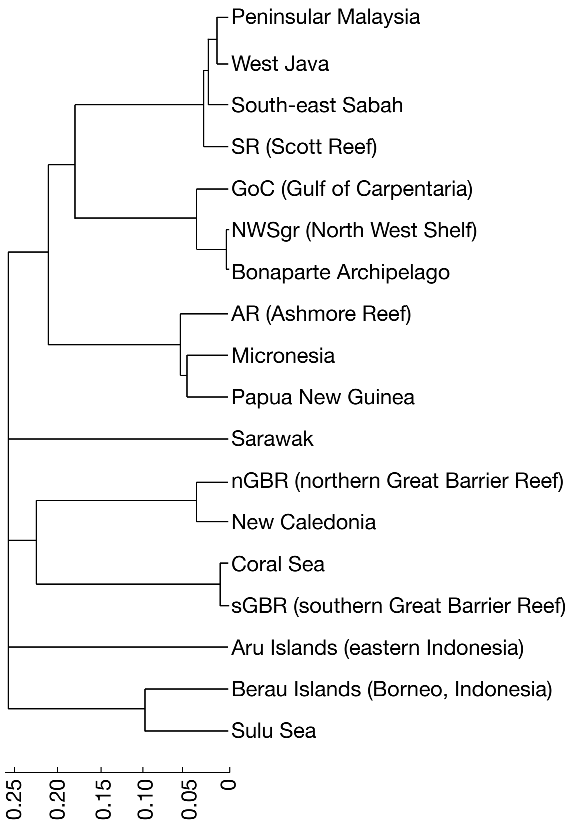


Figure 7-14: Similarity tree showing the relationships (neighbour-joining) among green turtle management units based on haplotype frequencies; the scale indicates genetic distance

Flatback turtles

It appeared that the DNA from a number of the flatback turtle samples from the Maret Islands had degraded prior to the analysis. Of the 28 flatback turtle tissue samples collected during the 2007–2008 nesting season, only 14 had enough mtDNA material for genetic testing. In the case of the other 14 samples that could not be used, ten did not yield DNA of adequate quality to produce sufficient polymerase chain reaction products for sequencing; three were taken from hatchling turtles and could not be used because they could have been offspring of the sampled females; and one could not be used as the sample included an olive ridley haplotype, suggesting that this flatback turtle might have been a hybrid.

The mtDNA from flatback turtles sampled at nesting beaches at the Maret Islands was significantly different from that of turtles from the Cape Domett and the North West Shelf (NWSfl) populations. However, the exact tests of population differentiation and conventional F_{ST} values indicated that there were greater genetic differences between the Maret Islands and the Cape Domett samples ($P = 0.0007$, $F_{ST} = 0.036$) than between the Maret Islands and the North West Shelf samples ($P = 0.003$, $F_{ST} = 0.078$) (Table 7-5). The relatively high F_{ST} P value between the Maret Islands and the North West Shelf samples suggests a past connection between these rookeries or some ongoing gene flow. This linkage is the more likely given the proximity of these rookeries to one another and the mixing of flatback turtles from southern rookeries within the northern foraging areas of the Kimberley region.

The genetic evidence lends some support to the suggestion that the flatback turtle population of the Maret Islands and surrounding islands could be a distinct management unit, the "Bonaparte Archipelago Management Unit". The sample sizes on which this study was based were small, however, and additional studies will be required to confirm this.

Table 7-5: Tests of genetic divergence among flatback turtle populations in Western Australia

Comparison	Distance (km)	Exact test *P* value	F_{ST}	F_{ST} *P* value
Maret Islands vs North West Shelf	400	0.003	0.078	0.038
Maret Islands vs Cape Domett	430	0.0007	0.036	0.00098
Cape Domett vs North West Shelf	830	0.0091	0.14	0.00098

Regional nesting habitat

A total of 1157 fresh turtle tracks were counted on beaches of various Bonaparte Archipelago islands over three consecutive days during the regional aerial surveys on 31 January, 1 February and 2 February 2007 (Table 7-6). Only about half of the tracks could be attributed to a particular species as they were too close together in some areas (e.g. the Lacepede Islands) or the resolution of some of the still images from the video recordings was low. The surveys showed that nesting was widespread, with the greatest abundance of tracks recorded at the Lacepede Islands, the Maret Islands and Cassini Island (Figure 7-15). The offshore islands surrounding the Maret Islands (including the Montalivet Islands and Albert Island) had medium numbers. Low numbers of tracks were recorded on nearshore islands such as Champagny Island, Jackson Island, Colbert Island, Lafontaine Island, the Osborn Islands and North Eclipse Island, as well as at Hat Point on the mainland near Cape Bougainville. No tracks were recorded from the mainland beaches between Broome and Cape Leveque, or from the coastal area along the Mitchell Plateau. Most mainland beaches were identified as unsuitable nesting habitats, for example with rocky outcrops, unstable dune systems, muddy substrates and narrow beaches that are inundated during spring tides.

Of the tracks recorded, 50% were identified to species level based on the track-count methods described above. The unidentified tracks were mostly recorded in high-density track areas (e.g. at the Lacepede Islands). Both green turtles and flatback turtles were recorded on the majority of island beaches.

Table 7-6: Abundance and density of turtle tracks on surveyed islands with sandy beaches between Broome and the Anjo Peninsula

Location	Turtle species identified	Length of beach(es) (km)	No. of tracks	Density (tracks per kilometre)	Percentage of tracks (%)
Lacepede Islands	Green and flatback	8.5	723	85.06	62.49
Maret Islands	Green and flatback	5.66	198	34.96	17.11
Cassini Island	Green and flatback	2.12	70	33.00	6.05
Montalivet Islands	Green and flatback	1.17	38	32.53	3.28
Albert Island	Green and flatback	0.82	26	31.55	2.25
Berthier Island	Green and flatback	1.36	19	14.02	1.64
Prudhoe Island	Green	1.51	19	12.62	1.64
Lamarck Island	Green and flatback	1.10	15	13.60	1.30
Corvisart Island	Green and flatback	0.84	11	13.16	0.95
Colbert Island	Green	2.07	7	3.38	0.61
Lafontaine Island	Green	1.49	7	4.71	0.61
Champagny Island	Green and flatback	0.42	6	14.35	0.52
Keraudren Island	Green	0.29	5	17.18	0.43
Osborn Islands	Green	5.95	4	0.67	0.35
Jackson Island	Green	0.24	3	12.35	0.26
Eclipse Islands	Green	6.75	2	0.30	0.17
Lucas Island	Green	0.28	2	7.22	0.17
Trig Rock (Turbin Beach)	Green	0.20	2	10.15	0.17
Corneille Island	–	2.33	–	–	–
Desfontaines Island	–	0.64	–	–	–
Don Island	–	0.18	–	–	–
Vulcan Island	–	0.33	–	–	–

– = no data.

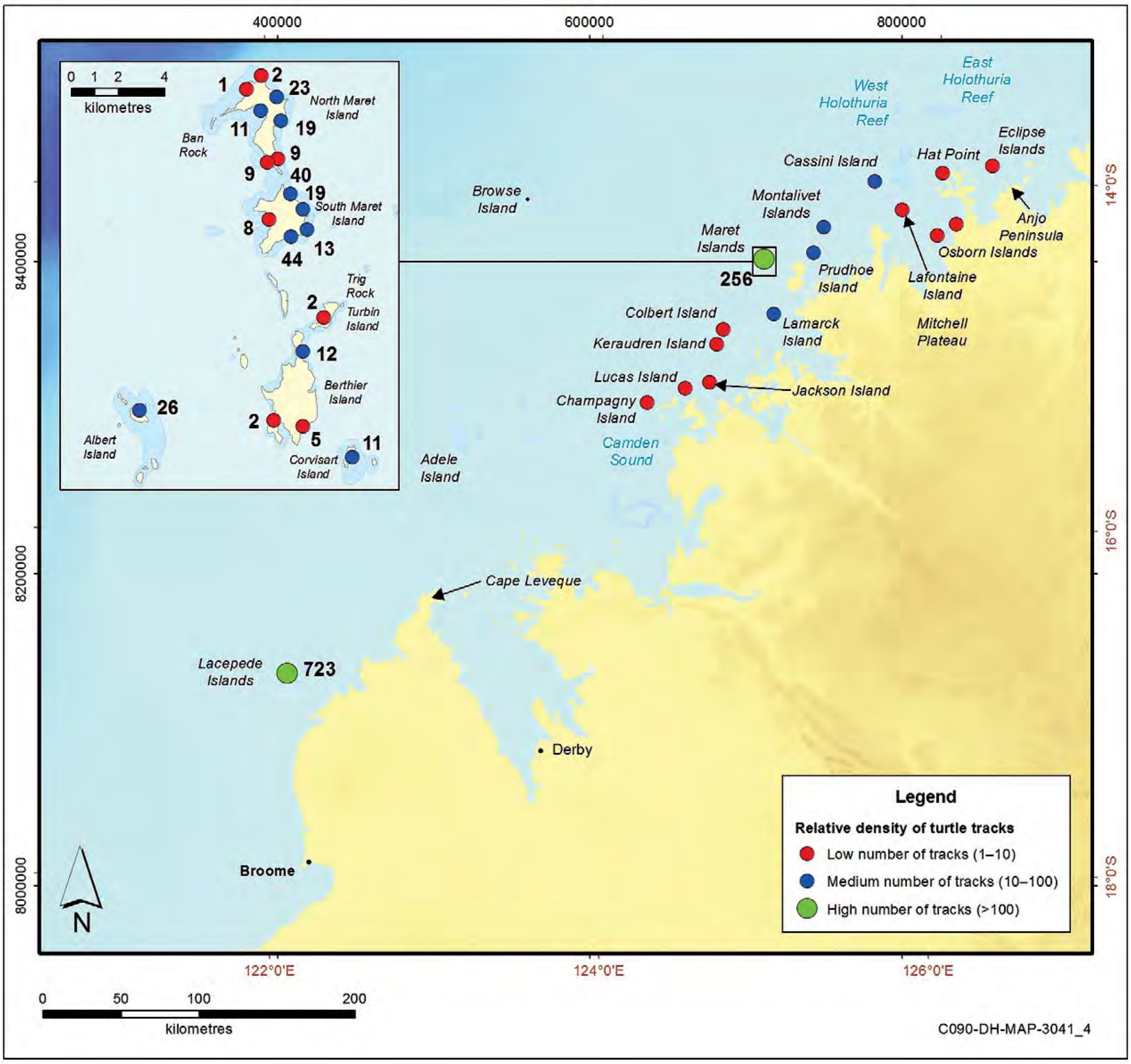


Figure 7-15: Number and distribution of turtle tracks on Kimberley beaches in January 2007

Nearshore habitat

Nearshore aerial surveys

A total of 262 turtles were recorded in the nearshore waters of the Bonaparte Archipelago over two consecutive days in November 2006 (Table 7-7). Not all of these could be positively identified, although the majority of sightings were recorded as green turtles. In 2006, the greatest density of turtles was observed in the waters surrounding the Maret Islands (128 turtles, calculated as 6.2 turtles per square kilometre). Three mating pairs were recorded adjacent to Sparrowhawk Beach on South Maret Island. Ten aggregations (10–20 turtles) were recorded in the nearshore waters encompassing South Maret, North Maret, Berthier, Albert, Lamarck, West Montalivet and Bigge islands (Figure 7-16). Five of these aggregations were around the Maret Islands. There were 11 smaller aggregations (5–10 turtles) of which only two were adjacent to the Maret Islands.

In November 2007 a total of 2144 turtles were recorded during the aerial surveys (Table 7-7). Seventy-eight per cent of these were sighted at Long Reef (Figure 7-17) and of these, 1062 were recorded along the western edge of Long Reef, giving a density of 580 sightings per square kilometre. The density of turtles was also high at Cassini Island, with 129 sightings per square kilometre. The majority of sightings (84%) were of adult green turtles. Flatback and hawksbill turtles were recorded in all sections of the survey area, while only three loggerhead turtles were identified (in shallow water at Long Reef).

Table 7-7: Summary of turtle sightings in the nearshore waters of the Maret Islands and surrounding islands detected during the nearshore aerial surveys in November 2006 and November 2007

Sections	November 2006			November 2007		
	Area covered (km²)	No. of sightings	Density (turtles/km²)	Area covered (km²)	No. of sightings	Density (turtles/km²)
Coronation Islands	n.s.	n.s.	n.s.	13.2	47	3.6
Lamarck Island	5.7	23	4.0	1.4	34	24.6
Maret Islands	20.8	128	6.2	5.0	83	16.6
Robroy Reefs	n.s.	n.s.	n.s.	6.6	17	2.6
Montalivet Islands	9.4	36	3.8	2.3	56	24.7
Bigge Island	82.4	75	0.9	6.2	41	6.6
Cassini Island	n.s.	n.s.	n.s.	1.2	194	158.5
Long Reef	n.s.	n.s.	n.s.	12.9	1672	129.4
Total	**118.3**	**262**	**n.a.**	**48.8**	**2144**	**n.a.**

n.s. = not surveyed

n.a. = not applicable

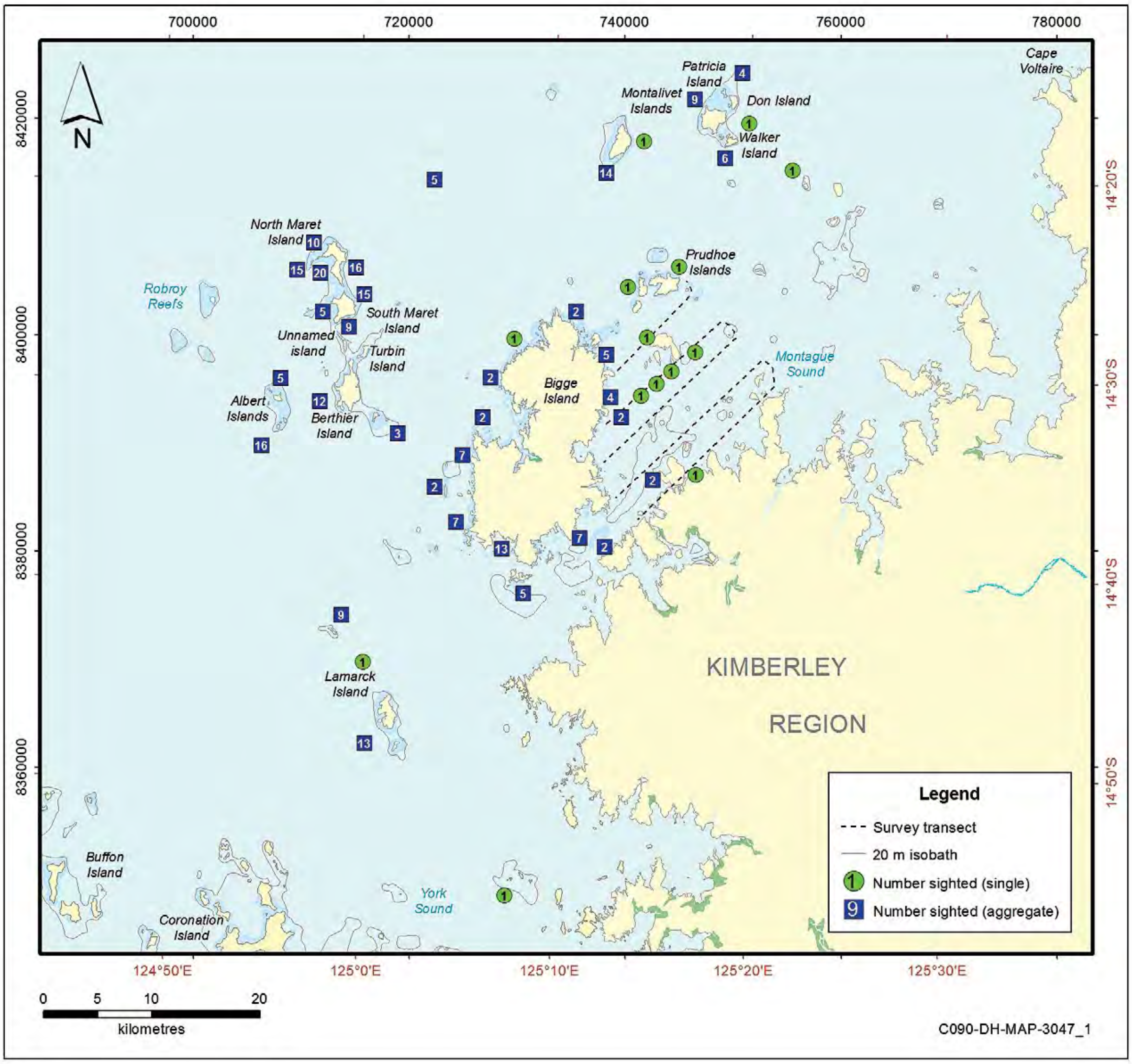


Figure 7-16: Numbers of sightings of turtles in the Bonaparte Archipelago during the nearshore aerial surveys in November 2006

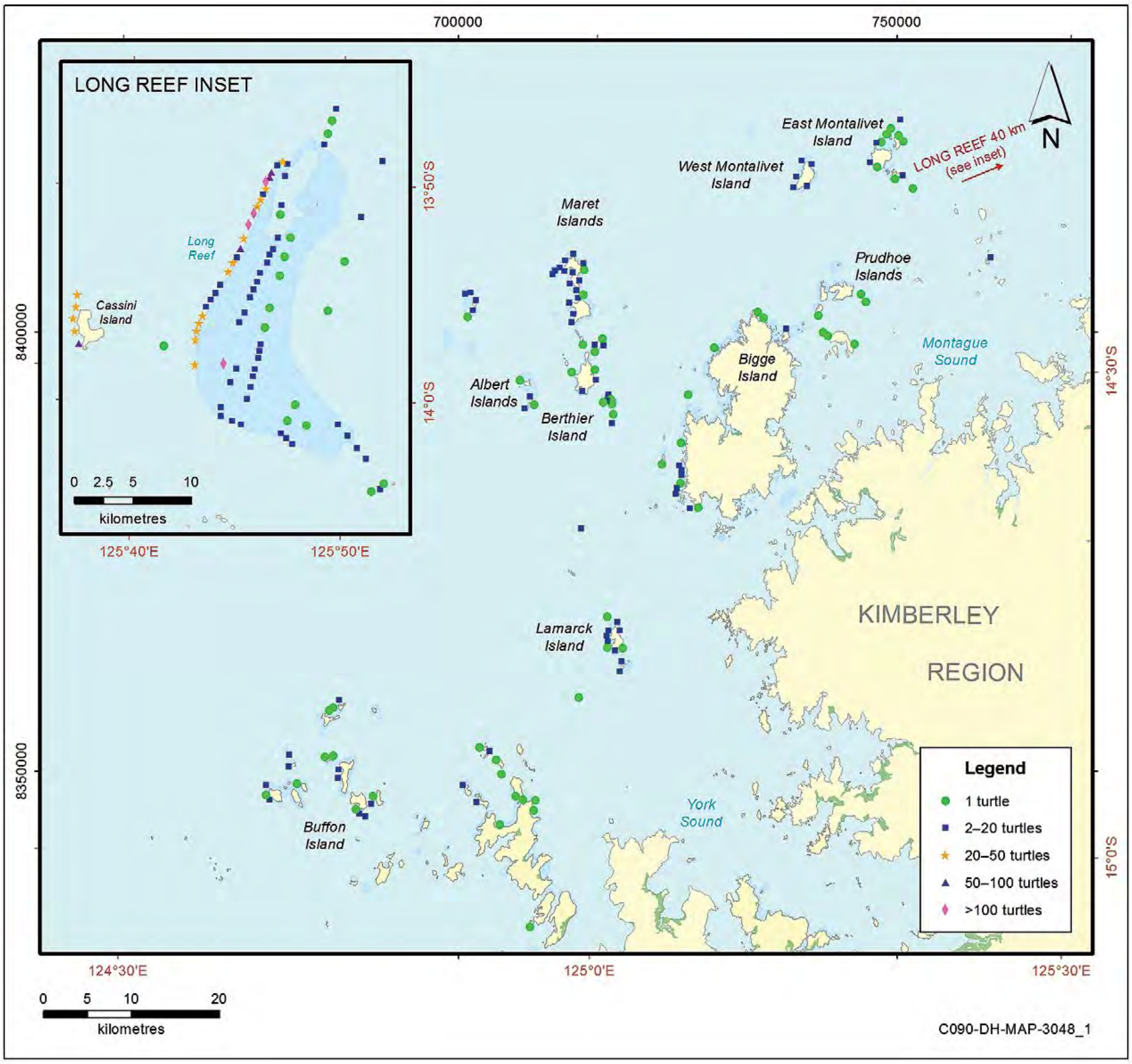


Figure 7-17: Distribution of turtle activity in the Bonaparte Archipelago during the nearshore aerial surveys in November 2007

Vessel surveys

Point surveys

Vessel-based point surveys in nearshore areas of the Bonaparte Archipelago were conducted in October 2007. The localities with the highest number of turtle sightings were the northern section of the Robroy Reefs (49 turtles), the northern point of North Maret Island (44 turtles), an islet off the north-west point of North Maret Island (32 turtles), an area to the north of Lamarck Island (30 turtles), and an area to the south-west of West Montalivet Island (29 turtles) (Figure 7-18). All of these sites were in waters less than 6 m deep and consisted of either coral reef or macroalgal habitats.

During the point surveys in October 2007, 289 turtles were positively identified (93% of the total seen) and 283 of these were green turtles (98%), with most of them being observed over extensive meadows of brown macroalgae of the genus *Sargassum*. Flatback turtles were recorded at Corvisart Island (two sightings) and in the northern section of the Robroy Reefs (two sightings). Hawksbill turtles were recorded at Patricia Island (two sightings).

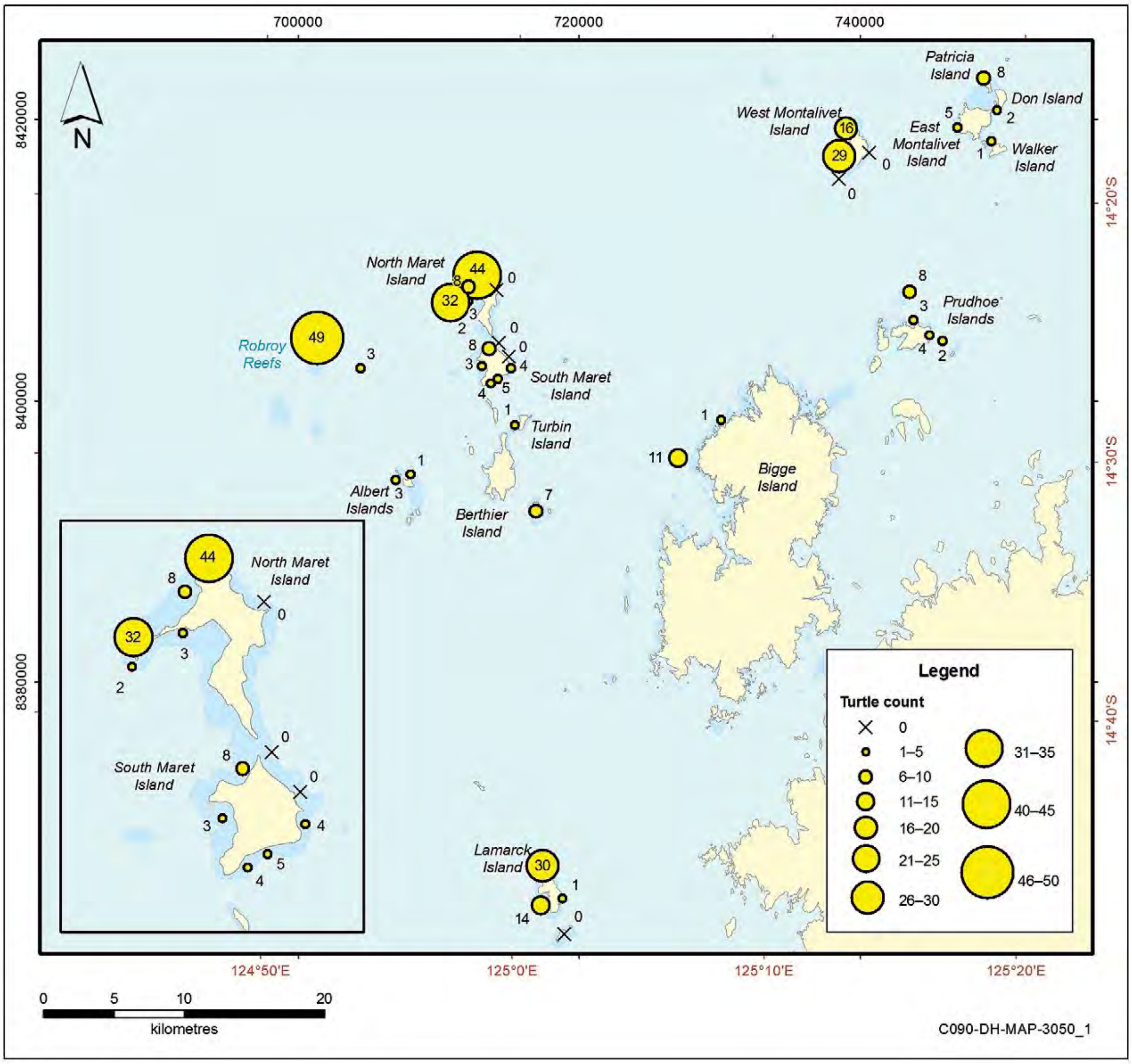


Figure 7-18: The distribution of turtles at the Maret Islands and surrounding islands from a vessel-based survey in October 2007

Fifty-six per cent of the turtles seen were juveniles (n = 176) and 38% were adults (n = 120). Adult, subadult and juvenile turtles were found at the majority of sites surveyed. Most of the adults were recorded at North Maret Island, whereas juvenile and subadult turtles were mostly sighted in the northern section of the Robroy Reefs. Although both male and female adult turtles were observed, the proportion of males to females is unknown because of difficulties in sighting the tails of many individuals (males have markedly longer tails than females).

Most turtles (82.3%, n = 255) were recorded when they surfaced to breathe and some dived under the water when they saw the boat. No mating activity was observed at any of the sites.

Line transects

The highest number of turtles encountered along line transects were north of West Montalivet Island (34 turtles), north of Lamarck Island (23 turtles) and at the Robroy Reefs (10 turtles). The most commonly identified species was the green turtle (79%).

The majority of turtles sighted along the Robroy Reefs transect were adults (60.0%, n = 10). Subadults and juveniles were most common at the north of Lamarck Island (82.6%, n = 23) and at the north of West Montalivet Island (58.8%, n = 34). One juvenile green turtle was seen feeding in *Sargassum* seaweed on the sea surface during the line-transect survey north of Lamarck Island. As with the observations from the point surveys, the majority of turtles were seen as they were surfacing to breathe.

Opportunistic sightings

Opportunistic sightings were made during the baseline data collection phase of the survey. Green turtles were observed mating in nearshore areas around the Maret Islands during morning track-count surveys between 6 a.m. and noon in December 2007 and January 2008 (Figure 7-19). Sightings were generally in the nearshore waters off South Beach, Sparrowhawk Beach, Cormorant Beach and Brunei Bay Beach. Single adult green turtles were sighted mainly in nearshore waters adjacent to the north-western side of North Maret Island and the eastern and southern beaches of South Maret Island.

Opportunistic sightings of turtles from other scopes of work included the following:

- A pair of flatback turtles was observed mating in the nearshore waters adjacent to Brunei Bay Beach. Two single adult flatback turtles were also sighted at Cormorant and Fraser's beaches.
- An adult loggerhead turtle was sighted in the sea off East Montalivet Island.
- A leatherback turtle was observed in the water off South Beach in late January 2007. The turtle was described as a large black subadult, approximately two metres in length and one metre in width. Leatherback turtles were also recorded off Browse Island during vessel-based whale surveys in October 2006.
- Two hawksbill turtles were seen in the water at East Montalivet Island during track-count surveys. A hawksbill turtle was also found on the reef platform on North Maret Island in September 2007 (Figure 7-19).

Nesting habitat on the study beaches

In the 46 days surveyed between 6 December 2006 and 21 March 2007, 4280 tracks were recorded at the Maret Islands and surrounding islands, with 34% (1470) of these tracks resulting in a nesting event. Green turtles were the predominant species, making up 87% of the nesting effort. The number of green turtles decreased in the 2007–2008 nesting season, with flatback turtles predominating and making up 65% of the nesting effort.

Although tracks were recorded on all beaches on the Maret Islands, some beaches, including Risso's and Fraser's beaches on North Maret Island and Kingfisher Beach on South Maret Island, were not considered to be productive beaches as their nesting densities were very low and no hatchling emergences were detected. These beaches are periodically inundated by spring high tides, which would drown any clutches.

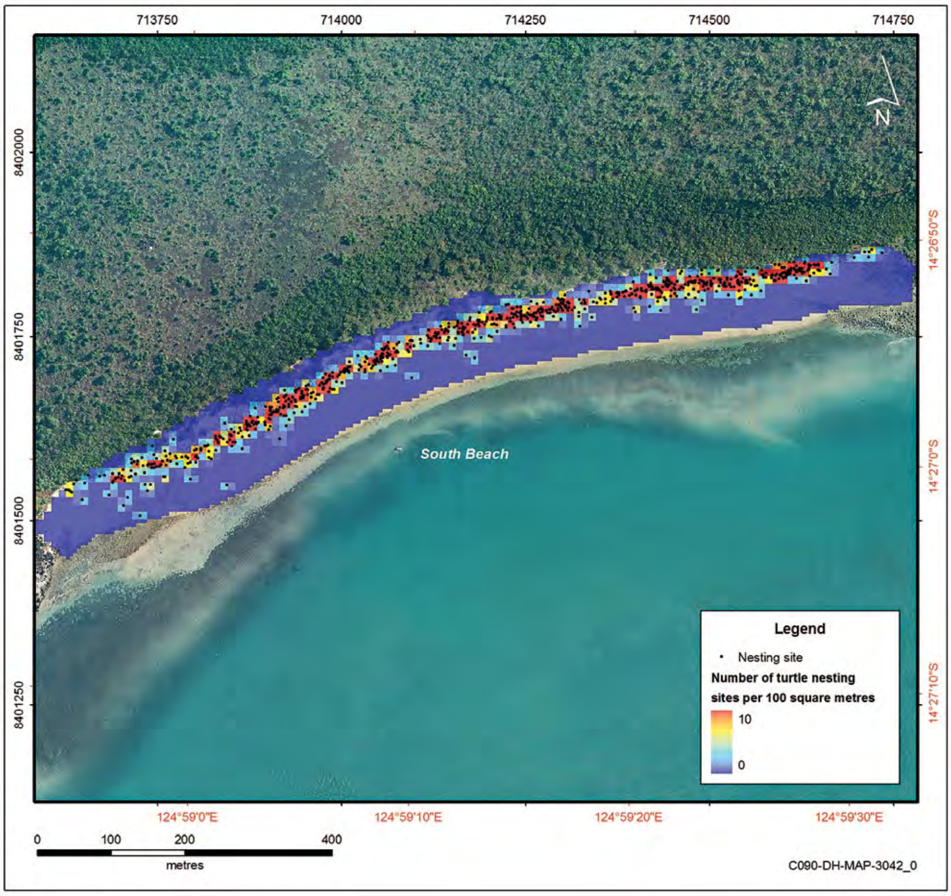
Nests were evenly distributed along beaches on the Maret Islands (figures 7-20 and 7-21). The majority of nests on all beaches surveyed were on the primary dune or at the edge of the terrestrial vegetation. Few nests were recorded below the spring-tide high-water mark or landward of the secondary dune.

The mean sand temperatures at nest depth were consistent between most beaches, although at East Montalivet and Lamarck islands the sand temperatures were slightly cooler (Table 7-8). Sand temperatures ranged between 25.3 °C and 34.7 °C during the 2007–2008 nesting season. All sites showed a similar pattern in temperature changes over the five-month study period.

Photographs courtesy of David Waayers (left) and Raquel Carter (right)

Figure 7-19: Green turtles mating at the water's edge at South Beach in December 2007 (left), and a hawksbill turtle found on a reef at North Maret Island in September 2007 (right)

7 MARINE TURTLES



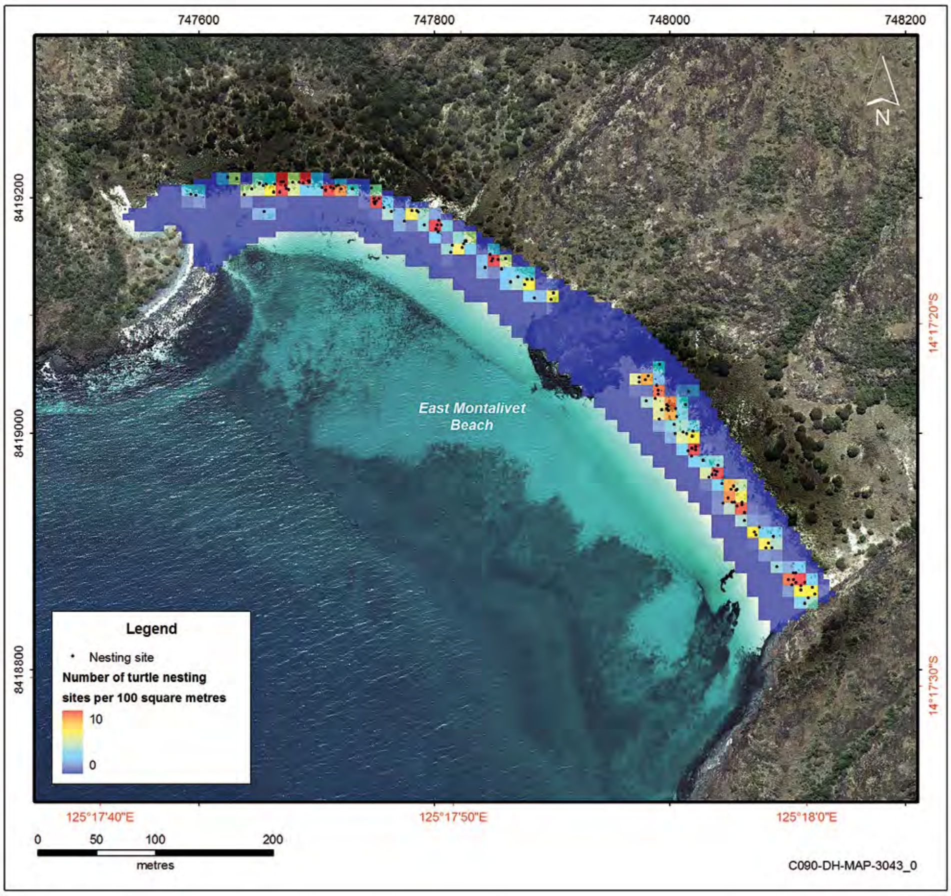


Figure 7-20: Distribution of nesting sites of green and flatback turtles along South Beach on South Maret Island (above) and East Montalivet Beach (below) between December 2006 and March 2007

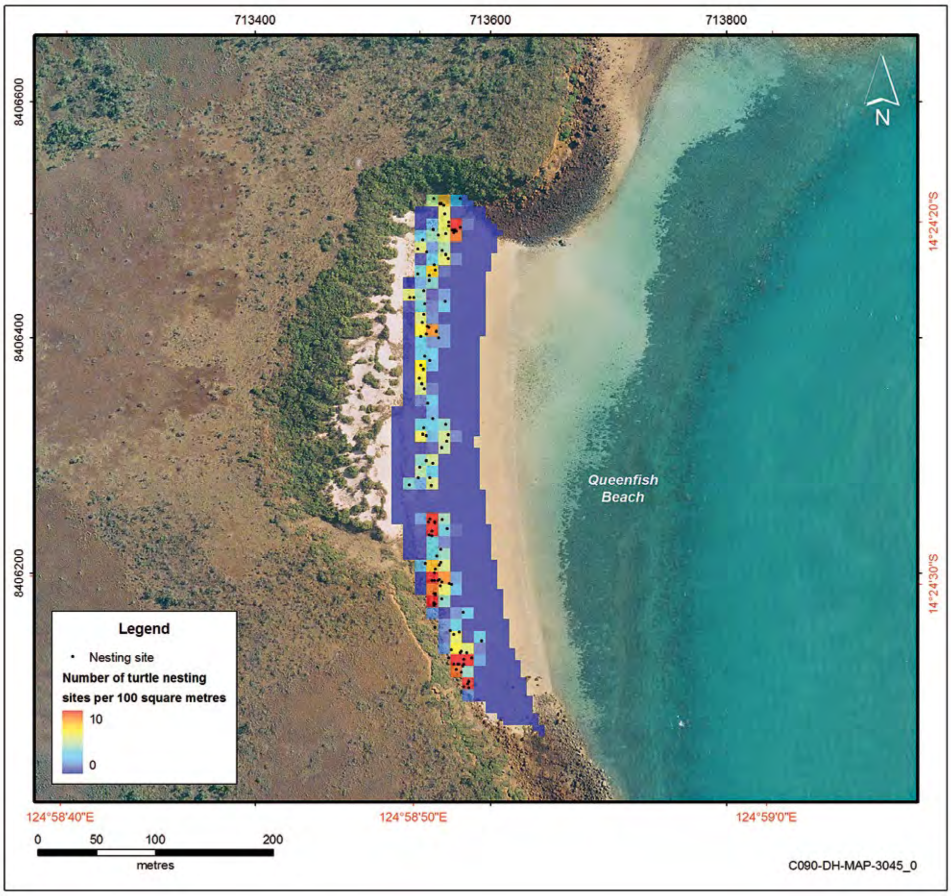


Figure 7-21: Distribution of nesting sites of green and flatback turtles along Cormorant Beach on South Maret Island (above) and Queenfish Beach on North Maret Island (below) between January and March 2007

Figure 7-22 presents the sand temperature fluctuations at South Beach from 10 November 2007 to 17 May 2008. It shows a gradual increase in temperature from November to mid-December followed by two dramatic decreases in temperature (approximately 7 °C) in early January and mid-February, which coincided with dense cloud cover, heavy rainfall and tropical cyclone activity in the region.

Table 7-8: Summary of sand temperatures at nest depth for South Beach (South Maret Island), Lamarck Beach and East Montalivet Beach during the 2007–2008 survey

Location	Minimum temperature (°C)	Maximum temperature (°C)	Mean temperature (°C) (standard error in brackets)
South Beach west	28.7	33.8	31.9 (0.03)
South Beach east	28.8	33.1	31.4 (0.02)
Lamarck Beach south	26.2	34.7	31.5 (0.04)
Lamarck Beach north	26.6	33.9	31.6 (0.03)
East Montalivet Beach east	25.3	33.9	31.1 (0.04)
East Montalivet Beach west	25.5	33.9	31.0 (0.03)

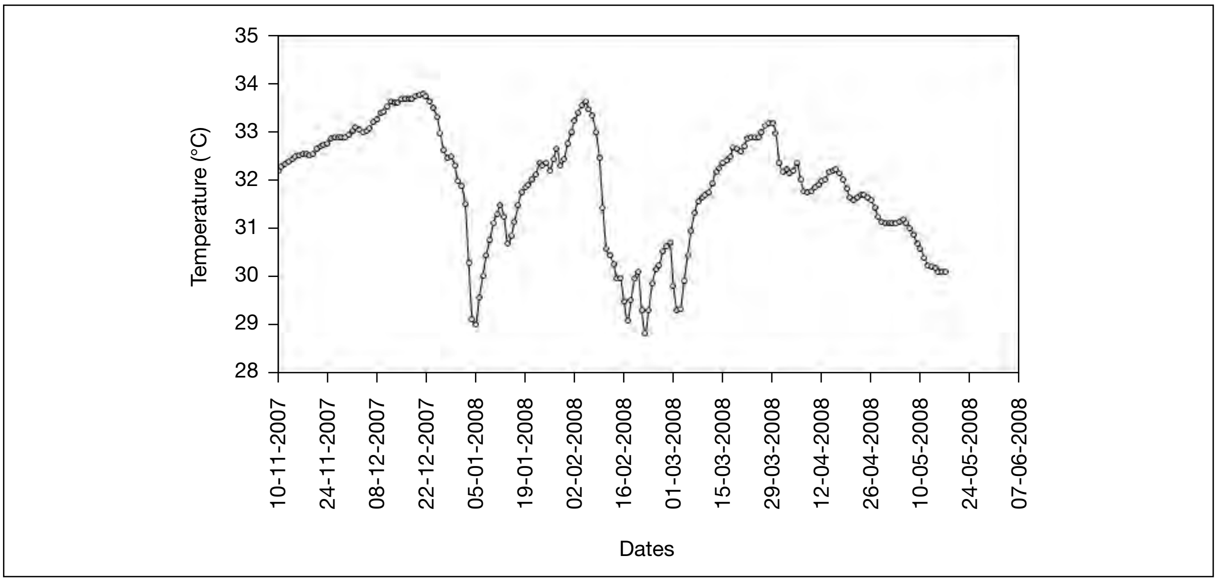


Figure 7-22: Sand temperatures at nest depth for South Beach, South Maret Island, during the 2007–2008 nesting season

Green turtles

Seasonal variation

Figure 7-23 shows the mean number of green turtle nests per day at South Beach on South Maret Island during the 2006–2007 and 2007–2008 nesting seasons. The turtles were already nesting when the survey commenced on 6 December 2006. The results showed that the number of green turtle nests per day increased twofold from December 2006 to the peak of the nesting season in January and February 2007, and then gradually decreased in March.

The number of tracks per day also showed a similar seasonal pattern with the peak occurring in early February (Figure 7-24). The seasonal trend indicated that the nesting season continued beyond 21 March 2007. (This was also evident in the following season, with nesting continuing beyond 11 April 2008.) No surveys were conducted in April, May, June, August, September and October 2007. However, a 14-day survey in July 2007 recorded one green turtle nest at South Beach.

In the 2007–2008 nesting season, green turtles commenced nesting at South Beach on South Maret Island in December 2007; low-level nesting activities were recorded from 9 November 2007 on other beaches of the Maret Islands. The mean number of green turtle nests per day on South Beach decreased by a quarter in the 2007–2008 nesting season compared with the previous season.

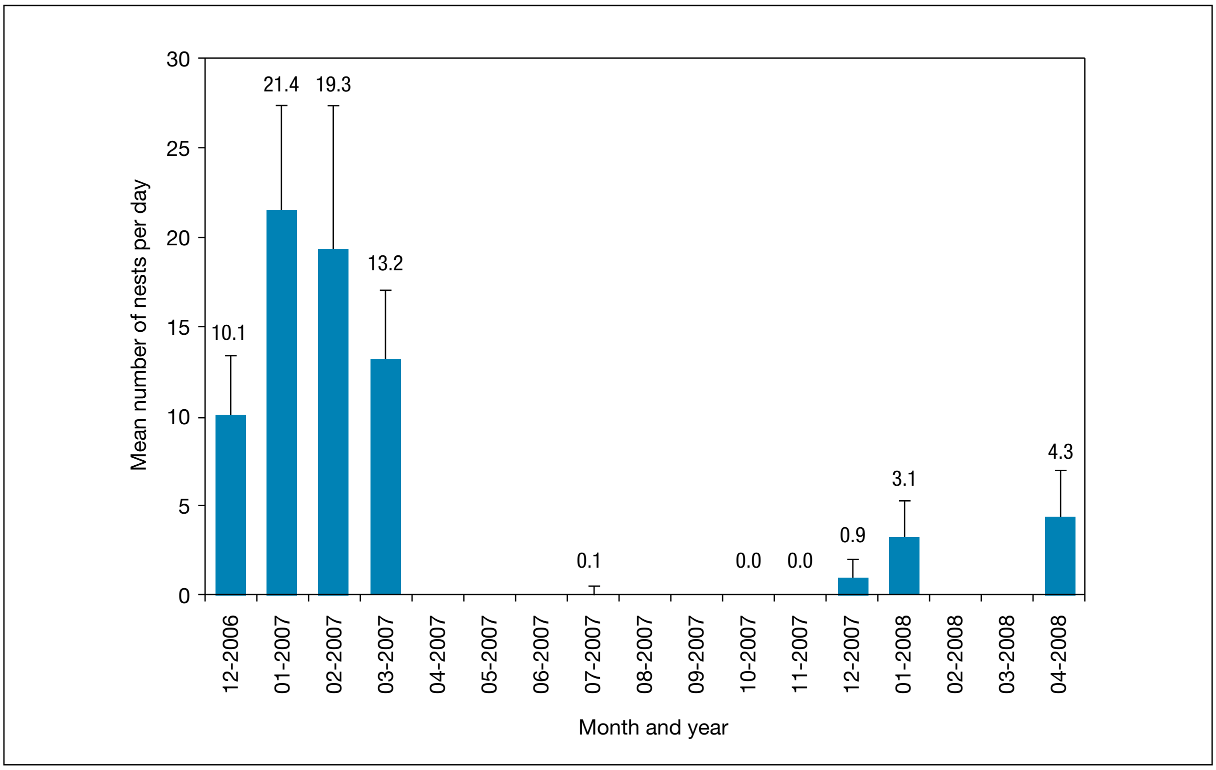


Figure 7-23: Mean number of green turtle nests per day for each month surveyed at South Beach, South Maret Island, between December 2006 and April 2008. Error bars represent the standard deviations. Months without data were not surveyed (April–June 2007, August–September 2007 and February–March 2008). No nests were recorded during the November 2007 survey. All surveys were undertaken over 14-day periods, with the exception of April 2008 when saltwater crocodiles were sighted at South Beach and the survey was restricted to 6 days

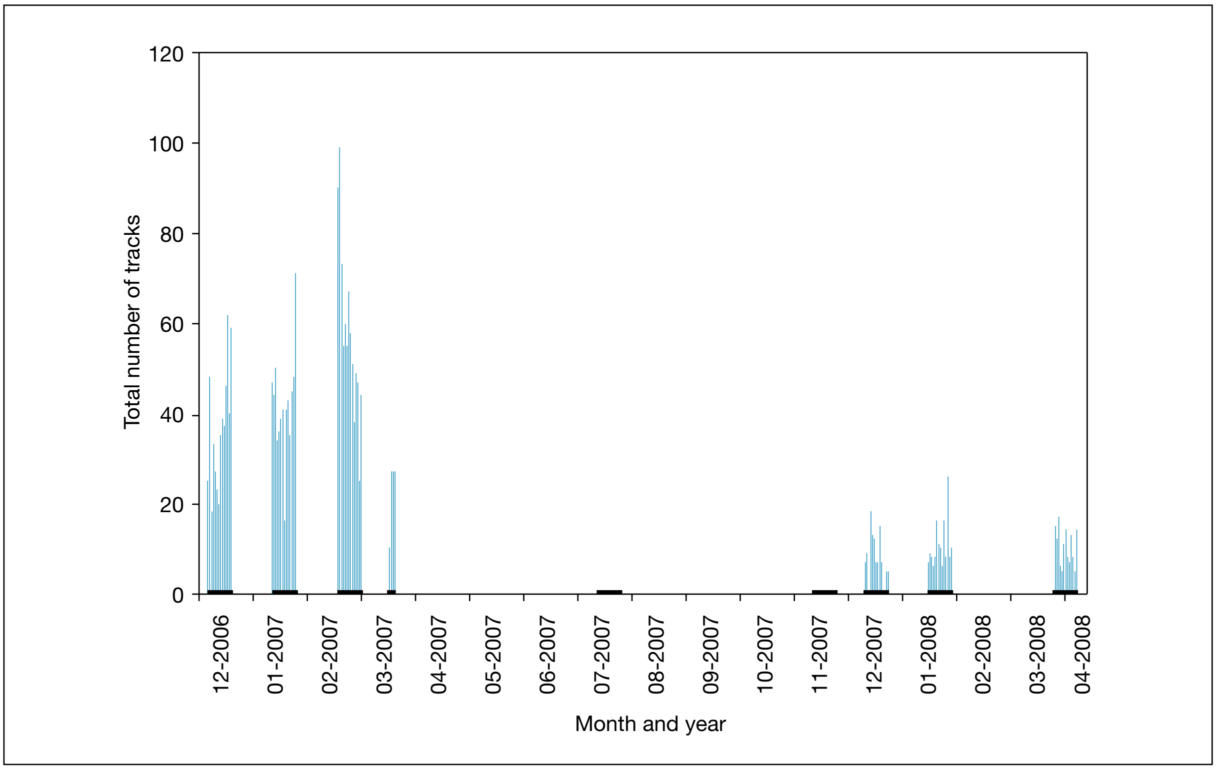


Figure 7-24: Total number of green turtle tracks per day on South Beach, South Maret Island, between 6 December 2006 and 11 April 2008. The black bars on the x-axis represent the survey periods

7 MARINE TURTLES

Spatial distribution and abundance

Figure 7-25 summarises the data collected at each of the study sites in January 2007. During 14 days at the peak of the nesting season in January 2007, 61% of green turtle nests were recorded on South Maret Island and 14% were found on North Maret Island. The mean nesting frequencies were highest at South Beach and Cormorant Beach on South Maret Island, at Brunei Bay Beach on North Maret Island, and at East Montalivet Beach. The average nesting success for green turtles across all survey sites was 40% (n = 10, mean = 0.4, SE = 0.04). Nesting success was relatively consistent between sites, with the highest nesting success at Cormorant Beach (56%), Sparrowhawk Beach (56%) and South Beach (51%).

In January 2008, the majority of green turtle nests were recorded on South Maret Island (53%), with 5% recorded on North Maret Island. No green turtle nests were recorded on Turbin Beach or Lamarck Beach in January 2008 (Figure 7-25). As in 2007, the mean nesting frequencies of green turtles were highest on South Beach, West Montalivet Beach, East Montalivet Beach and Cormorant Beach. However, the average nesting success for green turtles across all survey sites in January 2008 was less than in the previous year (n = 6, mean = 0.22, SE = 0.05). Of the beaches included in the analysis, nesting success was highest at West Montalivet Beach (38%) and South Beach (30%), but lowest at Brunei Bay Beach (5%). Nesting success was not calculated for Queenfish, Albert, Turbin, Lamarck and Berthier beaches because of the low numbers of nests.

Clutch characteristics

The times of green turtle hatchling emergences at the Maret Islands in February–March 2007 are shown in Figure 7-26. Of the 33 green turtle hatchling emergences recorded on the Maret Islands, the majority (79%) occurred early in the night, between 6 p.m. and 9 p.m. Most of the hatchlings (33%) emerged from their nests immediately after sunset, between 6 p.m. and 7 p.m. Hatchlings from the same nest often emerged from the nest over several consecutive nights.

The productivity parameters for green turtles at the Maret Islands in the 2006–2007 nesting season are given in Table 7-9. Green turtles deposited an average of 67 eggs per clutch, with 85% of the eggs hatching during the peak nesting period. No significant difference in clutch success was found between sites (single-factor ANOVA: n = 46, F = 1.78, P > 0.05). The average egg diameter was 4.12 cm. The nest depth was relatively consistent across all beaches with an average of 53 cm from the surface to the top of the egg chamber and a further 34 cm to the bottom of the egg chamber (Table 7-9).

Carapace size measurements for nesting green turtles

Carapace size measurements were made for a number of green turtles returning to the sea after nesting.

The mean minimum curved carapace length of nesting green turtles at the Maret Islands was 95.2 cm (n = 61, SD = 0.7, range = 84–107) and the mean curved carapace width was 86.3 cm (n = 61, SD = 0.8, range = 74–97).

Table 7-9: Productivity parameters for green turtles at the Maret Islands in the 2006–2007 nesting season

Parameters	Mean	Standard deviation	Range	Number
Eggs per clutch	66.63	2.10	31–98	46
Hatching success	85.05%	2.02	29–100	46
Egg diameter	4.12 cm	0.13	38–43	96
Nest depth (beach surface to top of egg chamber)	53 cm	2.18	31–89	33
Nest depth (top of egg chamber to bottom of egg chamber)	34 cm	1.75	17–61	31

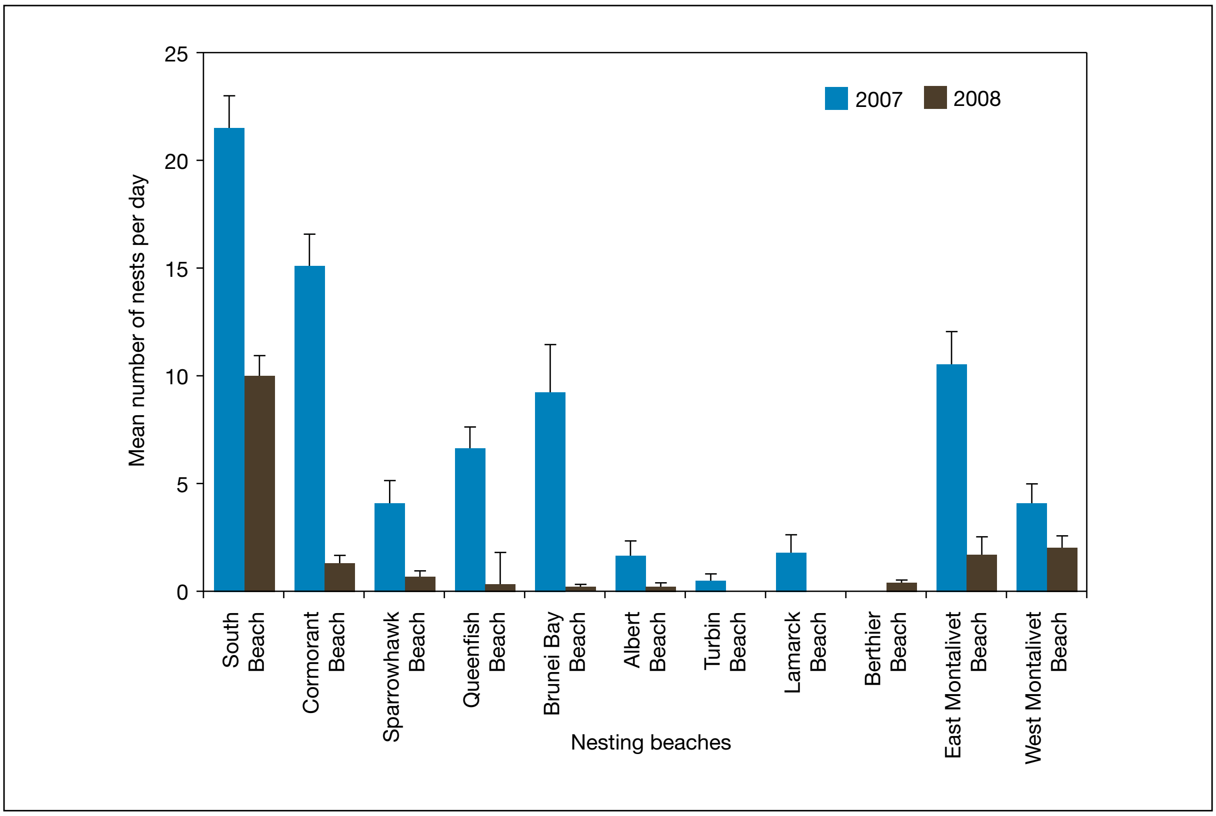


Figure 7-25: Mean number of green turtle nests per day at all study sites in January 2007 and 2008 (n = 14 days), with bars representing the standard errors

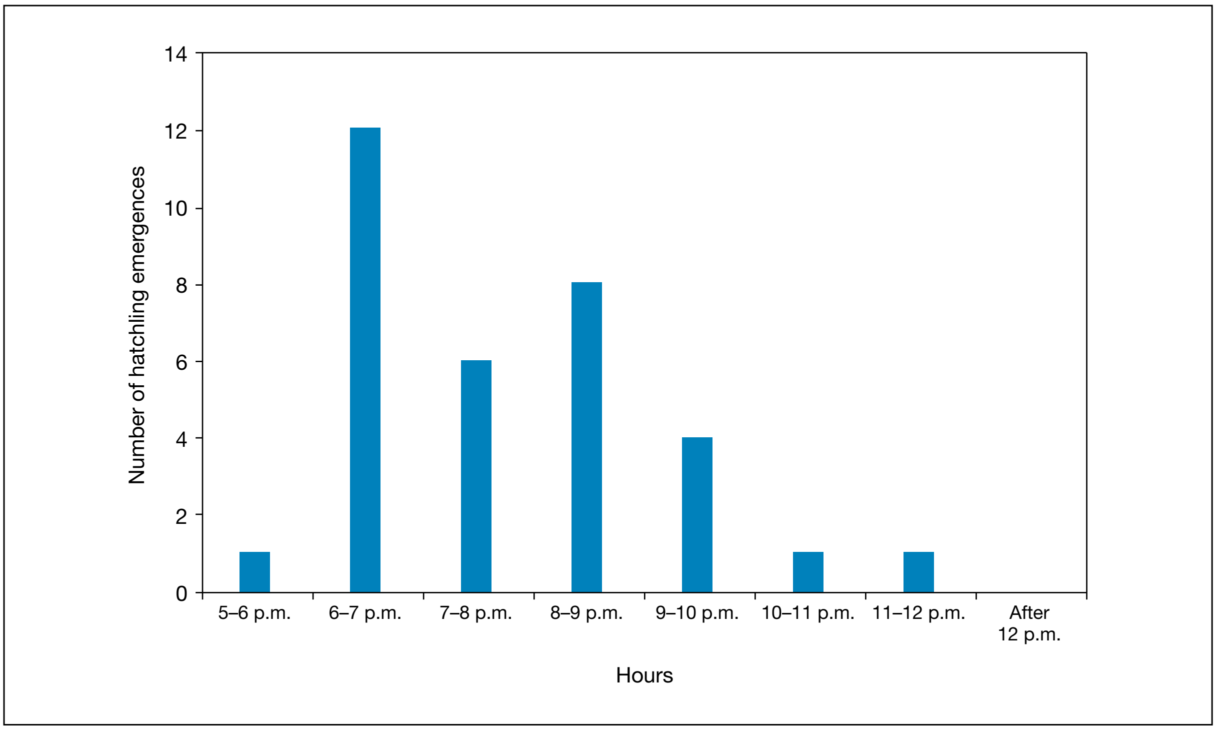


Figure 7-26: Time of green turtle hatchling emergences at the Maret Islands in February and March 2007 (n = 33)

Flatback turtles

Seasonal variation

Figure 7-27 shows the mean numbers of flatback turtle nests per day at South Beach on South Maret Island during the 2006–2007 and 2007–2008 nesting seasons. The nesting period for flatback turtles during 2006–2007 appeared to have begun before the survey commenced on 6 December 2006. This was also observed in the following season, with nesting occurring after 15 October 2007 (when the survey team left the island) and before 6 November 2007 (when the survey recommenced). The mean number of nests per day gradually decreased after December 2006, with low levels of nesting activity in February and March 2007. No flatback turtle nests were recorded on South Beach during the 14-day survey period in July 2007. However, low levels of flatback turtle nesting activity were recorded in that month on the northern beach of Albert Island and on Cormorant Beach on South Maret Island.

No flatback turtle nests were recorded on South Beach during the 14-day survey period in October 2007. The 2007–2008 nesting season commenced in November 2007 and peaked in December; thereafter there was a gradual decrease in nesting activity to April 2008. No observations were made in February and the survey ended in mid-April. Low levels of nesting activity appear to have continued beyond April 2008.

The number of tracks per day also showed a similar seasonal pattern with the peak occurring in mid-December (Figure 7-28).

Spatial distribution and abundance

The mean numbers of flatback turtle nests per day at all survey beaches in January 2007 and January 2008 are shown in Figure 7-29. In January 2007, the highest mean nesting frequencies were recorded at Cormorant Beach, Albert Beach, South Beach and Queenfish Beach. In the following year, the majority (56%) of flatback turtles nested on South Maret Island (South, Cormorant and Sparrowhawk beaches), with only 7% nesting on North Maret Island. Although no flatback turtles nested on Brunei Bay Beach, Turbin Beach or Berthier Beach in January 2008, some were recorded at these beaches at other times during the season.

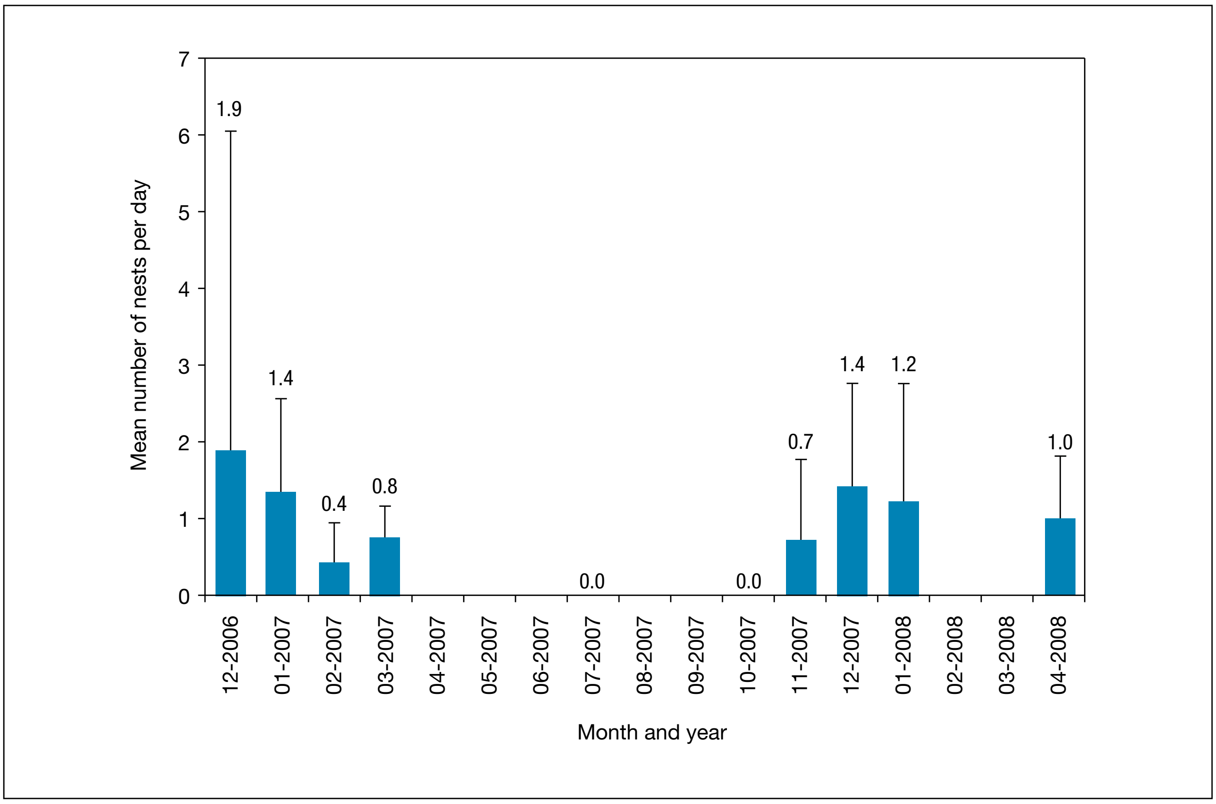


Figure 7-27: Mean number of flatback turtle nests per day for each month surveyed at South Beach between December 2006 and April 2008. Error bars represent the standard deviations. Months without data were not surveyed. Months without data were not surveyed (April–June 2007, August–September 2007 and February–March 2008). No nests were recorded during the November 2007 survey. All surveys were undertaken over 14-day periods, with the exception of April 2008 when saltwater crocodiles were sighted at South Beach and the survey was reduced to 6 days

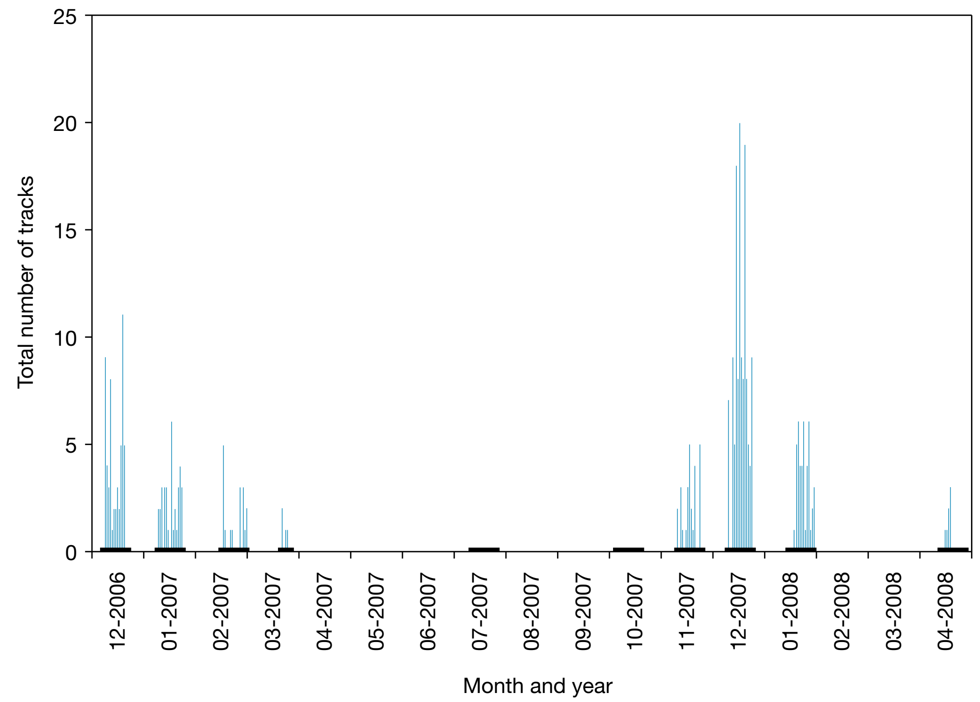


Figure 7-28: Total number of flatback turtle tracks per day at South Beach, South Maret Island, between 6 December 2006 and 11 April 2008. The black bars on the x-axis represent the survey periods

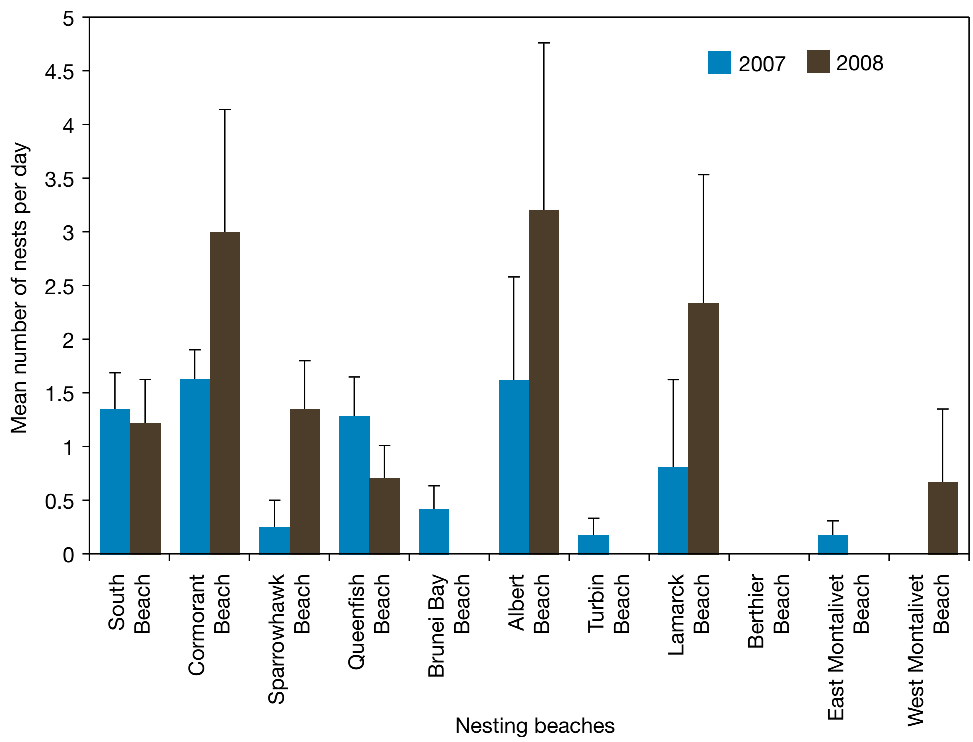


Figure 7-29: Mean number of flatback turtle nests per day at all survey beaches in January 2007 and January 2008, with bars representing the standard errors

The average nesting success for flatback turtles across all sites in January 2007 was 62% (n = 5, mean = 0.62, SE = 0.06). Low levels of nesting activity on Brunei Bay, Sparrowhawk, Turbin, East Montalivet and West Montalivet beaches caused them to be excluded from this analysis. The locations with the highest level of nesting success were Albert Beach (80%) and Queenfish Beach (70%). In January 2008, the average nesting success for flatback turtles decreased (n = 7, mean = 0.45, SE = 0.04). Brunei Bay, Turbin, Berthier, East Montalivet and West Montalivet beaches were again excluded from this analysis because of low levels of nesting activity. Nesting success was observed to be greater for flatback turtles than green turtles at all sites during both seasons.

Clutch characteristics

The productivity parameters for flatback turtles at the Maret Islands in the 2006–2007 nesting season are given in Table 7-10. In this season flatback turtles laid an average of 50 eggs per clutch, with 76% of the eggs producing hatchlings. The average egg diameter was 4.76 cm. The nest depth was consistent across all beaches with an average of 40 cm from the surface to the top of the egg chamber and a further 33 cm to the bottom of the egg chamber.

Carapace size measurements for nesting flatback turtles

Carapace size measurements were made for a number of flatback turtles returning to the sea after nesting.

The mean minimum curved carapace length of nesting flatback turtles at the Maret Islands, East Montalivet Island and Lamarck Island was 87.23 cm (n = 70, SD = 0.33, range = 77–93) and the mean curved carapace width was 73.99 cm (n = 70, SD = 0.30, range = 68–80).

Hawksbill turtles

In July 2007, two false-crawl hawksbill turtle tracks were recorded at Brunei Bay Beach (Figure 7-30). On both occasions, the egg chamber was abandoned and no eggs were laid.

In October 2007, three false-crawl hawksbill turtle tracks were observed on Sandpiper Beach and single hawksbill turtle tracks were also recorded at West Montalivet Island in November and December 2007. A hawksbill turtle hatchling emergence occurred at Brunei Bay Beach in early October 2007. The clutch contained 48 eggs, with 41 hatched and 7 undeveloped eggs (85% hatching success).

Inter-nesting distribution

Green turtles

Table 7-11 presents a summary of inter-nesting activity of green turtles at the Maret Islands obtained from satellite telemetry studies. It shows that of the 21 green turtles tracked by satellite, 16 provided data during the inter-nesting period. Although the first nesting event was not confirmed, turtles that were tagged in mid-December 2006 (G1, G2, G3, G4, G5 and G6) remained within the inter-nesting area for 57 ± 19 days (n = 6, range = 33–86) and nested 6 ± 1.2 times. The inter-nesting interval was 10.7 ± 1.3 days (n = 51, range = 7–13).

The tracked green turtles showed a moderate degree of fidelity to the general vicinity of their nesting sites, with three (G2, G7 and G16) nesting on more than one beach on the Maret Islands. Of the 16 turtles which showed inter-nesting behaviour, 12 remained within 13 km of the nesting sites at the Maret Islands; the majority of transmissions were recorded within 1 km of the shore (Figure 7-31). The other four turtles (G9, G13, G14 and G16) displayed long-distance “looping” behaviour, travelling up to 88 km out to sea from their nesting beaches between nesting events (Figure 7-32). Turtle G9, for example, journeyed for eight days between 18 and 26 April 2008, averaging 22 km per day, and reached Cassini Island before returning to Brunei Bay on North Maret Island to re-nest. Interestingly, Cassini Island is close to G9’s final foraging area at Long Reef. The purpose of this behaviour is unclear as the turtles travelled to different areas and in different directions.

Table 7-10: Productivity parameters for flatback turtles at the Maret Islands in the 2006–2007 nesting season

Parameters	Mean	Standard deviation	Range	Number
Eggs per clutch	50.00	6.51	37–57	3
Hatching success	76.18%	2.29	60–89	3
Egg diameter	4.76 cm	0.31	44–50	24
Nest depth (beach surface to top of egg chamber)	40 cm	2.80	23–55	13
Nest depth (top of egg chamber to bottom of egg chamber)	33 cm	1.69	21–42	13

Figure 7-30: Hawksbill turtle track on Brunei Bay Beach on North Maret Island in July 2007

Table 7-11: Summary of inter-nesting activity of green turtles nesting at the Maret Islands

Turtle number	Days spent within the inter-nesting area*	Minimum number of nesting events*	Mean inter-nesting interval with standard error in brackets (days)	Range of inter-nesting interval (days)†	Maximum distance travelled from the nesting beach
G1	33	–	–	–	4.5 km north of South Beach.
G2	62	5	10.22 (0.08)	10–11	4.2 km from South Beach. Also nested at Queenfish Beach.
G3	86	8	9.40 (0.60)	7–10	6 km south of South Beach.
G4	69	6	9.00 (0.55)	7–10	5 km from South Beach.
G5	43	5	10.00 (0.41)	9–11	2 km from South Beach.
G6	50	6	10.33 (0.65)	8–13	1 km from South Beach.
G7	42	5	10.5 (0.87)	9–13	6.5 km from Brunei Bay Beach. Also nested at Speargrass Beach.
G9	25	3	12.5 (0.5)	12–13	88 km north-east from Brunei Bay Beach to Cassini Island.
G11	12	2	12	12	7.4 km from Sandpiper Beach.
G13	14	2	9	9	65 km east of Brunei Bay Beach towards Cape Voltaire.
G14	36	3	11	11	60 km south-east of Brunei Bay Beach to the vicinity of Kartja Island.
G16	48	5	11(0.91)	9–13	70 km south from Brunei Bay Beach to Buffon Island in the Coronation Island group. Also nested at South Beach.
G17	47	3	11.5 (0.5)	11–12	13 km south of Brunei Bay Beach.
G18	53	7	10.1 (0.17)	10–11	9 km from Sparrowhawk Beach.
G19	45	5	9.75 (0.48)	9–11	5 km north of Sandpiper Beach.
G21	22	–	–	–	7 km north of Sandpiper Beach.

* It is not known how many days the turtles had spent in the vicinity of the nesting sites prior to satellite tagging.

† Note that because of the possibility of satellite error, the inter-nesting interval is indicative only.

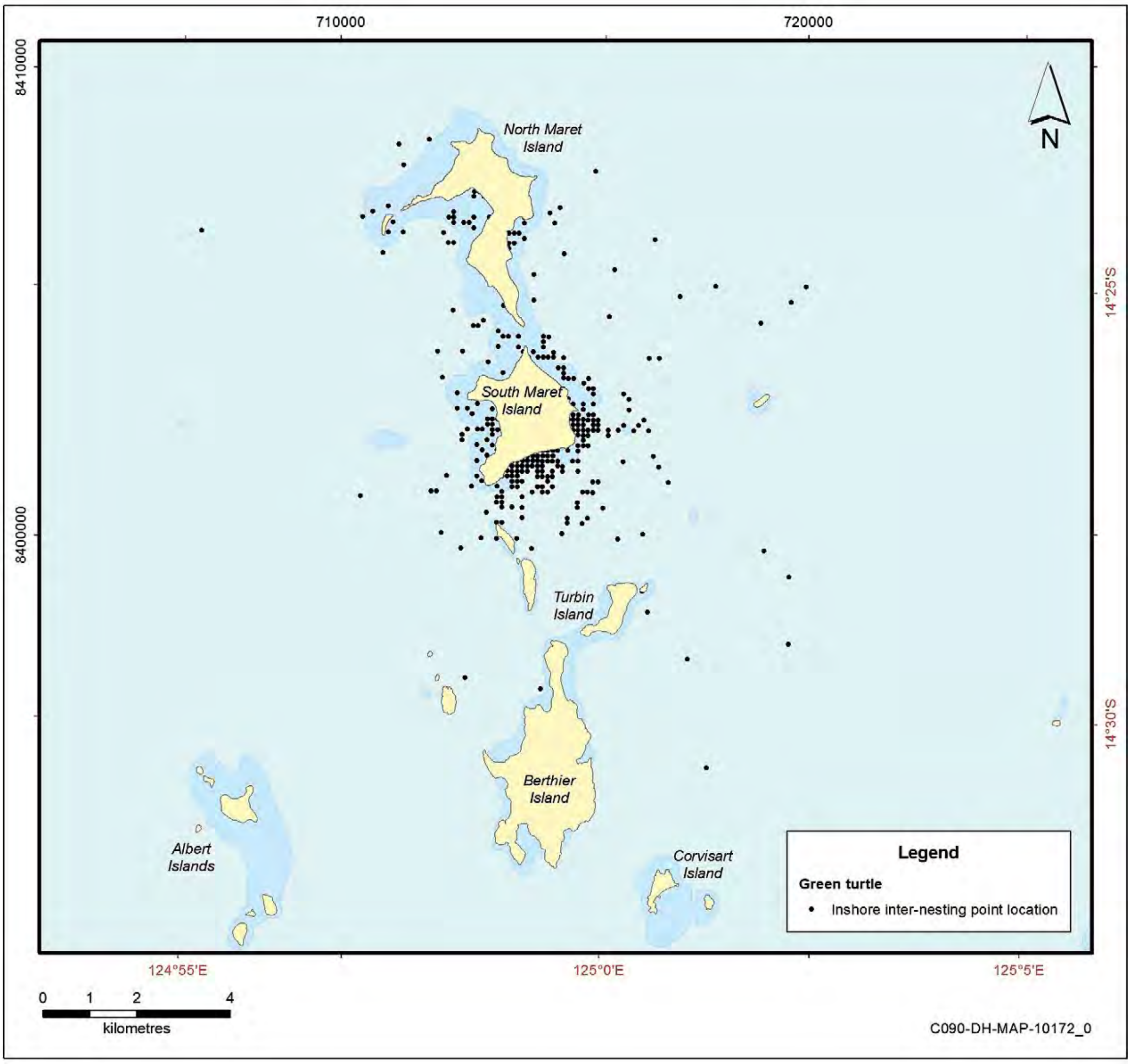


Figure 7-31: Nearshore inter-nesting period distribution points for the 12 green turtles that remained adjacent to their nesting beaches at the Maret Islands, as determined through satellite telemetry

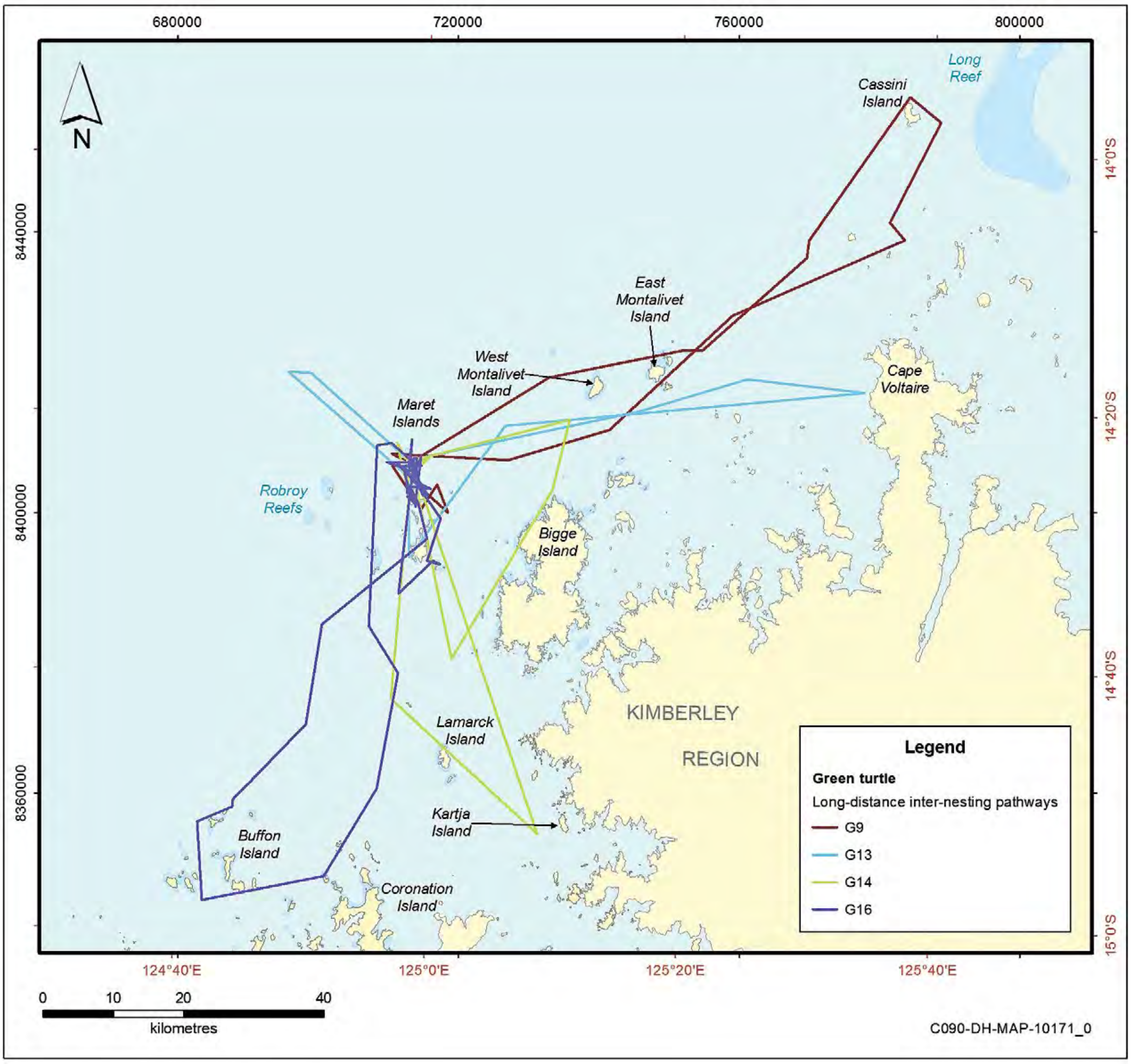


Figure 7-32: Offshore inter-nesting period pathways followed by the four green turtles from nesting beaches at the Maret Islands that displayed long-distance looping behaviour, as determined through satellite telemetry

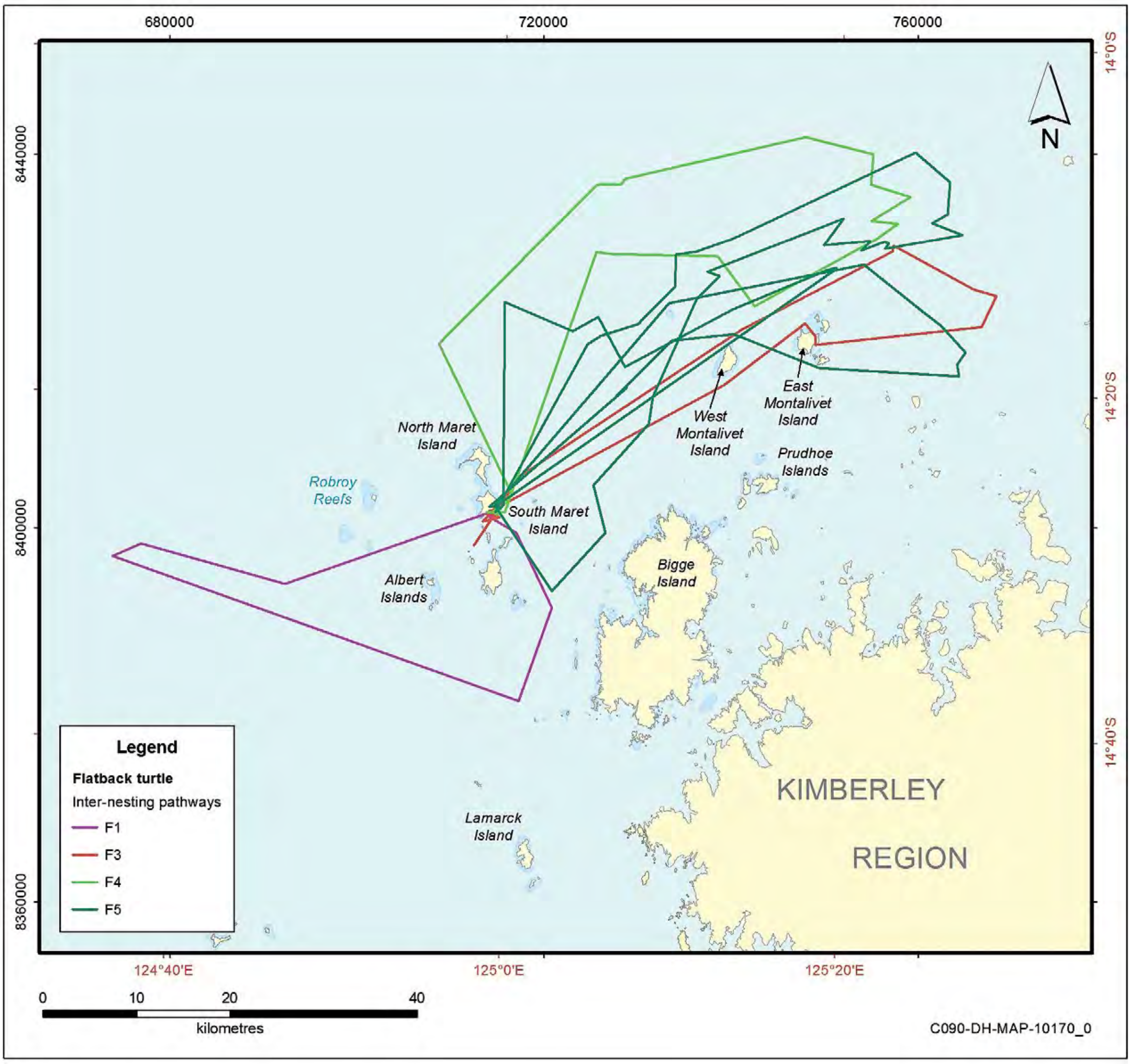


Figure 7-33: Offshore inter-nesting period pathways followed by four flatback turtles from nesting beaches at the Maret Islands that displayed long-distance looping behaviour, as determined through satellite telemetry

Flatback turtles

A summary of the inter-nesting activity of flatback turtles nesting at the Maret Islands is presented in Table 7-12. Four of the seven turtles fitted with transmitters, F1, F3, F4 and F5, provided inter-nesting data. Although it was unclear whether or not they were tagged on their first nesting emergence for the season, one of them, turtle F5, continued to nest for at least 50 days. The inter-nesting interval for the turtles was calculated as 13.2 ± 1.7 days (*n* = 8, range = 10–19).

Figure 7-33 shows the pathways of the four flatback turtles which transmitted data on their movements during the inter-nesting period. All of the turtles displayed a high degree of fidelity to their nesting sites but travelled long distances from the Maret Islands between nesting events in the looping behaviour noted above for green turtles G9, G13, G14 and G16.

Turtle F1 moved 45 km west of the Maret Islands, then turned south-east and returned to South Maret Island. Turtles F3, F4 and F5 travelled approximately 60 km north-east of the nesting site between successive nesting events. During the inter-nesting period these turtles travelled in a loop north of the Montalivet Islands and then returned to the Maret Islands to nest. Turtle F5 showed this inter-nesting movement pattern during all of its three inter-nesting intervals.

Table 7-12: Summary of inter-nesting activity of flatback turtles nesting at the Maret Islands

Turtle number	Days spent within the inter-nesting area*	Minimum number of nesting events*	Mean re-nesting interval with standard error in brackets (days)	Range of re-nesting interval (days)†	Maximum distance travelled from the nesting beach
F1	34	4	11.0 (0.58)	10–12	A single broad loop of 45 km, west of the Maret Islands.
F3	23	3	11.5 (0.50)	11–12	A single loop reaching 58 km from the Maret Islands, circling the Montalivet Islands.
F4	15	2	15	15	A single loop 60 km to the north-east, and to the north of the Montalivet Islands.
F5	50	3	15.3 (2.02)	12–19	Three loops approximately 60 km north-east around the Montalivet Islands.

* It is not known how many days the turtles had spent in the vicinity of the nesting sites prior to satellite tagging.

† Note that, as with the green turtles, because of the possibility of satellite error the inter-nesting interval should be regarded as indicative only.

Post-nesting migration

Green turtles

Table 7-13 describes the post-nesting migration pathways and foraging areas of 15 of the green turtles fitted with PTTs after nesting at the Maret Islands and which provided information on post-nesting movements away from the Maret Islands. Six other turtles were fitted with PTTs but these lost transmission before the post-nesting migration began. Of the turtles from which migration transmissions were received, 10 travelled north-east and five travelled in a south-westerly direction.

Figures 7-34, 7-35 and 7-36 show the pathways of the 15 green turtles which transmitted data on their movements during the post-nesting migration. The majority of the turtles (12) reached their foraging areas (G7–10, G13–17 and G19–21), while three were still migrating at the time of last transmission (G11, G12 and G18).

Of the 10 green turtles which migrated in a north-easterly direction (figures 7-34 and 7-36), five were last recorded in Western Australia, four in the Northern Territory and one in far north Queensland. Two of the five turtles last recorded in Western Australia (G9 and G18) were recorded at Long Reef, while the other three (G11, G13 and G21) had travelled north-eastwards along the mainland coast and remained within approximately 150 km of the Maret Islands. All four of the green turtles last recorded in the Northern Territory (G7, G16, G17 and G19) travelled to waters around Melville and Bathurst islands north of Darwin.

Turtle G12 was tracked to Queensland. She travelled across the Joseph Bonaparte Gulf to the waters surrounding Melville Island and Bathurst Island, and then followed the Northern Territory coastline from the Cobourg Peninsula to Truant Island. She then proceeded across the Gulf of Carpentaria and was last recorded near Prince of Wales (or Muralug) Island off the northern tip of Cape York Peninsula. At final transmission she had covered a total distance of 2283 km in 106 days, averaging approximately 21 km per day.

Of the five green turtles which migrated in a south-westerly direction (figures 7-35 and 7-36), G20 was last recorded in waters adjacent to Eighty Mile Beach between Broome and Port Hedland, while G14 and G15 were last recorded in Roebuck Bay at Broome after travelling south-west along the mainland coast. G10 followed the outer coastal islands for about 10 days until she reached the Cockell Reefs, some 70 km south-west of Augustus Island. Turtle G8 also followed the outer coastal islands until she reached Adele Island. She then headed west before returning to Adele Island for about 10 days.

Table 7-13: Post-nesting migration pathways and foraging areas of green turtles nesting at the Maret Islands

Turtle number	CCLmin* (cm)	Nesting beach	Dates of deployment and of last transmission	Date of arrival in foraging area	Days tracked	Distance travelled (km)	Migration pathway	Foraging area
Short north-eastern migration (less than 250 km)								
G9	95.0	Brunei Bay Beach	03-04-2008 21-10-2008	03-05-2008	201	392	North-east 105 km to Long Reef, Western Australia.	Long Reef, Western Australia.
G11	99.3	Kingfisher Beach	04-04-2008 25-08-2008	Unknown	143	270	North-east 169 km along the Kimberley coast to Deep Bay in Napier Broome Bay, north of Kalumburu, Western Australia.	Unknown.
G13	98.7	Brunei Bay Beach	05-04-2008 05-09-2008	22-04-2008	153	420	North-east 151 km along the Kimberley coast to Troughton Island, north of Cape Bougainville, Western Australia.	Troughton Island, north of Cape Bougainville, Western Australia.
G18	89.5	Sparrowhawk Beach	08-04-2008 13-08-2008	Unknown	127	251	North-east 108 km on a straight pathway to Long Reef, Western Australia.	Unknown.
G21	91.5	Sandpiper Beach	10-04-2008 23-01-2009	18-05-2008	288	231	North-east 156 km along the Kimberley coast to Jar Island, Vansittart Bay, Western Australia.	Jar Island, Vansittart Bay, Western Australia.
Long north-eastern migration (more than 250 km)								
G7	–	Brunei Bay Beach	31-03-2008 19-11-2008	07-06-2008	234	881	North-east 671 km across Joseph Bonaparte Gulf to Melville Island, Northern Territory.	Shoal Bay at the south end of Apsley Strait separating Bathurst and Melville islands, Northern Territory.
G12	95.3	Sparrowhawk Beach	07-04-2008 22-07-2008	Unknown	106	2283	North-east 1898 km across northern Australia to Prince of Wales (= Muralug) Island, off the northern tip of Cape York Peninsula, Queensland.	Unknown.
G16	102.1	Brunei Bay Beach	07-04-2008 20-11-2008	28-07-2008	227	1113	North-east 791 km along the Kimberley coast to Melville Island, Northern Territory.	North-east of Melville Island near Quanipiri Bay, Northern Territory.

Table 7-13: Post-nesting migration pathways and foraging areas of green turtles nesting at the Maret Islands (continued)

Turtle number	CCLmin* (cm)	Nesting beach	Dates of deployment and of last transmission	Date of arrival in foraging area	Days tracked	Distance travelled (km)	Migration pathway	Foraging area
G17	92.0	Brunei Bay Beach	07-04-2008 22-09-2008	19-06-2008	168	940	North-east 766 km along the Kimberley coast to Melville Island, Northern Territory.	Cobham Bay at the eastern end of Melville Island, Northern Territory.
G19	95.0	Sandpiper Beach	09-04-2008 03-02-2009	30-06-2008	300	886	North-east 786 km across Joseph Bonaparte Gulf to Melville Island, Northern Territory.	North of Napier Bay off the eastern coast of Melville Island, Northern Territory.
Short south-western migration (less than 250 km)								
G8	95.0	Brunei Bay Beach	01-04-2008 31-05-2008	09-04-2008	60	529	South-west 228 km seaward of the outer islands.	Adele Island, Western Australia.
G10	85.9	Brunei Bay Beach	04-04-2008 14-06-2008	10-04-2008	71	415	South-west 182 km seaward of the outer islands.	Cockell Reefs, south-west of Augustus Island, Western Australia.
Long south-western migration (more than 250 km)								
G14	108.0	Brunei Bay Beach	06-04-2008 11-07-2008	24-05-2008	96	806	South-west 511 km along the Kimberley coast to Roebuck Bay, Broome, Western Australia.	Roebuck Bay, Broome, Western Australia.
G15	98.7	Brunei Bay Beach	06-04-2008 23-11-2008	21-04-2008	231	638	South-west 528 km along the Kimberley coast to Roebuck Bay, Broome, Western Australia.	Roebuck Bay, Broome, Western Australia.
G20	96.0	Sparrowhawk Beach	09-04-2008 23-09-2008	04-05-2008	167	757	South-west 705 km along the Kimberley coast to Eighty Mile Beach, Broome, Western Australia.	Eighty Mile Beach, Broome, Western Australia.

* Minimum curved carapace length.

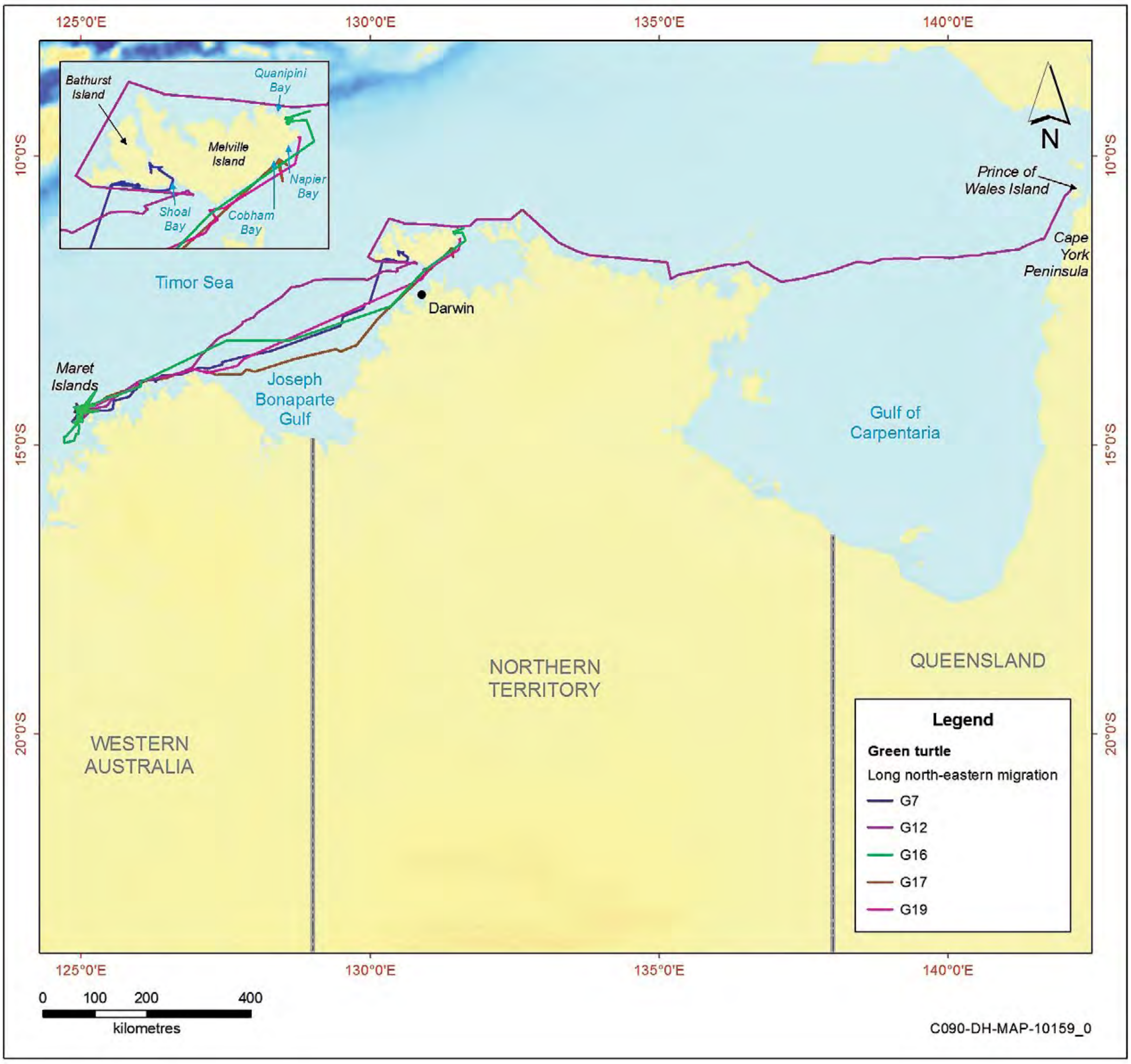


Figure 7-34: Long north-eastern migration pathways and foraging grounds for five green turtles from nesting beaches at the Maret Islands, as determined through satellite telemetry

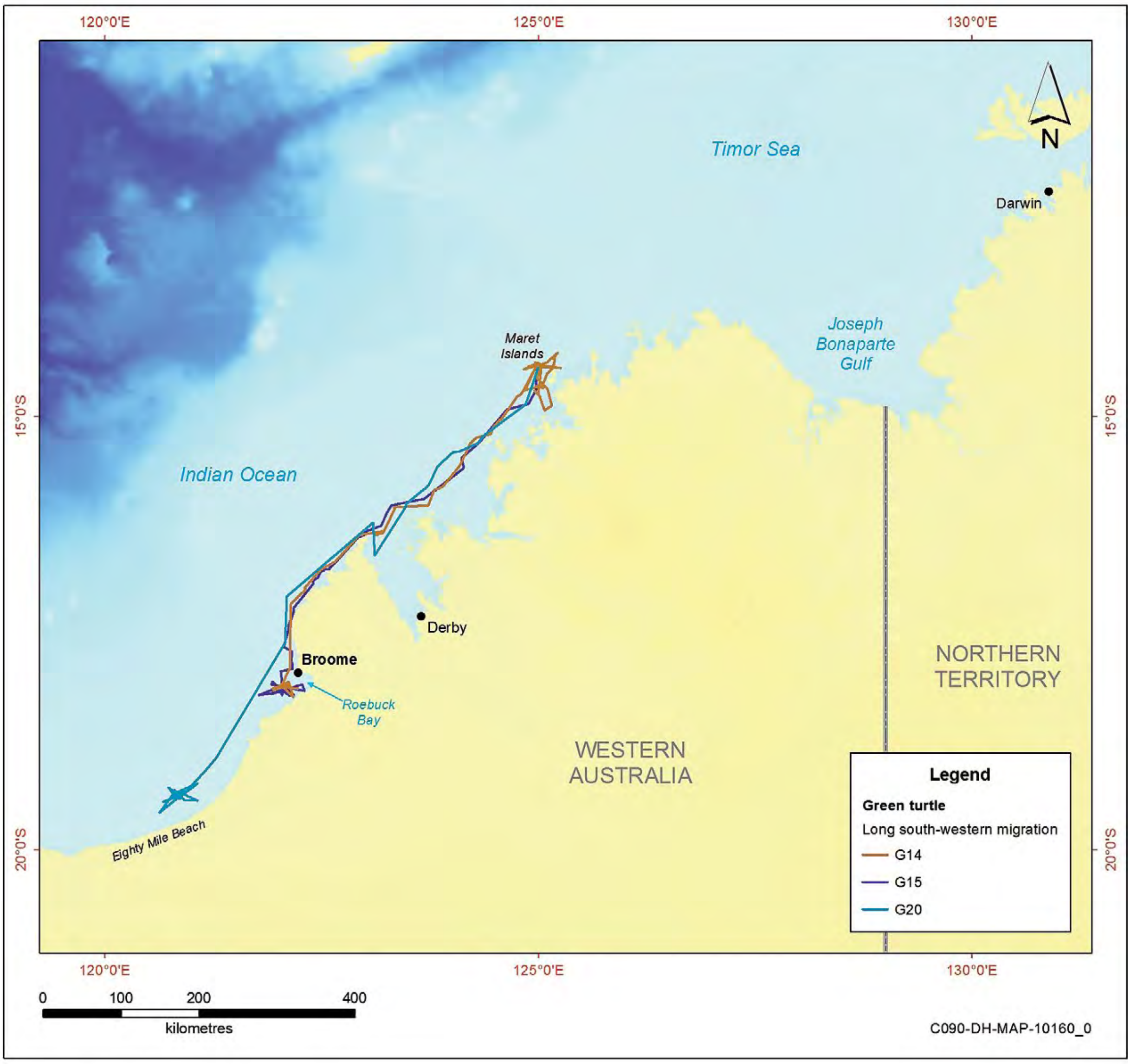


Figure 7-35: Long south-western migration pathways and foraging grounds for three green turtles from nesting beaches at the Maret Islands, as determined through satellite telemetry

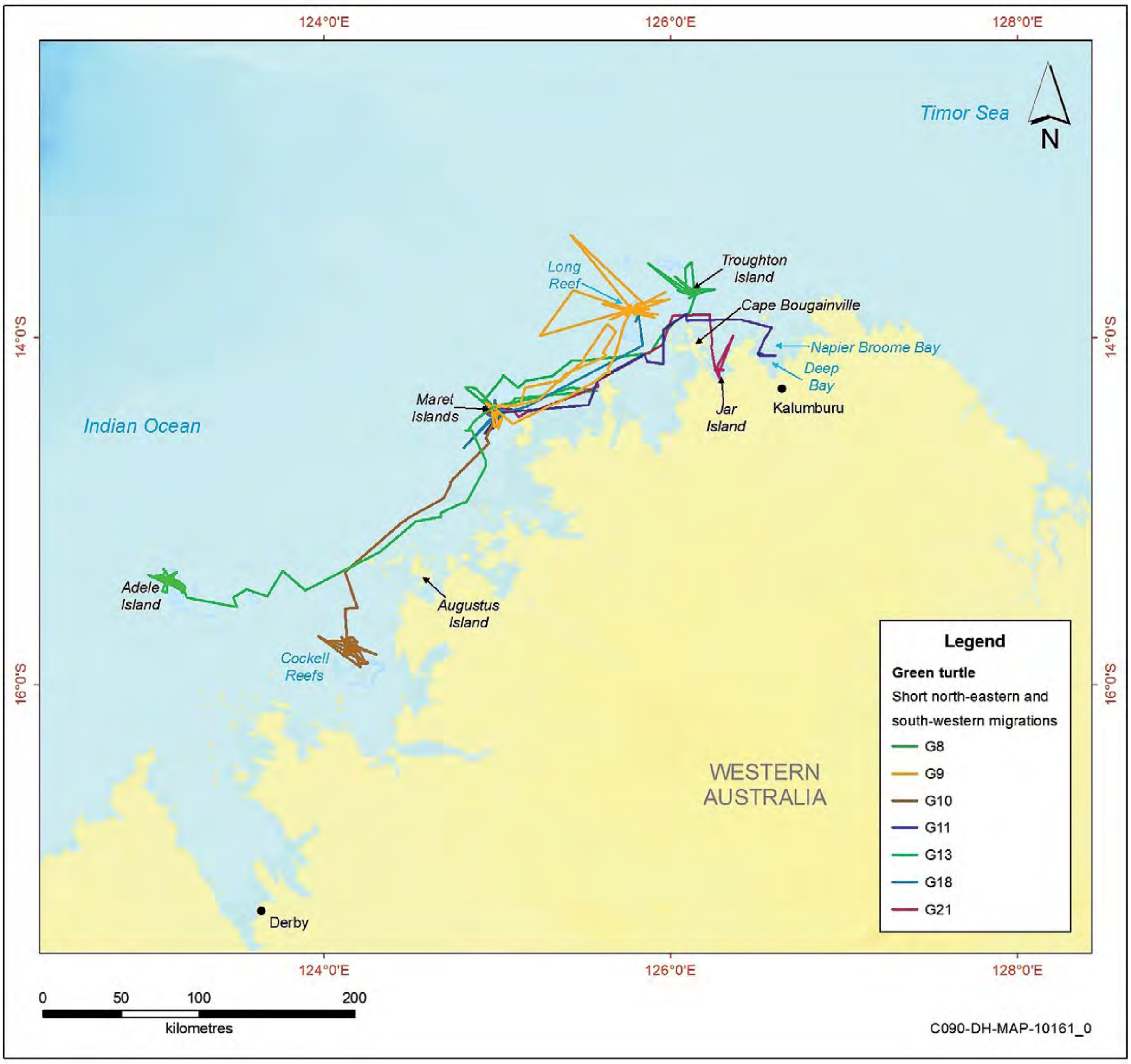


Figure 7-36: Short north-eastern and short south-western migration pathways and foraging grounds for seven green turtles from nesting beaches at the Maret Islands, as determined through satellite telemetry

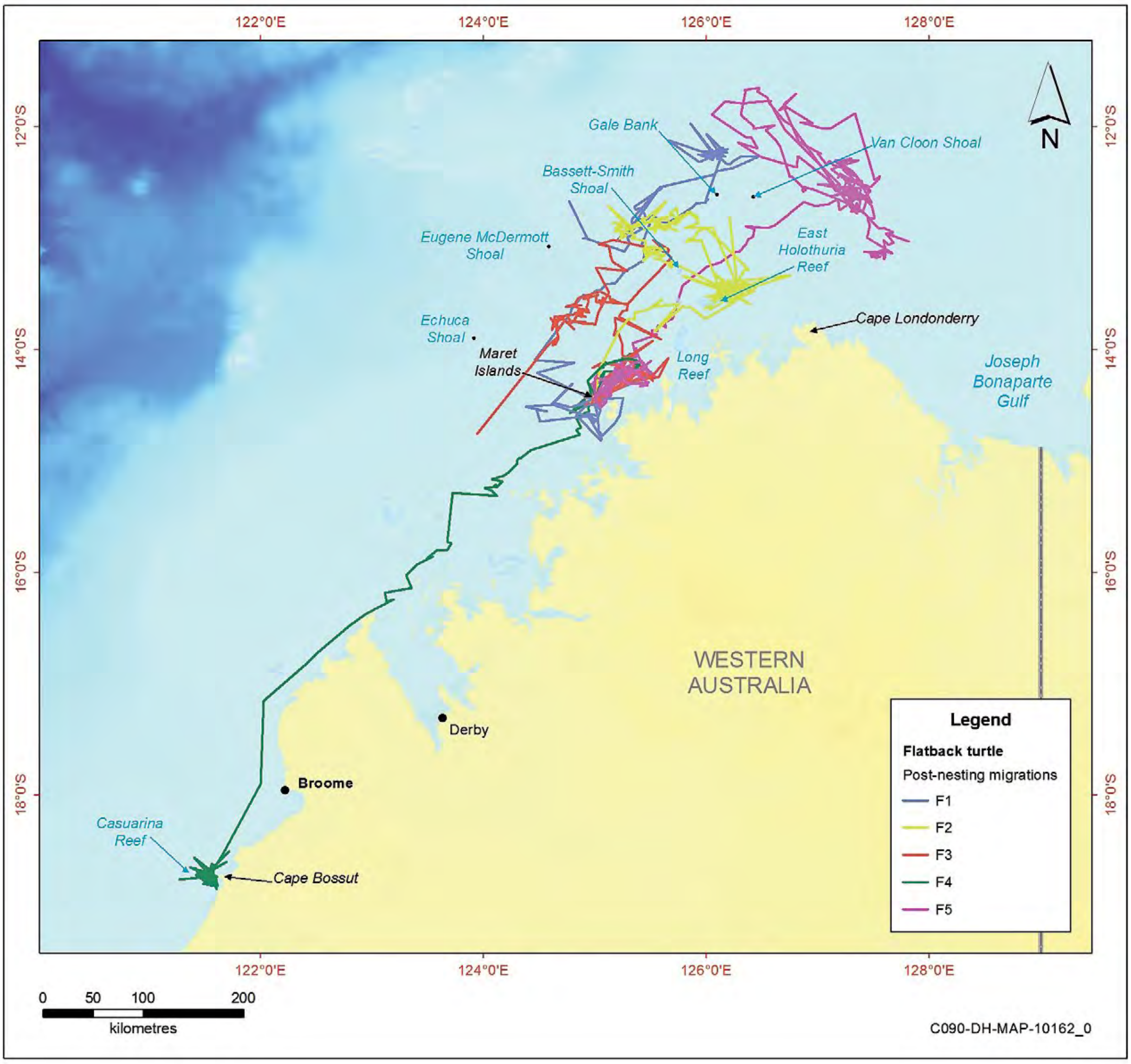


Figure 7-37: Migration pathways and foraging grounds for five flatback turtles from nesting beaches at the Maret Islands, as determined through satellite telemetry

Flatback turtles

Table 7-14 describes the migration pathways and foraging areas of flatback turtles nesting at the Maret Islands. Five of the seven flatback turtles fitted with transmitters at the Maret Islands provided post-nesting locations (Table 7-14 and Figure 7-37). Four of the turtles (F1, F2, F3 and F5) travelled less than 330 km north-eastwards towards the Sahul Shelf where there are several offshore shoals and reefs. The behaviour of these turtles suggests that they move between foraging areas, for example Gale Bank, Eugene McDermott Shoal, East Holothuria Reef and Bassett-Smith Shoal.

Turtle F5 migrated to an area east of Van Cloon Shoal and then engaged in an apparent foraging pattern which consisted of travelling 240 km in a generally north-west direction and then returning. Turtle F5 remained in this foraging area for 355 days until the transmission ceased. Turtle F4 travelled 597 km south-west to the vicinity of Cape Bossut around 105 km south-west of Broome, where it remained in a relatively small foraging area around Casuarina Reef for 96 days until the transmission ceased.

Turtles F6 and F7 were tracked until transmissions ceased after 12 and six days respectively and provided no migration data.

Table 7-14: Post-nesting migration pathways and foraging areas of flatback turtles nesting at the Maret Islands

Turtle number	CCLmin* (cm)	Nesting beach	Dates of deployment and of last transmission	Date of arrival in foraging area	Days tracked	Distance travelled (km)	Migration type and pathway	Foraging area
F1	90.0	South Beach	11-01-2007 22-04-2007	10-03-2007	101	682	Short north-eastern migration. North-east 205 km directly to Gale Bank, Western Australia.	Along the Sahul Shelf between the north of Gale Bank and Eugene McDermott Shoal (around 125 km north-east of Echuca Shoal), Western Australia.
F2	87.5	South Beach	13-01-2007 30-08-2007	22-01-2007	229	1148	Short north-eastern migration. North-east 122 km to East Holothuria Reef.	East Holothuria Reef and out to Bassett-Smith Shoal, Western Australia.
F3	88.6	South Beach	14-01-2007 11-04-2007	22-02-2007	87	823	Short north-eastern migration. North-east around 150 km to Bassett-Smith Shoal.	No firm foraging data available. Travelled north of Bassett-Smith Shoal, then foraged sporadically along the Sahul Shelf to Eugene McDermott Shoal (around 125 km north-east of Echuca Shoal), Western Australia.
F4	88.8	South Beach	10-12-2007 28-04-2008	28-01-2008	141	865	Short south-western migration. South-west 597 km along the Kimberley coast to Casuarina Reef off Cape Bossut.	Casuarina Reef off Cape Bossut (around 105 km south-west of Broome), Western Australia.
F5	88.5	South Beach	10-12-2007 28-01-2009	09-02-2008	415	2130	Long north-eastern migration. North-east 331 km straight to an area east of Van Cloon Shoal.	100 km east of Van Cloon Shoal and 135 km north of Cape Londonderry on the Sahul Shelf.
F6	87.1	Cormorant Beach	03-12-2007 15-12-2007	Unknown	12	51	Unknown.	Unknown.
F7	90.0	South Beach	15-11-2007 21-11-2007	Unknown	6	97	Unknown.	Unknown.

* Minimum curved carapace length.

DISCUSSION

Genetic studies

Green turtles

The frequencies of green turtle haplotypes investigated in this study showed that there is a continuous unit of green turtles occupying the continental shelf in the north of Australia. Nesting green turtles in the Bonaparte Archipelago were found to be genetically related to the NWSgr Management Unit turtles, but genetically distinct from those found at the offshore islands and reefs (Ashmore, Cartier and Browse islands and Scott Reef).

The relative genetic similarity of the NWSgr and Bonaparte Archipelago groups to the GoCgr groups also suggests that there is likely to be some connection between the adjacent coastal management units, including unsampled rookeries in the Northern Territory and elsewhere in the Kimberley region. This is thought to be due to a historical connection, as Dethmers et al. (2006) had previously hypothesised that the rookeries in the Gulf of Carpentaria were colonised by individuals from the North West Shelf after sea levels rose between 6500 and 10 000 years ago. However, there may still be some genetic exchange between the NWSgr and GoCgr stocks. Prince (1994) found that some NWSgr turtles foraged in the Gulf of Carpentaria, which suggests that occasional interbreeding could be possible.

A relatively large number of the haplotypes were found across the Bonaparte Archipelago population, including two that had not been previously identified from other North West Shelf populations. This variation within the breeding stock is expected from a group that covers such a large geographic area. The unique haplotypes are likely to have arisen from mutations within the management unit, being derived from one of the most common haplotypes (C1) in the NWSgr and GoCgr units. If these haplotypes have arisen within the management unit, it would indicate that the Bonaparte Archipelago turtles primarily breed with turtles from the same region.

Flatback turtles

Before the present study was carried out, two genetically distinct populations of flatback turtle were recognised in Western Australia: the WAL Management Unit (West Arnhem Land, based on samples from Cape Domett), and the NWSfl Management Unit (North West Shelf, based on samples from Barrow Island, the Dampier Archipelago and Cape Thouin). However, the genetic analyses carried out on flatback turtles during this study indicate that the flatback turtle population of the Maret Islands and surrounding islands constitutes a breeding stock partially isolated from the NWSfl and WAL management units, and may represent a "Bonaparte Archipelago Management Unit".

Additional surveys will be required to confirm this, as there is evidence of some genetic exchange between the flatback turtles nesting in the Bonaparte Archipelago and the main flatback turtle population of the North West Shelf Management Unit and the sample sizes on which this study was based were small.

Hybridisation has been recorded for several combinations of marine turtle species, including loggerhead turtles with green and hawksbill turtles (Karl, Bowen & Avise 1995) and green with hawksbill turtles (Seminoff et al. 2003). The presence of an olive ridley turtle haplotype in a flatback turtle sample (reported earlier in this chapter) suggests that the sample came from a hybrid turtle. This was also found from a sample collected in the Northern Territory (FitzSimmons 2008), which suggests that hybridisation between flatback and olive ridley turtles is also occurring in northern Australia.

Nesting habitat

Regional

High nesting densities of marine turtles were recorded on the Maret Islands, Cassini Island and the Lacepede Islands as evidenced by beach track counts. The Lacepede Islands were identified as supporting high nesting densities (723 tracks per night), which is consistent with the findings of other studies that recorded more than 1000 green turtles per night (Prince 1993, 1994; Waayers 2010). The aerial surveys showed that the Bonaparte Archipelago hosts a regionally important rookery concentration in the Kimberley, with 23% of all turtle tracks recorded during the survey period being found at the Maret Islands and surrounding islands, including Albert, Turbin and East Montalivet islands.

Bonaparte Archipelago

Mating activity

Based on the known nesting frequency of green turtles in the Bonaparte Archipelago, it was expected that breeding turtles would arrive at the archipelago in September. Green turtles were in fact observed mating in these waters from September to January.

Little is known about the mating activity of flatback turtles in Australia. During this study, a single pair of flatback turtles was observed mating in nearshore waters off Brunei Bay Beach. Similar mating behaviour of flatback turtles has also been observed adjacent to Bare Sand Island and Roche Reef in the Northern Territory (Dr Michael Guinea, Faculty of Engineering, Health, Science and the Environment, Charles Darwin University, Darwin, Northern Territory, pers. comm. 2007).

Seasonal variation

Without long-term data, it is impossible to achieve a high level of understanding of regional turtle ecology because interannual variation can confound spatio-temporal patterns. In addition to interannual variation in the size of the breeding population, there is considerable variation between individuals (Broderick, Godley & Hays 2001; Limpus et al. 2003; Limpus & Nicholls 1988). Although this study only covered two nesting seasons, the number of green turtle nests found per day varied significantly between the two seasons. Track-count data from the Ningaloo region in Western Australia have also demonstrated high variability in the seasonal abundance of breeding green turtles (Kelliher, Lusty & Prophet 2011). The Ningaloo study found that the numbers of green turtle nests at Ningaloo between mid-December and mid-January over nine years ranged between 600 and 3500. Such variations are thought to be caused by fluctuations in environmental conditions such as sea-surface temperature (Solow, Bjorndal & Bolten 2002) and food availability (Broderick, Godley & Hays 2001; Carr & Carr 1970).

This study indicated that the nesting season for green turtles commences in November and continues through to April. This interpretation was based on the nesting trend found during 2006–2007 and was confirmed by further nesting data collected during the 2007–2008 nesting season. It is consistent with findings from other green turtle rookeries in the NWSgr stock, including Barrow Island (Pendoley 2005) and the Ningaloo region (Waayers 2010).

The nesting season for flatback turtles at the Maret Islands appears to be between October and March with a December peak, followed by low-level nesting activity throughout the year. This nesting during the summer months is characteristic of flatback turtle populations in the North West Shelf Management Unit (Pendoley 2005; Waayers, Smith & Malseed 2011), as opposed to the winter nesting activity which prevails at the nearby Cape Domett rookeries in Joseph Bonaparte Gulf and rookeries in the Northern Territory, for example at Bare Sand Island (Chatto 1998; Whiting & Guinea 2006).

The consistency in the abundance of flatback turtles between years may be attributed to their diet. Flatback turtles are carnivorous (Limpus 2007), often feeding at higher trophic levels than other turtle species such as green turtles (Broderick, Godley & Hays 2001). Annual variations in the numbers of nesting flatback turtles are therefore less likely than for the herbivorous green turtle whose numbers can be influenced by changes in broad climate conditions that affect the availability of seagrass or algae (Broderick, Godley & Hays 2001).

The nesting season for hawksbill turtles in Western Australia is between August and January, with a peak in October and November (Pendoley 2005; Robinson 1990). However, although there were some sightings of hawksbill turtles in the waters surrounding the Maret Islands, the small number of hawksbill turtle tracks found during this study suggests that these turtles rarely nest in the islands of the Bonaparte Archipelago investigated during this survey.

Nesting distribution and abundance

The Bonaparte Archipelago supports a medium-sized green turtle population in comparison with other rookeries in Australia such as those at the Lacepede Islands (Prince 2000; RPS 2010a), Bramble Cay (Limpus, Carter & Hamann 2001) and Raine Island (Limpus et al. 2003). The numbers of green turtles at the Maret Islands are comparable to the numbers in the Ningaloo region, with approximately 1000 female green turtles nesting during a productive nesting season (extrapolated from data presented in Kelliher, Lusty & Prophet 2011). The Bonaparte Archipelago supports low nesting densities of flatback turtles compared with Barrow Island (Pendoley 2005), Mundabullangana (Chevron 2009), Port Hedland (RPS 2009b) and Cape Domett (Whiting et al. 2008). However, the size of the nesting population is similar to that reported at Curtis Island in eastern Australia (Limpus, Parmenter & Limpus 2002).

Clutch assessment

The majority of green turtle hatchlings emerge from their nests in the two hours following sunset. This is the period during which the sand temperature at the upper surface of the nests declines rapidly. Hatchlings are thought to use this dramatic decrease in temperature as a cue to commence emerging from the nest (Glen et al. 2005; Gyuris 1993). This survey indicated that 45% of hatchlings dispersed from the nest during the first emergence event, with smaller emergences over the following nights.

The average clutch size of the green turtles nesting at the Maret Islands (67 eggs per clutch) was smaller than the clutch sizes reported in eastern Australia, including Heron Island with 115 eggs per clutch (Limpus, Fleay & Guinea 1984), Bramble Cay with 111 eggs per clutch (Limpus, Carter & Hamann 2001), and the nearby Ashmore Banks in Western Australia with 98 eggs per clutch (Guinea 1995). However, the average egg size, nest depth and hatching success of green turtles recorded at the Bonaparte Archipelago was consistent with records from these other locations.

The clutch parameters for flatback turtles were slightly different from those for green turtles in the Bonaparte Archipelago. The average clutch size at the Maret Islands was 50 eggs; this is the same as for rookeries elsewhere in Australia, for example the Bundaberg coast (Limpus 1971) and Peak Island in eastern Queensland (Parmenter & Limpus 1995), Crab Island in the Gulf of Carpentaria (Limpus, Couper & Couper 1993), Fog Bay in the Northern Territory (Blamires, Guinea & Prince 2003) and Varanus Island in Western Australia (Pendoley 2005). Measurements for average egg size, nest depth and hatching success at the Bonaparte Archipelago were also similar to those recorded at these other Australian rookeries.

All marine turtle species have temperature-dependent sex determination, where the sex of the embryo is determined by egg temperature during the middle third of incubation (Standora & Spotila 1985; Yntema & Mrosovsky 1982). The temperatures of green turtle nests were tested during February and of flatback turtle nests during January, the expected periods of the middle third of incubation. The sand temperatures during these periods were predominantly above the transitional range of temperatures[11] suggesting that the islands of the Bonaparte Archipelago are typically female-biased for both species during the nesting season. However, the occurrence of cyclones in the area can influence the range of temperatures expected during the turtle nesting season, and cyclones during the critical incubation period could potentially change the sex of embryos. The data collected in the Bonaparte Archipelago showed that the critical period for the majority of green turtles was in February. This coincided with the second cyclonic event of the season, which caused sand temperatures to decrease and to fall within the typical transitional range of temperatures. The critical incubation period (January) for flatback turtles had temperatures mostly above 30 °C at South Beach on South Maret Island and therefore could have been expected to produce a preponderance of female hatchlings. However, the sand temperature at East Montalivet Beach was below the transitional range of temperatures for flatback turtles in January, suggesting that a higher proportion of males could have been produced.

Inter-nesting activity

Green turtles

Individual green turtles nested on different beaches around the Maret Islands during the season, a behavioural pattern which is often displayed within archipelagos (Limpus et al. 2003). They generally remained within close proximity (13 km) of the shallow (<30 m deep) nearshore area during the inter-nesting period, as described in other studies (Limpus 2008; Waayers, Smith & Malseed 2011). However, four green turtles had a broader inter-nesting distribution, travelling between 40 and 90 km from the Maret Islands. This pattern has also been recently documented for green and flatback turtles nesting at the Lacepede Islands 120 km north of Broome (Waayers, Smith & Malseed 2011). The purpose of their travelling great distances between nesting events remains unclear. However, while previous studies indicate that green turtles do not feed while in the inter-nesting habitat (Hamann, Limpus & Owens 2003; Tucker & Read 2001), this travelling behaviour may be associated with opportunistic foraging.

Although the first green turtle nesting event was not able to be confirmed before the satellite transmitters were deployed at the Maret Islands, the number of clutches per season was similar to the numbers at Bramble Cay (Limpus, Carter & Hamann 2001). The inter-nesting interval calculated for green turtles at the Maret Islands (10.7 days) was similar to the interval noted at the Lacepede Islands (RPS 2010a), but shorter than the average intervals recorded at Heron Island (14 days) (Limpus, Fleay & Guinea 1984), Bramble Cay (12 days) (Limpus, Carter & Hamann 2001) and Raine Island (12 days) (Limpus et al. 2003).

Flatback turtles

All of the flatback turtles displayed looping behaviour during the inter-nesting period. This behaviour is typical of flatback turtle inter-nesting behaviour in Western Australia, where females travel up to 70 km from the nesting site between each nesting event (Chevron 2009; Waayers, Smith & Malseed 2011). As with the green turtles, it was not known whether the study's flatback turtles were tagged on their first nesting event; however the average inter-nesting interval at the Maret Islands (13.2 days) was less than the average interval recorded for the Bundaberg coast in Queensland (Limpus, Fleay & Baker 1984), but similar to the intervals recorded on Wild Duck Island (unpublished data, Queensland Turtle Conservation Project, Department of Environment and Heritage Protection, Brisbane).

11 The "transitional range of temperature" is that range between male- and female-producing nest temperatures in which the incubation of turtle eggs produces individuals of both sexes.

7 MARINE TURTLES

Post-nesting migration

Green turtles

Although green turtles are known to undertake long-distance migrations from nesting areas to foraging areas, some remain in foraging areas near their rookeries and only make short post-nesting migrations (Limpus et al. 1992; Waayers & Fitzpatrick 2013).

In this study, 15 green turtles performed post-nesting movements from their nesting beaches at the Maret Islands (Table 7-13). While they fanned out in a broad dispersal front from the Maret Islands, there were four main pathways:

Type 1: a short north-eastern migration (<250 km)
Type 2: a long north-eastern migration (>250 km)
Type 3: a short south-western migration (<250 km)
Type 4: a long south-western migration (>250 km).

Of the five green turtles that carried out a Type 1 migration (G9, G11, G13, G18 and G21), two reached Long Reef which was identified as a probable foraging area in the nearshore aerial surveys in November 2007. The other three turtles travelled along the mainland coast and remained within approximately 150 km of the Maret Islands (Figure 7-36).

Five green turtles exhibited a Type 2 migration: four of these (G7, G16, G17 and G19) followed the Kimberley coast to Cape Londonderry (the northernmost point of Western Australia) and crossed the Joseph Bonaparte Gulf to Melville Island (Waayers & Fitzpatrick 2013); the fifth (G12) followed the Joseph Bonaparte Gulf pathway to the Melville Island and Bathurst Island area north of Darwin, then followed the Northern Territory coastline from the Cobourg Peninsula to Truant Island and travelled across the Gulf of Carpentaria to Prince of Wales (or Muralug) Island off the northern tip of Cape York Peninsula in northern Queensland (Figure 7-34). In a separate study, a green turtle from the Lacepede Islands also followed a similar pathway and reached a probable foraging area at Thursday Island (Waayers & Fitzpatrick 2013). Furthermore, flipper tag recoveries from turtles tagged along the North West Cape and Muiron Islands coast have been collected in the Gulf of Carpentaria, which has previously been identified as an important foraging area for green turtles (Prince 2000). These data provide further evidence that there are strong linkages between the GoCgr and the NWSgr management units.

The two green turtles that carried out a Type 3 migration (G8 and G10) travelled approximately 200 km south from the Maret Islands to reach the Cockell Reefs and Adele Island (Figure 7-36).

The three turtles that carried out a Type 4 migration (G14, G15 and G20) were last recorded 500–700 km from the Maret Islands in waters adjacent to Eighty Mile Beach and Roebuck Bay, south-west of Broome (Figure 7-35). All of these locations were also utilised by green turtles nesting at the Lacepede Islands in 2011–2012 (Waayers & Fitzpatrick 2013), suggesting that they could be established foraging grounds for green turtles from other rookeries in Western Australia.

Flatback turtles

This study provided post-nesting migration data for flatback turtles from the Maret Islands, one of the most northerly rookeries for the species in Western Australia. Five turtles (F1, F2, F3, F4 and F5), which had nested on the islands and which had been fitted with satellite transmitters, provided post-nesting locations (Figure 7-37). Turtles F1, F2, F3 and F5 moved relatively short distances (around 200, 120, 150 and 330 km respectively) in a north-easterly direction, with turtles F1, F2 and F3 migrating directly to the Holothuria Banks foraging area, which includes Gale Bank, Eugene McDermott Shoal, East Holothuria Reef and Bassett-Smith Shoal over the Kimberley Shelf, Londonderry Rise and Sahul Shelf in the Timor Sea. Turtle F5 moved directly to Van Cloon Shoal over the Londonderry Rise.

Turtle F4 was the only one to travel south, moving in a relatively direct line to Cape Leveque and thence along the Dampier Peninsula to Casuarina Reef off Cape Bossut, where it remained as a resident. The beaches along Eighty Mile Beach are known to support nesting and foraging turtles (DSEWPaC 2012).

Foraging grounds

Green turtles

Green turtles have a broad distribution of foraging areas across northern Australia (Limpus 2008).
The present study identified several potential foraging grounds utilised by the green turtles nesting at the Maret Islands. Resident foraging areas of both adult and juvenile green turtles in the Bonaparte Archipelago were at the Robroy Reefs, North Maret Island, Lamarck Island and West Montalivet Island. All of these sightings were in waters less than 6 m deep in either coral reef or macroalgal habitats.

The nearshore aerial surveys conducted in the Bonaparte Archipelago in November 2007 identified Long Reef as being potentially regionally significant for foraging green turtles. This linear reef wall supported large numbers of green turtles (580 turtles/km^2 at the surface), while also supporting lesser numbers of flatback, hawksbill and loggerhead turtles. Despite the high densities of turtles in this area, detailed knowledge of the extent of its ecological significance to turtles in the region is still lacking.

Satellite telemetry data showed that four of the ten green turtles which migrated in a north-easterly direction from the Maret Islands moved to Melville and Bathurst islands just north of Darwin in the Northern Territory. Melville Island has been recognised by other studies as supporting nesting and foraging green turtle populations from the Lacepede Islands (Waayers & Fitzpatrick 2013) and from the northern Great Barrier Reef Management Unit (Limpus et al. 2003).

Although turtle G12 did not provide foraging data, it moved 1898 km north-east from the Maret Islands to Prince of Wales (or Muralug) Island off the northern tip of Cape York Peninsula in Queensland; it showed that green turtles may travel long distances to specific foraging areas. Other satellite telemetry studies in Western Australia have also shown this area off Cape York Peninsula to support foraging turtles, including green turtles nesting on the Lacepede Islands (Waayers & Fitzpatrick 2013) and loggerhead turtles nesting on the North West Cape in the Pilbara region of Western Australia near Exmouth.

Flatback turtles

The Holothuria Banks foraging area has only relatively recently been identified as an important foraging area for flatback turtles. It supports flatback turtles that nest at a number of southern and western rookeries in Western Australia, including the Lacepede Islands (Waayers & Fitzpatrick 2013; Thums et al. in prep.), Port Hedland, Barrow Island, Mundabullangana, Thevenard Island (Pendoley et al. 2014) and Ashburton Island (RPS 2010b). The results of satellite tagging carried out on the North West Cape near Exmouth show loggerhead turtles foraging along the Kimberley Shelf up to the Londonderry Rise (Mau et al. 2013). The Holothuria Banks foraging area covers an area of approximately 25 000 km² and is delineated by the Jabiru, Penguin and Eugene McDermott shoals and Gale Bank. Other studies show similar foraging ranges, although the data from these studies have not yet been consolidated to enable the entire extent of the foraging ground to be determined.

This area in the Timor Sea where the turtles appear to be focusing their foraging activities is associated with the Sahul Shelf in a region with a complex topography of banks, shoals, channels and canyons (Van Andel & Veevers 1965). This topography is thought to support a high diversity of marine life as a result of its providing a range of suitable substrates for the settlement and growth of benthic invertebrates; in addition, the channelling of water around the numerous banks and rises creates locally enhanced productivity (Brewer et al. 2007). Both features would improve the foraging habitat for flatback turtles.

CONCLUSION

The baseline surveys conducted between 29 June 2006 and 12 April 2008 and described in this chapter have provided new information relating to marine turtles in the Kimberley region. The aerial surveys identified important rookeries of green turtles at the Lacepede Islands, Maret Islands and Cassini Island and important foraging areas at Long Reef and the coastal waters surrounding the Maret Islands. The genetic analysis spatially extended the NWSgr Management Unit to the northern Kimberley, closing the gap in genetic information between the Lacepede Islands and Cape Domett. Satellite telemetry from green turtles showed predominantly northern long-distance migrations through northern Australian waters, requiring a collaborative approach between states and the Northern Territory to manage the population.

Nesting flatback turtles were recorded in lower abundances in the Kimberley region in comparison with Pilbara region populations such as those of Barrow Island and of Mundabullangana Station on the coast south-west of Port Hedland. Satellite telemetry data showed that flatback turtles migrate shorter distances in comparison with green turtles and travel to the Holothuria Banks foraging area, which also supports flatback turtles from other rookeries in Western Australia. Further research is required to shed light on the extent of the foraging area and to establish its level of importance to flatback turtles in Western Australia.

Genetic analyses of tissue samples enabled the identification of a potential new flatback turtle management unit at the Bonaparte Archipelago, but further samples need to be analysed to confirm this finding as there is evidence of some genetic exchange between the flatback turtles nesting in the Bonaparte Archipelago and the main flatback turtle population of the North West Shelf Management Unit and the sample sizes on which this study was based were small.

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Marine ecology

8

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ABSTRACT

This chapter summarises the findings of a survey program in the period 2005–2007 to investigate marine habitats in the Browse Basin and Bonaparte Archipelago off the coast of Western Australia's Kimberley region.

Ecological studies were conducted in the Browse Island reef complex and in the Maret, Albert, Berthier and Montalivet island groups in the Bonaparte Archipelago. Specialist teams undertook reef-walk and video-transect surveys. Hand collections and coral assemblage studies were also carried out during the reef-walk surveys and reef-profile investigations, while fishes were sampled using the piscicide rotenone in intertidal rock pools at Browse Island, the Maret Islands and the Montalivet Islands.

Subtidal benthic habitats were surveyed using a tow camera in the Bonaparte Archipelago and a remotely operated underwater vehicle (ROV) was used along cross-shelf transects at Echuca Shoal. Sledge-sampling and grab-sampling surveys were carried out at selected islands.

Approximately 162 species of macroalgae were recorded during the study, with the community compositions at the Browse Island reef and the Bonaparte Archipelago being found to be similar. The assemblages consist largely of species that are widespread across the Indo-Pacific region and include the coralline alga *Mastophora rosea* which is a new record for Australia but is a species that is otherwise widely distributed. However, five hitherto unknown species of algae were collected during the survey: a brown alga of the genus *Sargassum* was collected at South Maret Island, and four red algae of the genera *Ceramium*, *Crouania*, *Hypoglossum* and *Martensia* were collected at the Maret Islands and Browse Island.

Macromollusc collections in the intertidal zones of the Browse Island reef complex and of the fringing reefs of the Maret, Albert, Berthier and Montalivet island groups yielded a total of 321 species of three classes: 3 chitons, 75 bivalves, 235 prosobranch gastropods and 8 pulmonate gastropods. The composition of the macromolluscan fauna of these island groups in the archipelago is typical of the nearshore molluscan coral reef faunas of the North West Shelf, including the Kimberley region. Most of these molluscs (86% with a known distribution) are recorded as widespread across the Indo-West Pacific region. It is notable, however, that the study found that the macromolluscan fauna at Browse Island was significantly different from that found in the archipelago: of 140 species found at Browse Island only 55 were shared with the Maret Islands and the other surveyed islands.

Fish collections made in rock pools on the Maret Islands, the Montalivet Islands and Browse Island yielded 97 species from 32 families. These species are also well represented throughout the Bonaparte Archipelago and northern Western Australia.

Two hundred and seventy-five species of scleractinian corals representing 15 families and 59 genera were recorded at intertidal locations in the Maret, Albert, Berthier and Montalivet island groups of the Bonaparte Archipelago. The high number of new records from the surveys—54 for the Kimberley Bioregion, two of which are new records for Australia—reflects the relative lack of research effort in the region prior to 2006. The coral communities on the fringing reefs of the Bonaparte Archipelago had a higher diversity and greater range of coral-dominated communities than those at the Browse Island reef complex. The species richness of the inshore reefs around the surveyed island groups was very high, suggesting that this area may be significant in terms of regional coral biodiversity.

In general, the molluscs, corals and fishes recorded during the survey were found to be typical of such assemblages across the Indo-Pacific region.

Sediment samples for the analysis of benthic infauna communities were collected in September 2005 at eight offshore sites north-west of Browse Island in the Browse Basin and between Browse Island and the Maret Islands. In May 2007 a further ten sediment samples were collected at inshore sites in the Bonaparte Archipelago near the Maret Islands and adjacent islands. The class Polychaeta (polychaete worms) and the subphylum Crustacea (crustaceans) were the most species-rich and numerically dominant taxa, contributing 65% of the species and 89% of all animals identified during the surveys.

INTRODUCTION

This chapter summarises the findings of investigations into the composition and distribution of marine habitats in the Kimberley region of Western Australia. It is based on an unpublished report by environmental consultants RPS Environment Pty Ltd (RPS 2008). The surveys included Browse Island and Echuca Shoal in the Browse Basin as well as the Maret Islands and a number of neighbouring islands, reefs and shoals in the Bonaparte Archipelago.

Browse Island and Echuca Shoal lie on the boundary of the North West Shelf and Oceanic Shoals meso-scale bioregions as delineated in the Integrated Marine and Coastal Regionalisation of Australia (DEH 2006), while the Bonaparte Archipelago forms part of the Kimberley Bioregion.

By far the majority of marine species that inhabit these bioregions have distributions that extend well beyond the study area into the greater part of the Indo-West Pacific region, including the tropical waters of the Indian Ocean, northern Australia and the western Pacific Ocean.

Brooke (1995, 1996, 1997) has described the geomorphology of many reefs in the bioregion, highlighting regional differences. Most notably, the fringing reefs of the islands of the Buccaneer Archipelago to the south-west are typically terraced and lack the gently sloping or ramped reef front that characterises fringing reefs at the Maret Islands and their associated islands. This may be reflected in differences in the coral reef communities between the Bonaparte Archipelago and the Buccaneer Archipelago. However, as comparative studies have not yet been carried out, it is not known whether such geomorphological differences are reflected in differences in the compositions of coral assemblages and those of other groups of marine organisms.

Algae and seagrasses

There have been few published works describing the algal and seagrass assemblages of the Kimberley region. Previous studies, however, have indicated that macroalgal diversity and abundance are lower in the Kimberley Bioregion than further south-west in the Buccaneer Archipelago (Walker 1996, 1997).

Ten seagrass species have been recorded from the Kimberley Bioregion, although the meadows in which these species occur are not as well developed as those in the bioregions further south along the coast (Walker 1992, 1996, 1997). The most abundant seagrass meadow habitats recorded in the Kimberley Bioregion are on terraced intertidal rocky flats in the Buccaneer Archipelago, where eight species were recorded by Walker (1995).

The most common of these species, *Thalassia hemprichii*, covered 30–50% of some parts of the flats and was widely distributed across the whole intertidal zone associated with coral rubble. Other common species were *Enhalus acoroides* and *Halophila ovalis* (Walker 1995).

Invertebrates

Infaunal invertebrates

The soft sediments in inshore zones of the Kimberley coast have previously been found to have a diverse infaunal community, consisting predominantly of crustaceans, annelids and molluscs (Wilson & Paling 2004).

Information on the characteristics of the marine sediments for the region, particularly those relating to offshore waters, is limited. The most extensive investigations to date have been conducted further to the north in the Timor Sea, where the soft sediments were found to be populated by an infaunal community dominated by crustaceans and polychaete worms (Heyward, Pinceratto & Smith 1997). Although relatively rare, small areas of exposed hard substrate in deep water can also support diverse filter-feeding assemblages.

Other invertebrates

Molluscs

Molluscs make a useful taxonomic group for studies of diversity and biogeography as the taxonomy and distribution of Indo-Pacific intertidal molluscs is better known than those for any other invertebrate group. Macromolluscs[1] of the Kimberley Bioregion have been reasonably well documented by Bryce (1997), Wells (1981, 1992) and Wells and Bryce (1995, 1996), but these reports have not been collated. The authors of those reports suggested that the molluscan fauna of the bioregion is depauperate, although Wells (1992) noted that when the species lists of his 1981 and 1992 reports are added together, the species count for the region totalled 536, reflecting a moderate diversity. This list is not comprehensive, however, as the full range of habitats in the region and the full range of taxa, especially those containing small species, have yet to be sampled sufficiently to accurately describe the molluscan fauna.

Polychaetes

The only accounts of polychaetes from the Kimberley Bioregion are those of Hanley (1992, 1995) describing the species collected during the Western Australian Museum expeditions to the Buccaneer Archipelago. From the first survey, 54 species were identified from 13 higher taxa.

[1] In this study, a macromollusc was taken to be a shelled mollusc with a maximum shell measurement of 5 mm or more.

The emphasis of the collecting was on the scale worms of the families Polynoidae, Acoetidae and Sigalionidae and, in fact, more than half of the species collected belonged to scale worm families and included 20 species of polynoids. The second survey produced 19 polynoids, of which only eight were found in the first survey.

Hanley (1995) noted that the taxonomy of this large and important component of the coastal fauna is poorly developed and that identification of many polychaetes is not possible.

Crustaceans

Jones (1992), reporting on the barnacles (infraclass Cirripedia) of the Kimberley islands and reefs, listed 49 species from 18 genera, including a large number of species that are commensal with other crustaceans, sponges, corals and gorgonians. She noted that the cirripedian fauna of the Kimberley was more diverse than expected.

Lists of crustaceans of the order Decapoda collected in the Kimberley Bioregion have been produced by Davie and Short (1995, 1996), Hewitt (1997) and Morgan (1990, 1992). Berggren (1997) reported on caridean shrimps of the bioregion, listing 80 species from 24 genera, most of them associates of other invertebrates. The benthic fauna of decapod crustaceans in the region appears to be moderately diverse, but information is patchy and incomplete.

There is little information on other crustaceans of the region, although a few species are included in the lists of Davie and Short (1995, 1996).

Echinoderms

The echinoderm fauna of the muddy habitats of the Kimberley Bioregion is depauperate in comparison with the shelf-edge reefs of the Oceanic Shoals Bioregion, and the suite of species normally associated with coral reefs is poorly represented (Marsh 1992). Of the five echinoderm classes, only the class Ophiuroidea (brittlestars) has been found to have moderate numbers of species present. Reporting on the results of the Western Australian Museum expedition in August 1991, Marsh (1992) listed 82 species from the bioregion compared with the 178 recorded at Ashmore Reef, noting that the inclusion of information from earlier collections would add only a few species to that total. The crown-of-thorns sea star (*Acanthaster planci*) was recorded at two sites, one at Cassini Island and the other at an islet near Fenelon Island in the Montesquieu Islands group in the 1991 survey. Further studies of echinoderms in the bioregion may extend this species list, but would be unlikely to add much new information to what is now known.

Cnidarians

There is little information on cnidarians in the Kimberley Bioregion other than for the stony corals of the order Scleractinia.

Venomous box jellyfishes of the class Cubozoa have been found in the Canning Bioregion (Gershwin & Alderslade 2005) and are considered likely to be present in the Kimberley Bioregion.

Information on the class Hydrozoa is lacking, except for the stony hydrozoan coral genera *Millepora* and *Stylaster*, both of which occur on coastal reefs of the Kimberley.

In the class Anthozoa, the stony octocoral *Heliopora coerulea* of the order Helioporacea is recorded from reefs on the Kimberley coast (Marsh 1992), while sea pens of the order Pennatulacea, although known to be present, are not recorded in the literature. Soft corals and sea fans of the order Alcyonacea are important components of coral reef ecosystems. They are mentioned in some field reports, but no taxonomic accounts of them have been recorded other than for the organ-pipe coral *Tubipora musica* (Marsh 1992). There is no information on the orders Antipatharia (black or wire corals), Ceriantharia (tube anemones), Actiniaria (sea anemones), Zoantharia (zoanthids), or Corallimorpharia (mushroom anemones).

The coral reef communities of the Kimberley Bioregion are structured differently from those in the less turbid water and less extreme tidal conditions of the adjacent Oceanic Shoals Bioregion, and there are significant differences in species composition.

Prior to the study reported on in this chapter, the known fauna of scleractinian corals in the entire Kimberley Bioregion comprised 181 species in 62 genera (Marsh 1992). Species lists have been published in Blakeway (1997), Marsh (1992), Veron (1993) and Veron and Marsh (1988).

Fishes

Reef and estuarine fishes of the Kimberley Bioregion have been surveyed during Western Australian Museum expeditions over the past 20 years (Allen 1992; Hutchins 1995, 1996), but the lists of species have not been collated. Each of those collecting trips produced new taxa and new records for the bioregion, suggesting that further work is needed before the region's ichthyofauna can be regarded as comprehensively described.

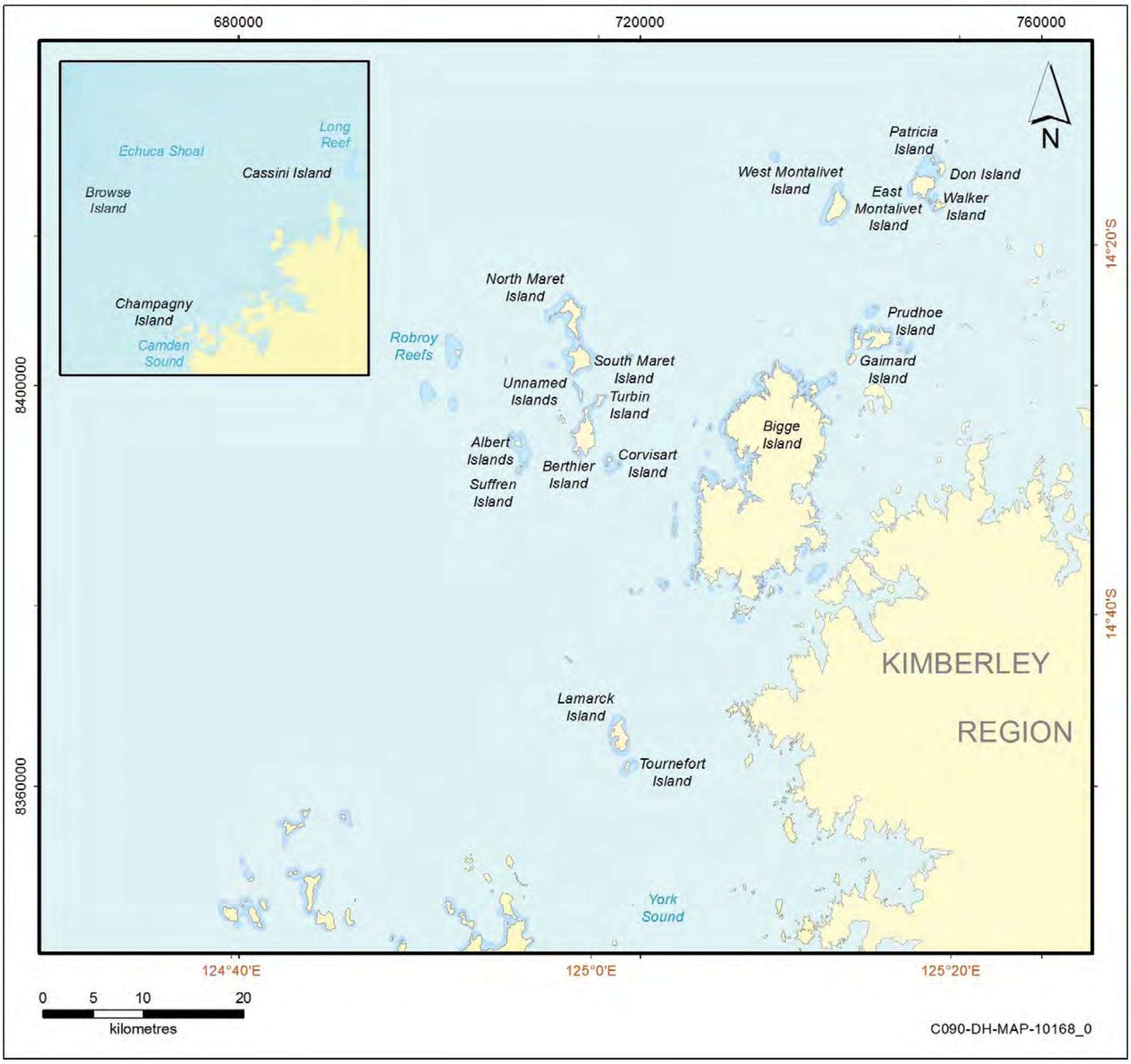

Figure 8-1: The study areas in the Bonaparte Archipelago

Objectives

This study is based on an unpublished report prepared for INPEX Browse, Ltd. by RPS (2008) on intertidal and benthic habitats and communities in the Browse Basin and the Bonaparte Archipelago.

The objectives of the study were as follows:

- to describe the distribution and composition of the marine intertidal and subtidal flora and fauna assemblages on selected islands in the Bonaparte Archipelago and Browse Basin
- to describe the physical structure of the intertidal and subtidal habitats of these islands
- to describe selected seabed habitats in the offshore Browse Basin and around selected islands of the Bonaparte Archipelago.

STUDY AREA

The areas surveyed during the study included intertidal and surrounding subtidal benthic shelf habitats of the islands and nearshore reefs of the Bonaparte Archipelago, Browse Reef and Echuca Shoal, and benthic habitats of the Browse Basin (Figure 8-1).

The intertidal and subtidal studies, with reef walks, reef-profile investigations, video transects, tow-camera surveys and other forms of sampling, were concentrated in the waters around the islands listed below:

- the Maret Islands: North Maret Island and South Maret Island
- the Albert Islands group: five small islands, the largest of which is informally named “Albert Island” and the southernmost of which is formally named as Suffren Island; there are also two very small islets

- the East Montalivet Islands group: East Montalivet Island, Walker Island, Patricia Island, Don Island and associated islets
- West Montalivet Island
- the Berthier Islands group: Berthier Island and three smaller unnamed islets off its north-west coast
- Turbin Island.

In the Bonaparte Archipelago the benthic studies were conducted in the waters around the following islands and reefs:

- Corvisart Island
- the “Unnamed Islands”[2]
- the Robroy Reefs
- Lamarck Island and Tournefort Island
- Bigge Island
- Prudhoe Island and Gaimard Island
- Champagny Island
- Long Reef.

In the Browse Basin the benthic studies were carried out at the following two localities:

- the Browse Island reef complex
- Echuca Shoal.

[2] Two unnamed islands between Berthier Island and South Maret Island, linked by a reef at low tide, were sampled during the survey (see Figure 8-1).

Infauna surveys were conducted at several sites around the Bonaparte Archipelago as well as in offshore waters close to Browse Island and between Browse Island and the Bonaparte Archipelago.

METHODS

A range of survey methods were employed in the Bonaparte Archipelago and at Browse Island to investigate the marine ecology of the study areas (tables 8-1 and 8-2). These were as follows:

- reef-profile investigations at the Maret Islands
- reef walks at the Maret Islands and various reference islands to establish habitat types and to examine algal, seagrass and faunal assemblages (with a special emphasis on the taxonomic investigation of the diversity of coral assemblages)
- hand collections of corals and macromolluscs for further investigation
- collections of fish from intertidal rock pools
- video-transect surveys of reef edges with well-developed coral assemblages.

In addition, subtidal surveys were conducted to investigate habitat, corals, epibenthic fauna and infauna using a tow camera, a benthic sledge and a Van Veen grab sampler. A camera-equipped remotely operated underwater vehicle (ROV) was used at Echuca Shoal.

Table 8-1: Survey methods employed in the Bonaparte Archipelago and Browse Basin

	Intertidal environment					Subtidal environment			
	Reef-profile investi-gations	Reef-walk surveys	Hand collections	Fish collections	Video-transect surveys	Tow-camera surveys	Sledge-sampling surveys	Grab-sampling surveys	ROV video surveys
Habitat	✓	✓	–	–	–	✓	–	–	–
Algae and seagrasses	–	✓	✓	–	–	✓	–	–	–
Molluscs	–	✓	✓	–	–	–	–	–	–
Corals	–	✓	✓	–	✓	✓	–	–	–
Other invertebrates	–	✓	–	–	–	–	–	–	–
Fishes	–	–	–	✓	–	–	–	–	–
Epibenthic communities	–	–	–	–	–	✓	✓	–	✓
Infauna	–	–	–	–	–	–	–	✓	–

Table 8-2: Locations of the surveys conducted in the Bonaparte Archipelago and Browse Basin

	Bonaparte Archipelago															Browse Basin	
	North Maret Island	South Maret Island	Albert Islands group*	East Montalivet Islands group†	West Montalivet Island	Berthier Islands group‡	Turbin Island	Corvisart Island	"Unnamed Islands"	Robroy Reefs	Lamarck and Tournefort islands	Bigge Island	Prudhoe and Gaimard islands	Champagny Island	Long Reef	Browse Island reef complex	Echuca Shoal
Intertidal environment																	
Reef-profile investigations	✓	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Reef-walk surveys	✓§	✓§	✓#	✓§	✓§	✓	✓**	–	–	–	–	–	–	–	–	✓§	–
Reef walk—coral assemblage surveys	✓	✓	✓	✓	✓	✓	✓	–	–	–	–	–	–	–	–	–	–
Hand collections	✓	✓	✓	✓	✓	–	–	–	–	–	–	–	–	–	–	✓	–
Fish collections	✓	✓	–	✓	✓	–	–	–	–	–	–	–	–	–	–	✓	–
Video-transect surveys	✓	✓	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Subtidal environment																	
Tow-camera surveys	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	–	–
Sledge-sampling surveys	✓	✓	–	–	–	✓	✓	–	–	–	–	✓	–	–	–	–	–
Grab-sampling surveys	✓	✓	✓	–	–	✓	–	–	–	–	–	–	–	–	–	–	–
ROV surveys	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	✓

* The Albert Islands group consists of five small islands (the southernmost of which is Suffren Island) and two islets. The largest island is officially unnamed but informally called Albert Island.

† The East Montalivet Islands group consists of East Montalivet Island, Walker Island (and three adjacent unnamed islets off its north-west coast), Patricia Island, and Don Island (and an unnamed islet off its south-west coast.

‡ The Berthier Islands group consists of four islands: Berthier Island itself, together with three smaller unnamed islets off its north-west coast.

§ Coral-community and -composition surveys were conducted in conjunction with surveys of habitat and of algal, seagrass and faunal assemblages.

\# Only habitat and algal, seagrass and faunal assemblage surveys were conducted.

** Only coral-community and -composition surveys were conducted.

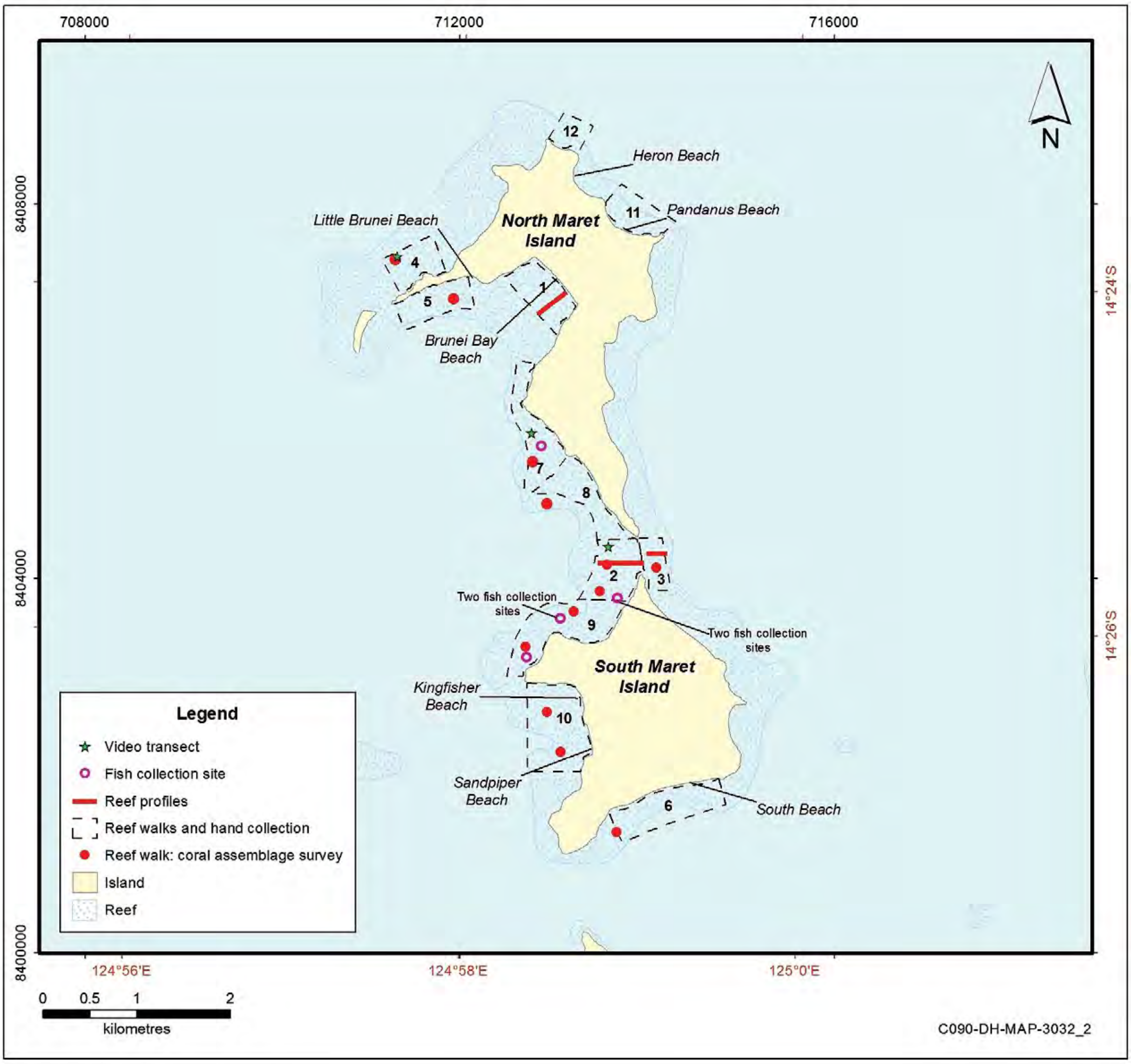

Figure 8-2: Intertidal survey locations at the Maret Islands

Intertidal surveys

Intertidal surveys were conducted at the Maret Islands (Figure 8-2), the Albert Islands group (Figure 8-3), the East Montalivet Islands group (Figure 8-4), West Montalivet Island (Figure 8-5) and the Browse Island reef complex (Figure 8-6). The techniques used are listed in Table 8-2 and discussed below.

Habitat descriptions of the locations for the intertidal surveys are provided for the Maret Islands in Table 8-13, for the Albert Islands group in Table 8-16, for the East Montalivet Islands group in Table 8-17 and for the Browse Island reef complex in Table 8-20. The habitat description for the single West Montalivet Island location is provided below in “Intertidal surveys—detailed results”.

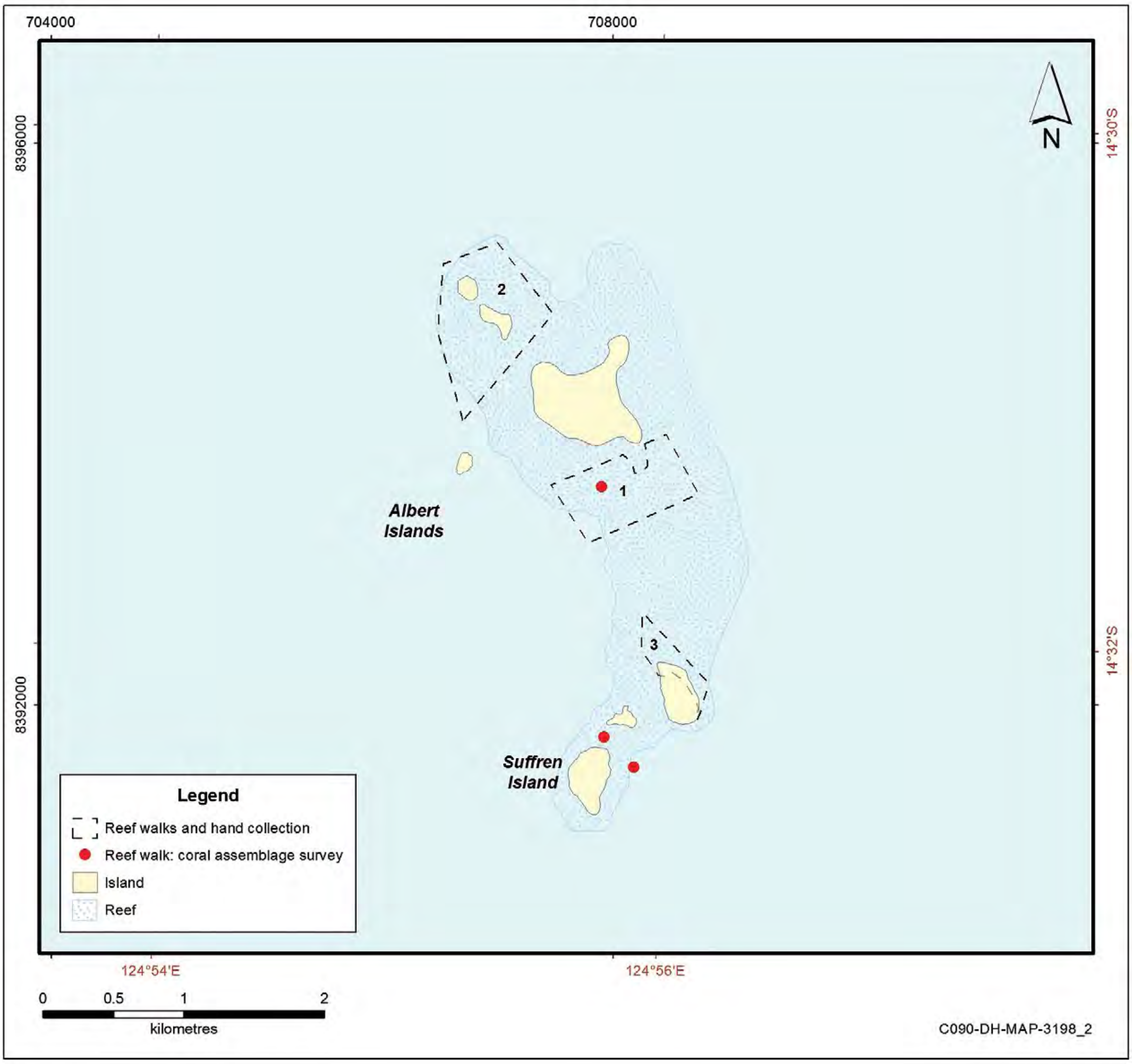

Figure 8-3: Intertidal survey locations in the Albert Islands group

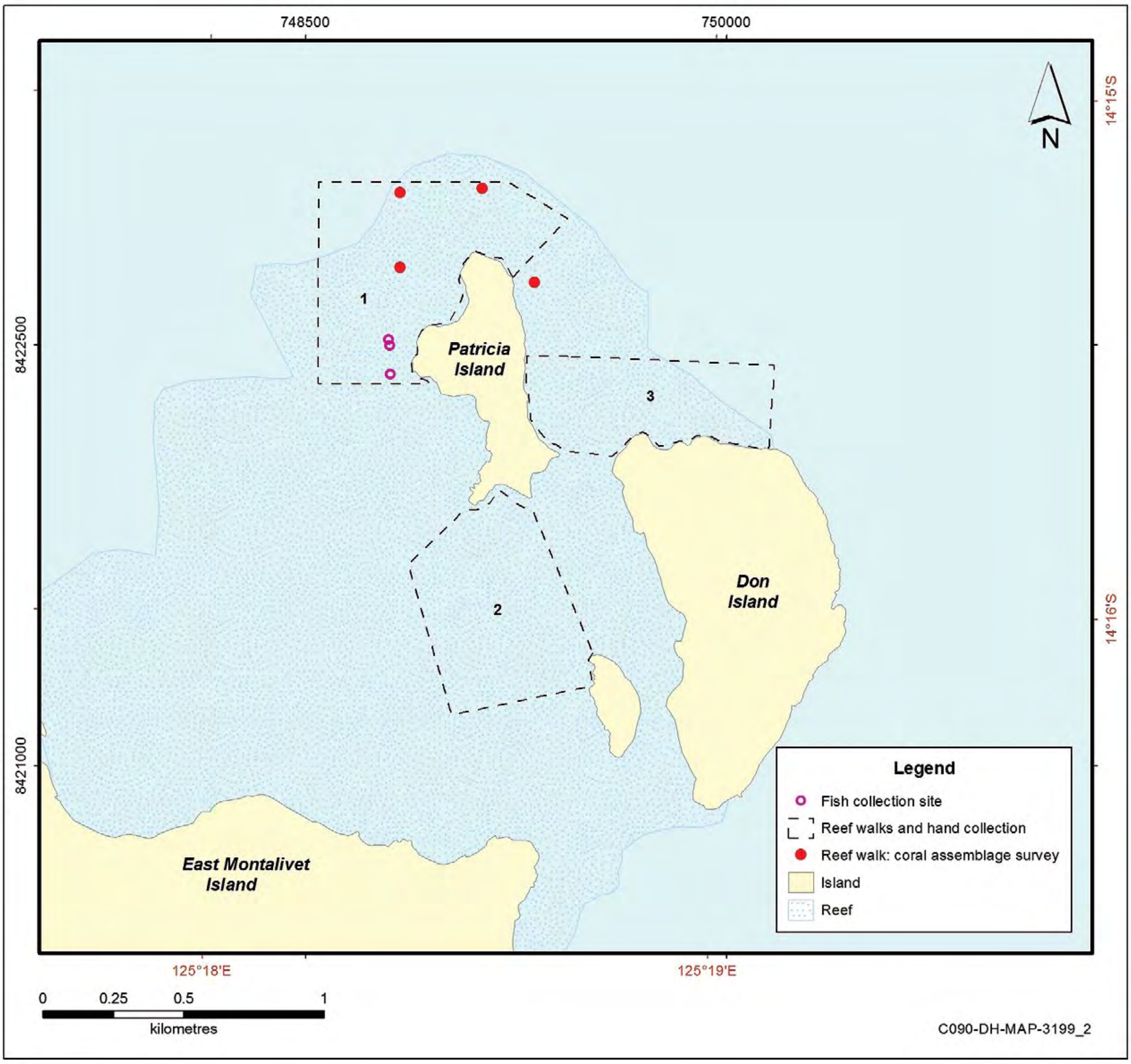

Figure 8-4: Intertidal survey locations in the East Montalivet Islands group

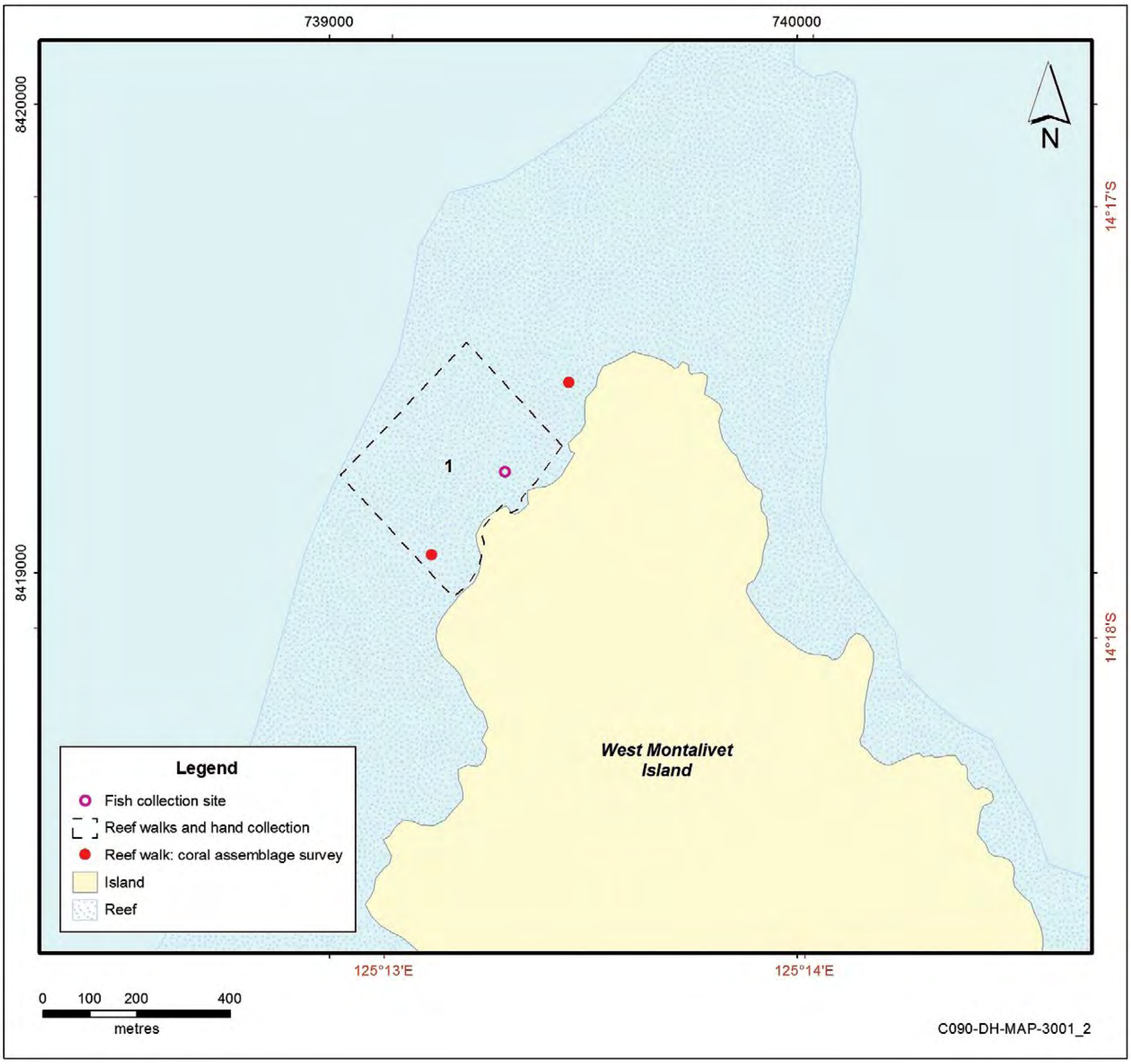

Figure 8-5: Intertidal survey locations at West Montalivet Island

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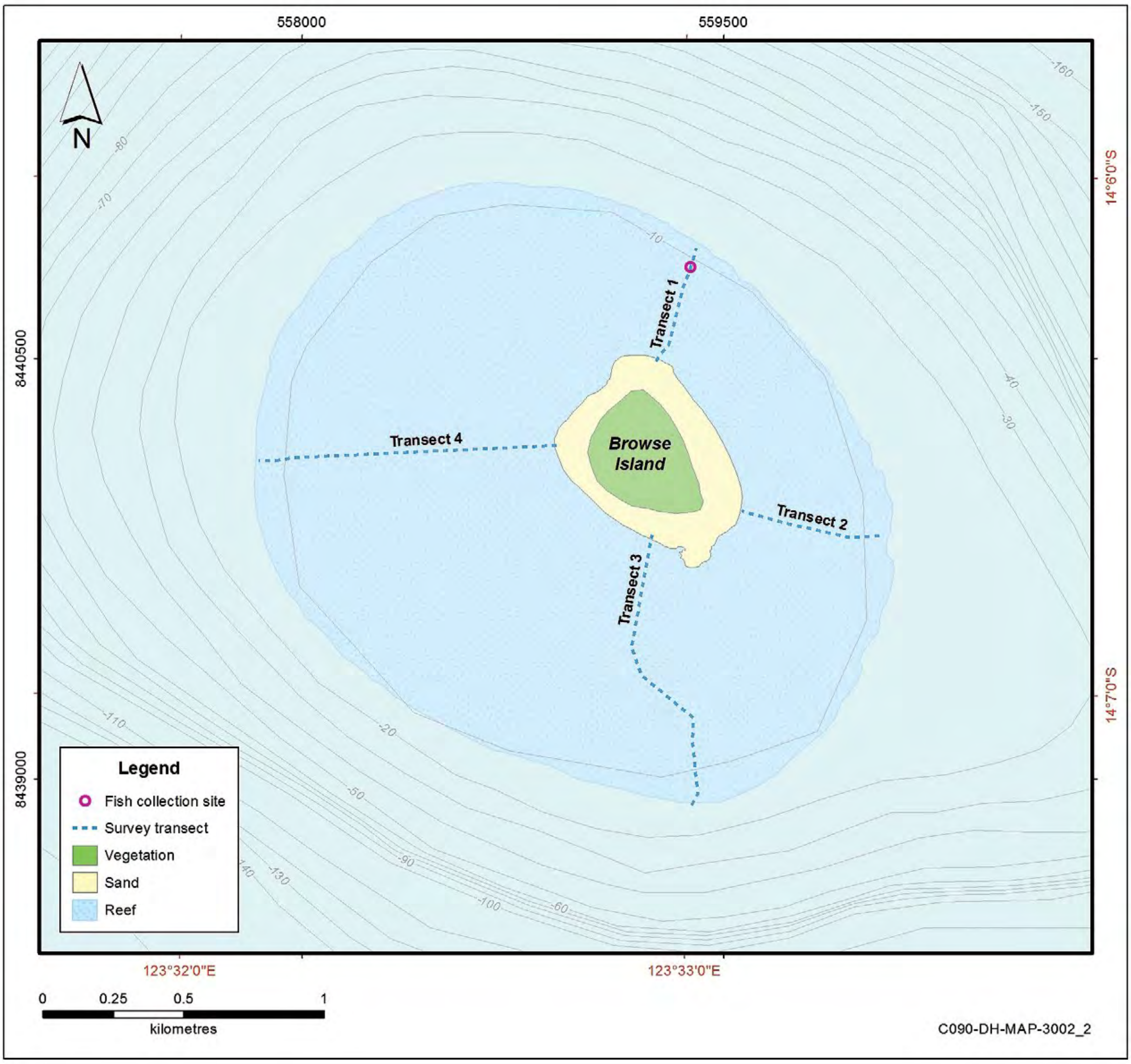

Figure 8-6: The intertidal survey transects at Browse Island used for reef-walk surveys, hand collections of invertebrates and fish collection

Reef-profile investigations

At the Maret Islands, generic reef profiles were described for representative areas around the islands to provide an indication of cross-sectional structure in the intertidal zone. At three locations, transect surveys were carried out to delineate the height–width profile of the reef platform (see Figure 8-2). These locations were chosen because they were considered to represent three of the main reef types at the Maret Islands: the sheltered bay with sand–rubble flats (Site 1), the exposed (seaward) fringing reef (Site 2), and the sheltered (leeward) fringing reef (Site 3). Transects were laid out from the high-water mark to the edge of the reef platform.

The heights above sea level of the various subzones identified along each transect were measured using survey equipment which included a dumpy level[3] and measuring staff[4].

Reef-walk surveys

Aerial photography and remote-sensing data were provided by INPEX and used to identify safe access points for researchers to carry out reef walks across the intertidal zone. Reef walks were carried out during spring low tides and features of the intertidal zone, such as the nature of the substrate, details of the reef profile, and the diversity of animal and plant life were recorded.

[3] A dumpy level is an optical instrument that is used to establish or check points in the same horizontal plane.

[4] A measuring staff or levelling rod is a graduated wooden or aluminium rod which is used to determine differences in elevation.

Photograph courtesy of Christine Lamont

Figure 8-7: Researchers arriving at a study location in the Bonaparte Archipelago

Marine habitat maps were constructed for the Maret Islands, the Albert Islands group, the East Montalivet Islands group and West Montalivet Island using aerial imagery (figures 8-15 to 8-19), and for Browse Island using satellite imagery (Figure 8-20). The levels of accuracy of these maps are a function of the intensity of the ground-truthing effort from reef walks and this varied from island to island. Categories were developed to capture all of the main habitat types encountered during the surveys. These were assigned to survey maps according to the field observations made at each site and were extrapolated to encompass other areas that appeared similar from the aerial imagery and remote-sensing data. The habitat categories were manually drawn on to the maps and these interpretations were later imported into a geographic information system (GIS) database for display purposes.

Reef-walk—coral assemblage surveys

Additional reef walks to investigate the abundance and diversity of coral assemblages in the intertidal zones of the Maret and Montalivet island groups were conducted between 26 September and 1 October 2007 by coral taxonomists Carden Wallace, Charlie Veron, Zoe Richards, Paul Muir and Annika Noreen. Four survey teams, each made up of a coral taxonomist and three scientists, investigated up to 2 km of separate intertidal reef platforms during spring low tides when the maximum area of intertidal reef was exposed. Readily identifiable species were recorded, and species whose identity was uncertain were photographed, labelled and collected. Estimates of coral cover were made during these surveys. Sampling intensity was not consistent between locations, varying both spatially and temporally.

Similar studies of intertidal corals at Berthier Island, Turbin Island and the Albert Islands group were undertaken at extreme low water during the spring low tide between 27 October and 30 October 2007.

The nomenclature of the corals referred to in the text and tables is based on a provisional list of the scleractinian coral species collected and observed during the field surveys by the coral taxonomists engaged by RPS to conduct this study (Table 8-9).

Figure 8-8: Marine biologist Natalie Rosser conducting a coral assemblage survey on North Maret Island

Hand collections

Common, well-known and larger species of invertebrates were identified on site, while less easily identified species, or those that appeared to be unusual, were collected during the reef walks for later identification. Samples collected were stored in 70% ethanol or 10% formalin in sea water; in the case of corals, the skeletons were bleached with sodium hypochlorite. Further descriptions of the collection methods for molluscs and corals are provided below.

It should be noted that the collecting effort was moderately intensive in the intertidal zone of the Maret Islands, but substantially less so at the other islands. The inventories for all localities sampled should be regarded as being incomplete.

Molluscs

During each intertidal survey, molluscs were collected by hand, identified and recorded. Often, because of time constraints, only the readily visible molluscs were recorded and cryptic species and the very small micromolluscs[5] were not recorded. Although this means that the inventory of molluscs presented in this chapter is not comprehensive, it is generally indicative of the macromolluscan assemblage at each of the study areas.

The nomenclature of gastropod molluscs applied in the text and tables generally follows that found in Wilson (1993, 1994). For bivalve molluscs the reference publications used were Lamprell and Whitehead (1992) and Lamprell and Healy (1998).

5 In this study, a micromollusc was taken to be a shelled mollusc with a maximum shell measurement of 5 mm or less.

Molluscs were selected as an indicator of levels of endemism in the marine invertebrate fauna of the Bonaparte Archipelago because they constitute a well-known group and consequently their regional affinities are much better defined than for most other marine invertebrate groups. Investigations of the similarities between the communities of macromolluscs present at Browse Island, and the islands of the Bonaparte Archipelago were conducted using a multidimensional scaling (MDS) analysis and a one-way analysis of similarity (ANOSIM) based on presence–absence data collected from all locations. The MDS and ANOSIM operations were performed on a matrix of Bray–Curtis similarity indices, with a fourth-root transformation using PRIMER (Plymouth Routines in Multivariate Ecological Research) software (Clarke 1993).

Corals

Coral samples were bleached using sodium hypochlorite solution. Once the non-calcified tissue had been removed, the coral skeletons were washed, dried and examined under a hand lens or dissecting microscope. They were identified to species level using recognised taxonomic keys for scleractinian corals.

Only corals found in intertidal habitats were collected and identified to species level. This was partly because of the risk of encountering saltwater crocodiles in the subtidal waters and partly because of the desire to avoid destructive sampling. The inventory of coral species recorded from the intertidal zones is therefore an incomplete list of the species that make up the coral communities of the region, as some species are limited to deeper waters. However, the very large tidal range that prevails in the region and the fact that the investigations were timed to take place during the lowest tides of the year resulted in the exposure of coral assemblages that are rarely recorded in the lower intertidal zone. Despite the team's inability to record subtidal corals, the intertidal coral studies provide a very sound indication of the composition of the coral community in the Bonaparte Archipelago, and represent the most comprehensive list of coral species so far produced for the Kimberley Bioregion.

Fish collections

An assessment of fish communities was carried out in 11 opportunistically selected intertidal rock pools located at North Maret Island and South Maret Island (one site and five sites respectively, Figure 8-2), at Patricia Island in the East Montalivet Islands group (three sites, Figure 8-4), at West Montalivet Island (one site, Figure 8-5) and at Browse Island (one site, Figure 8-6).

They took place during the lowest spring tides in October 2006 (Browse Island) and in March 2007 (the Bonaparte Archipelago sites). The piscicide rotenone was mixed with water and applied at a concentration of approximately 200 g of dry weight per 10 m^2 of pool area. When necessary, barriers were erected to contain the rotenone in the selected rock pool to ensure that neighbouring pools did not become contaminated. The sampled pools were between 6 m^2 and 60 m^2 in area and between 0.3 and 0.7 m deep. Fish became narcotised within approximately ten minutes of the application of the rotenone, allowing them to be collected in a scoop net with a 5 mm mesh. The sampled fish were stored in 70% ethanol, or 10% formalin in sea water.

The fishes were identified by trained researchers and selected species were archived for the scientific record. Fish surveys were only conducted in pools in the intertidal zone and only during one season. Consequently, this sampling regime provides only a "snapshot" of species diversity and abundance at Browse Island in 2006 and at the selected Bonaparte Archipelago islands in 2007.

Video-transect surveys

Video-transect surveys were carried out only on the Maret Islands.

A quantitative coral monitoring baseline was conducted by filming randomly chosen transects along the lower littoral reef front of survey sites 2, 4, and 7 (Figure 8-2) at the islands. Each transect starting point was randomly established on the reef crest with a 12 mm diameter stake driven into the platform. A 100 m fibreglass tape was laid parallel to the reef edge and held in position by additional stakes at the 50 m and 100 m marks. Each transect was videoed using a Sony HC1000 3CCD digital video camera, recording to MiniDV. This involved a slow traverse along each transect, with the camera held at a consistent height (approximately 1 m above the base level), at approximately 0.1 m/s (Figure 8-9).

The tapes were analysed on digital video players. Substrate and coral genera were identified in accordance with the AIMS Video Transect Analysis System (AVTAS), developed by the Australian Institute of Marine Science (AIMS) for the assessment of coral-community data from video transects. This technique provides estimates of coral cover, coral-community composition and coral abundance, while at the same time preventing any biased selection of substrates. Coral identifications to family and genus level were also derived from the video footage.

Figure 8-9: Biologist Mike Forde filming a video transect across the reef edge on North Maret Island

Browse Island reef complex

The intertidal habitats of the reef platform were examined at Browse Island along four transects during the spring low tide from 6 to 13 September 2006. The techniques used were the same as described above for reef-walk surveys and hand collections. This survey was much more intense than the surveys conducted in the Bonaparte Archipelago, where access and safety concerns restricted time on the islands. As a result, further analyses of molluscs and more detailed habitat maps (with finer-scale habitat categories) have been presented for the Browse Island reef complex than for the other localities examined.

Subtidal surveys

Subtidal surveys were carried out using tow cameras and benthic sledges at selected islands to ground-truth different habitat or seabed features that had been previously identified remotely by sidescan sonar or swath bathymetry. A ROV was used at Echuca Shoal.

Tow-camera surveys

Subtidal habitats were recorded and described using an underwater video camera towed behind the survey vessel along transects at selected locations in the Bonaparte Archipelago: the Maret Islands, the Albert Islands group, the East Montalivet Islands group (East Montalivet, Walker, Don and Patricia islands), West Montalivet Island, the Berthier Islands group, Turbin Island, Corvisart Island, the “Unnamed Islands” (two contiguous unnamed islands between Berthier Island and South Maret Island), the Robroy Reefs (North Robroy, West Robroy and South Robroy reefs), Lamarck and Tournefort islands, Bigge Island, Prudhoe and Gaimard islands, Champagny Island and Long Reef. Locations were chosen based on features that had been identified from sidescan sonar or swath bathymetry surveys.

The tow-camera assembly consisted of a Mako housing equipped with a low-light camera. The transmitted images were delivered through an umbilical cable to a control and recording station on the survey vessel. The live images were displayed on monitors, with scientists recording the benthic habitats observed. These images were also recorded simultaneously to DVDs (digital video discs) for backup. Qualitative descriptions of benthic habitats and assemblages were recorded, and positions along the survey route were registered using a Garmin GPS receiver. Positional data and habitat information were recorded directly to files using ArcPad GIS software. These video surveys targeted seabed features that were identified from aerial photography or acoustic mapping.

The video data were used to compile maps for the seabed. Habitat categories were created by analysing the data based on what could be discerned from the video footage. The maps were initially created manually using these habitat categories and were later imported into GIS for display purposes.

Sledge-sampling surveys

The epibenthic communities on non-reefal substrates were surveyed using a benthic sledge (Figure 8-10) at 23 locations in the Bonaparte Archipelago: at North Maret Island, South Maret Island and Turbin Island, between Berthier Island and the Albert Islands, and Bigge Island (Figure 8-11). The sledge was of an Ockelmann design (English, Wilkinson & Baker 1997) and its main element was a rectangular box collector 1.5 m long with a gape of 0.5 m. A pair of nets was attached to the box section to collect the samples that were dislodged by the sledge. The inner net had a mesh size of 10 mm, thus limiting the samples to macro-organisms. The on-seabed tows, at depths between 18 m and 47 m, were standardised to five minutes at the vessel's minimum speed (approximately 2 knots), roughly equating to a tow distance of 500 m. The samples were analysed by scientists in the field and sorted to broad taxonomic groups or to genus where possible. Digital photographs were taken of all specimens collected.

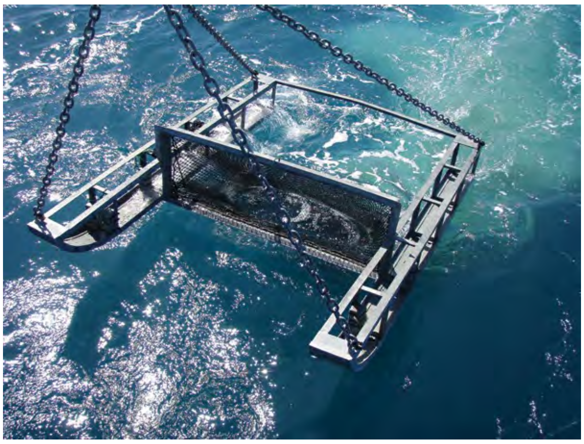

Figure 8-10: Benthic sledge sampler being retrieved from the ocean

Grab-sampling surveys for infauna

Sediment samples for the analysis of benthic infauna communities were collected by grab sampler in September 2005 at eight offshore sites north-west of Browse Island in the Browse Basin and between Browse Island and the Maret Islands. In May 2007 a further ten sediment samples were collected at inshore sites in the Bonaparte Archipelago near the Maret Islands and adjacent islands (Figure 8-12). A lightweight stainless-steel Van Veen grab sampler (0.25 m^2 spread, 60 L capacity) was used to collect the sediment; it was deployed manually and retrieved using a pneumatic winch.

Three replicate samples were collected at each site. After recovery, the samples were separated using a graduated divider to standardise the surface area to 0.15 m^2.

Following this, the infauna samples were filtered through a 1 mm sieve with sea water. Any material retained on the sieve was placed in a labelled calico bag. The samples were then drained of remaining water and placed in a solution of 10% formalin in sea water buffered with borax (sodium tetraborate).

The preserved infauna samples were analysed by scientists at the Zoology Department of the University of Western Australia under the supervision of Dr Jane Prince. The samples were washed and the infauna extracted by elutriation (washing, decanting, and settling). The remaining sediments were stained with rose bengal (a protein stain) and then examined for animals that were too heavy to be efficiently extracted by elutriation, for example bivalves and ostracods.

The infaunal animals were sorted under a binocular dissecting microscope and identified to the lowest practicable taxonomic level. Taxonomic resolution varied among phyla, but the most abundant taxa were generally identified to nominal species within families or suborders.

Remotely operated underwater vehicle (ROV) surveys

Visual inspections of the seafloor were conducted using a 20 HP Sea Pup Observation Class remotely operated underwater vehicle (ROV) at Echuca Shoal (Figure 8-13). The device was fitted with digital video cameras and was operated by Fugro Survey Pty Ltd. It transmitted live video images to a control station aboard the survey vessel where they were transferred to a digital hard drive and later recorded on to DVD.

RESULTS

A summary of the results of the intertidal surveys is presented for algae, seagrasses, molluscs, corals and fishes below.

Intertidal surveys—summary

Algae and seagrasses

Algae and seagrasses were recorded during reef walks at Browse Island, the Maret Islands, the Albert Islands group, the Berthier Islands group and Turbin Island.

Only two seagrass species, *Thalassia hemprichii* and *Halophila ovalis*, were recorded.

A total of 162 species of algae were recorded during the surveys. This number was made up of 44 green algae of the phylum Chlorophyta, 27 brown algae of the phylum Heterokontophyta, and 91 red algae of the phylum Rhodophyta (Table 8-3).

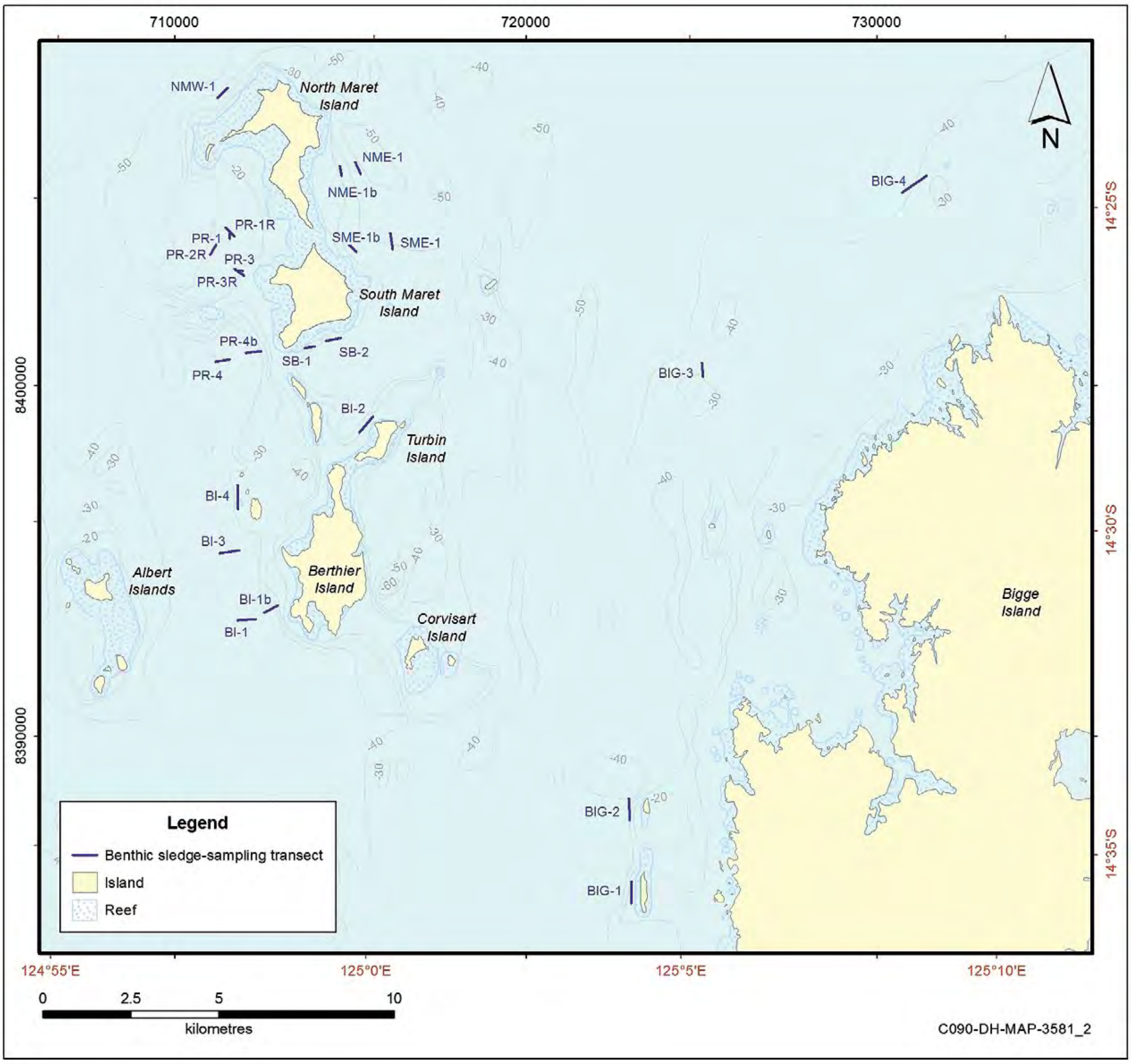

Figure 8-11: Benthic sledge-sampling locations in the Bonaparte Archipelago adjacent to the Maret Islands, Berthier Island, the Albert Islands, Turbin Island and Bigge Island

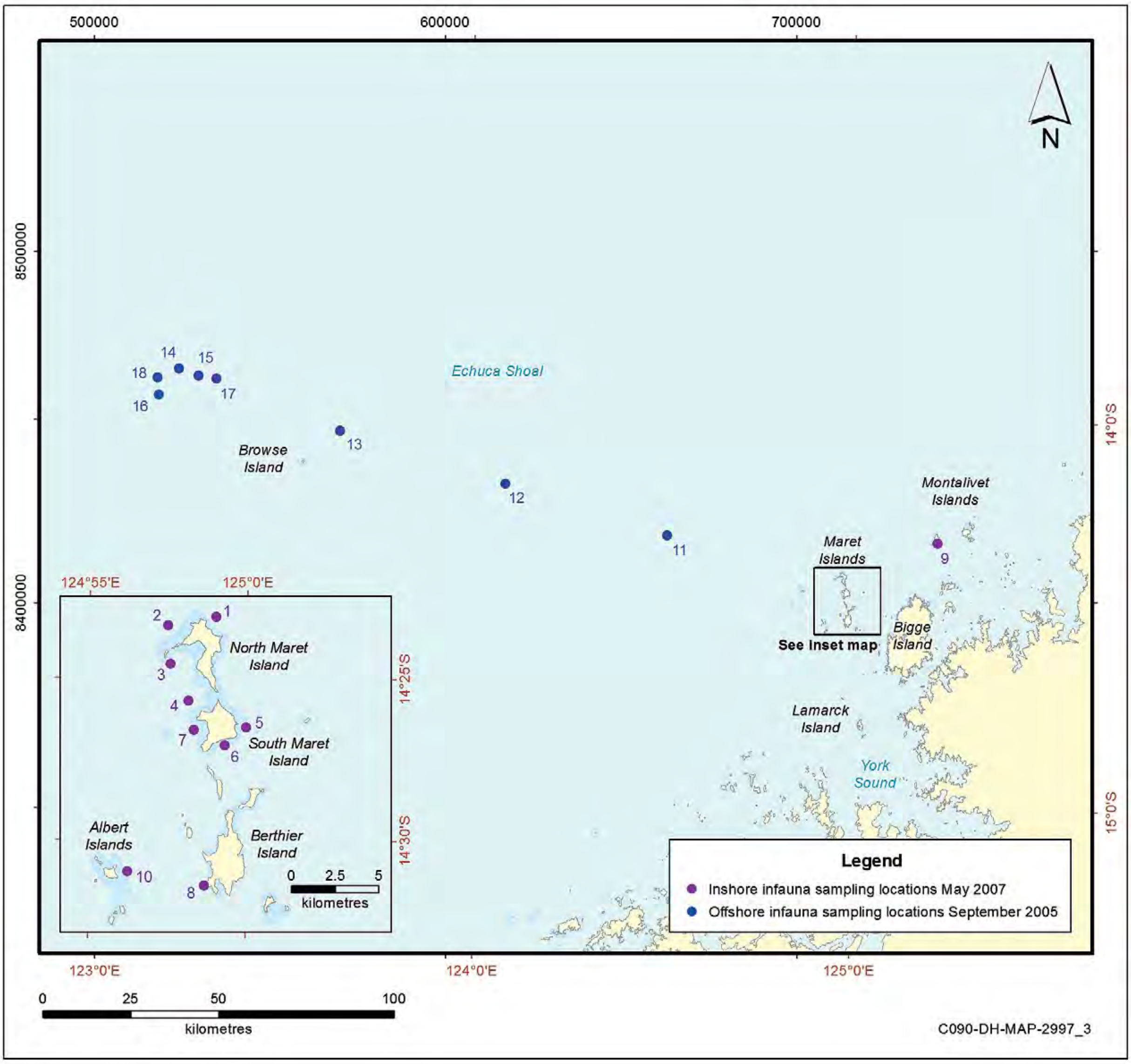

Figure 8-12: Infauna sampling locations in September 2005 in the Browse Basin and in May 2007 in the Bonaparte Archipelago

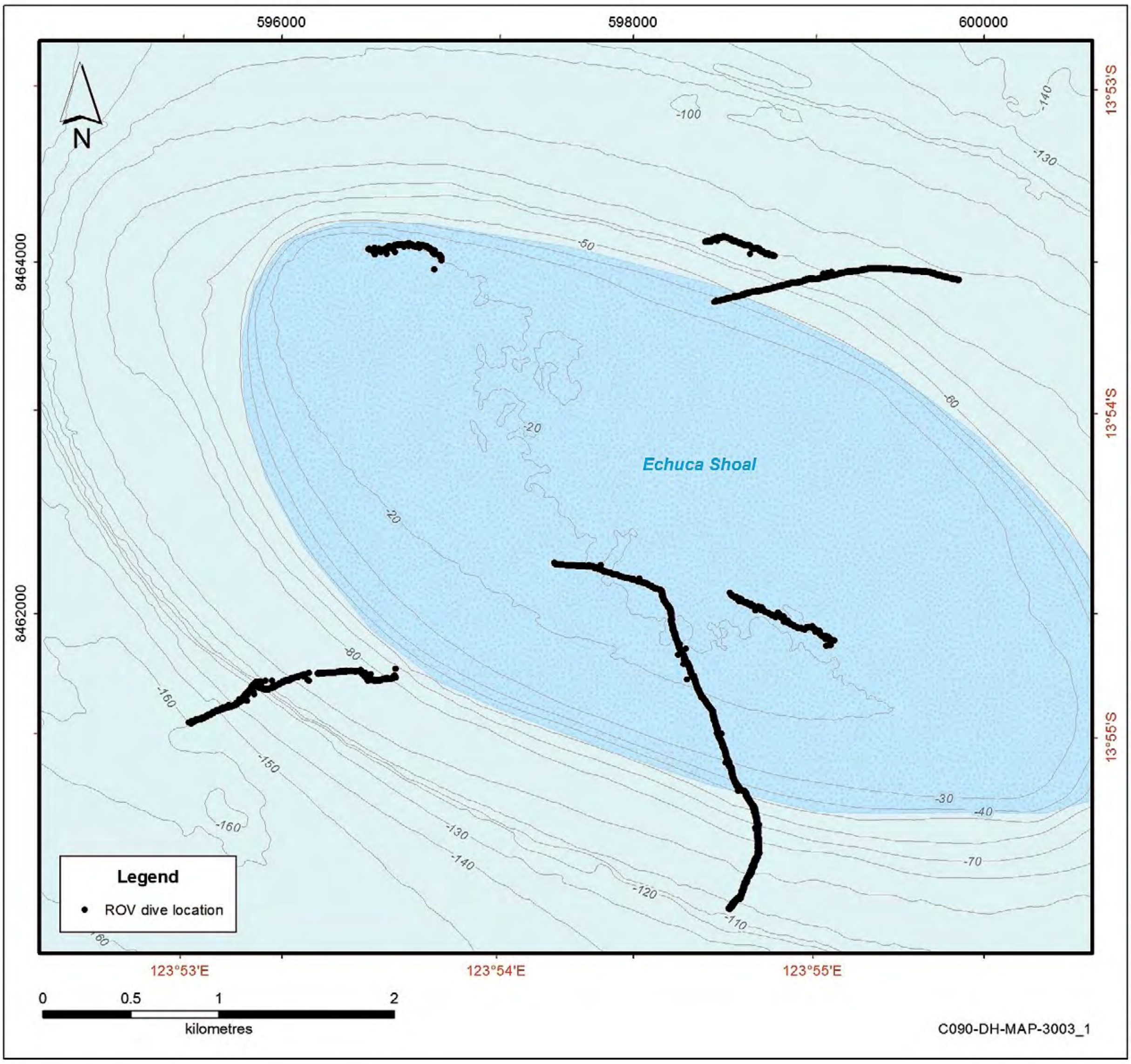

Figure 8-13: ROV transects conducted at Echuca Shoal

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Table 8-3: Inventory of the algal species recorded at the Maret Islands, the Berthier Islands, Browse Island, the Albert Islands and Turbin Island

Phylum	Species	Island or island group
Chlorophyta (green algae)	*Acetabularia caliculus*	BER
	Anadyomene plicata	NMI
	Avrainvillea sp.*	BRS
	Boergesenia forbesii	NMI, SMI
	Boodlea composita	NMI, BRS
	Boodlea vanbosseae	BRS
	Bornetella oligospora	NMI, SMI
	Bornetella sphaerica	"Maret Islands"†
	Caulerpa chemnitzia	NMI, SMI
	Caulerpa corynephora	NMI, SMI, ALB
	Caulerpa fergusonii	ALB
	Caulerpa lamourouxii	SMI
	Caulerpa lentillifera	NMI, SMI
	Caulerpa racemosa	NMI, SMI, ALB
	Caulerpa serrulata	SMI, ALB
	Caulerpa sertularioides	NMI, SMI
	Caulerpa verticillata	NMI
	Caulerpa webbiana	SMI
	Cladophora herpestica	ALB
	Cladophora sp.*	BER
	Cladophoropsis vaucheriiformis	NMI, SMI, ALB
	Codium arabicum	NMI, SMI
	Codium dwarkense	NMI, SMI
	Codium sp.*	BRS
	Dictyosphaeria cavernosa	BRS
	Dictyosphaeria versluysii	BRS
	Halimeda cylindracea	NMI, SMI
	Halimeda discoidea	NMI, SMI,
	Halimeda macroloba	TUR
	Halimeda opuntia	NMI, SMI, BRS
	Halimeda velasquezii	NMI, SMI, BRS
	Halimeda sp. 1*	BRS
	Halimeda sp. 2*	NMI
	Neomeris bilimbata	NMI, BRS
	Rhizoclonium riparium	SMI
	Pseudobryopsis hainanensis	NMI, BER
	Udotea flabellum	NMI, SMI
	Ulva flexuosa	NMI, SMI, BER, ALB, TUR
	Ulva paradoxa	SMI, ALB
	Ulva ralfsii	NMI
	Uronema marinum	ALB
	Valonia aegagropila	NMI, BRS
	Valoniopsis pachynema	NMI
	Ventricaria ventricosa	NMI, SMI, BRS

Table 8-3: Inventory of the algal species recorded at the Maret Islands, the Berthier Islands, Browse Island, the Albert Islands and Turbin Island (continued)

Phylum	Species	Island or island group
Heterokontophyta (brown algae)	*Canistrocarpus cervicornis*	SMI
	Colpomenia sinuosa	NMI, SMI
	Dictyopteris repens	NMI
	Dictyopteris woodwardia	NMI, SMI
	Dictyota ciliolata	NMI, SMI
	Hincksia sp.*	NMI, SMI
	Hormophysa cuneiformis	SMI
	Hydroclathrus clathratus	NMI, SMI
	Lobophora variegata	NMI, SMI, BRS, ALB
	Padina australis	NMI, SMI, BRS, ALB, TUR
	Rosenvingea nhatrangensis	NMI, SMI
	Sargassum aquifolium	NMI, SMI
	Sargassum decurrens	NMI, SMI, ALB
	Sargassum flavicans	NMI, SMI, ALB
	Sargassum ilicifolium	NMI, SMI, ALB
	Sargassum ligulatum	NMI, SMI, ALB
	Sargassum sp. cf. *linearifolium**	NMI, SMI, ALB
	Sargassum marginatum	ALB
	Sargassum polycystum	NMI, SMI, ALB
	Sargassum sp. nov.	SMI
	Sirophysalis trinodis	NMI, SMI
	Spatoglossum macrodontum	SMI
	Sphacelaria novae-hollandiae	NMI
	Sphacelaria rigidula	NMI, SMI, BRS
	Turbinaria conoides	SMI
	Turbinaria gracilis	SMI
	Turbinaria ornata	NMI, SMI
Rhodophyta (red algae)	*Acanthophora* sp. cf. *muscoides**	NMI
	Acanthophora spicifera	NMI, SMI
	Acrochaetium liagorae	BRS
	Acrochaetium microscopicum	SMI
	Actinotrichia fragilis	NMI, SMI, BRS
	Aglaothamnion cordatum	SMI
	Amphiroa foliacea	NMI, SMI, ALB
	Amphiroa fragilissima	NMI, SMI, BRS
	Amphiroa tribulus	NMI, SMI
	Anotrichium tenue	SMI
	Asparagopsis taxiformis	NMI, SMI, BRS
	Callithamnion sp.*	BRS
	Centroceras clavulatum	SMI, BRS
	Ceramium cingulatum	NMI
	Ceramium clarionense	ALB
	Ceramium flaccidum	NMI, SMI, BRS
	Ceramium isogonum	SMI
	Ceramium macilentum	NMI

Table 8-3: Inventory of the algal species recorded at the Maret Islands, the Berthier Islands, Browse Island, the Albert Islands and Turbin Island (continued)

Phylum	Species	Island or island group
Rhodophyta (red algae) (cont.)	*Ceramium subdichotomum*	NMI
	Ceramium sp. nov.	SMI, BRS
	Ceratodictyon spongiosum	NMI, SMI
	Champia sp. cf. *indica**	NMI, SMI
	Champia parvula	NMI, SMI, BRS
	Champia stipitata	NMI, SMI,
	Chondria dangeardii	SMI
	Chondria sp.*	SMI, BRS
	Chondrophycus sp. 1*	NMI, SMI, BRS
	Chondrophycus sp. 2*	BRS
	Colaconema robustum	SMI
	Crouania sp. nov.	SMI
	Dasya sp.*	NMI, SMI, BER
	Desikacharyella indica	NMI
	Dichotomaria marginata	NMI, SMI,
	Digenea simplex	NMI
	Eucheuma denticulatum	NMI
	Galaxaura rugosa	NMI, SMI, BRS
	Galaxaura filamentosa	ALB
	Ganonema farinosum	SMI
	Ganonema pinnatum	BRS
	Gayliella transversalis	SMI
	Gelidiella acerosa	NMI, SMI
	Gelidium sp.*	ALB
	Gracilaria sp. cf. *arcuata**	SMI
	Gracilaria sp. 1*	NMI, SMI
	Gracilaria sp. 2*	NMI
	Griffithsia heteromorpha	BER
	Halymenia floresii	NMI
	Halymenia sp.*	BRS
	Herposiphonia secunda	NMI
	Heterosiphonia crassipes	SMI
	Hommersandiophycus borowitzkae	NMI
	Hydrolithon reinboldii	NMI, SMI, ALB
	Hypnea cervicornis	SMI, BRS
	Hypnea charoides	NMI, SMI
	Hypnea pannosa	NMI
	Hypnea spinella	NMI, SMI
	Hypnea sp.*	NMI, BRS
	Hypoglossum sp. nov.	BRS
	Jania rosea	SMI
	Jania sp.*	NMI, SMI, BRS
	Kallymenia sp.*	BRS
	Laurencia brongniartii	NMI
	Laurencia sp. cf. *intricata**	SMI

Table 8-3: Inventory of the algal species recorded at the Maret Islands, the Berthier Islands, Browse Island, the Albert Islands and Turbin Island (continued)

Phylum	Species	Island or island group
Rhodophyta (red algae) (cont.)	*Laurencia similis*	NMI, SMI
	Laurencia sp.*	NMI, SMI, ALB
	Leveillea jungermannioides	NMI, SMI, BRS
	Liagora australasica	BRS
	Liagora ceranoides	NMI, SMI
	Liagora sp. 1*	NMI, SMI, BRS
	Liagora sp. 2*	BRS
	Lophocladia sp.*	SMI
	Macrocarpus kraftii	NMI
	Martensia sp. nov.*	NMI
	Mastophora rosea‡	NMI, SMI, ALB
	Neogoniolithon frutescens	ALB
	Neoizziella divaricata	SMI
	Neosiphonia ferulacea	SMI
	Peyssonnelia sp.*	BRS, ALB
	Pihiella liagoraciphila	BRS
	Polysiphonia sp. 1*	NMI, SMI, BER, BRS
	Polysiphonia sp. 2*	SMI
	Portieria hornemannii	NMI, SMI
	Pterocladiella caerulescens	BRS
	Sebdenia polydactyla	SMI
	Spyridia filamentosa	SMI
	Titanophycus setchellii	NMI, SMI, BRS
	Tolypiocladia condensata	NMI
	Tolypiocladia glomerulata	NMI, SMI, BER, BRS
	Tricleocarpa cylindrica	NMI, SMI
	Tricleocarpa sp.*	SMI
	Zellera tawallina	NMI, BRS

Note: NMI = North Maret Island; SMI = South Maret Island; BER = Berthier Islands group; BRS = Browse Island; ALB = Albert Islands group; TUR = Turbin Island.

* Species as yet undetermined.

† A specimen of this species is held by the Western Australian Herbarium, noted as having been collected at the "Maret Islands".

‡ This is the first record of this species from Australia.

Several species of algae were not immediately identifiable in the field and five of these were later found to be hitherto undescribed species:

- a brown alga of the genus *Sargassum*, collected at South Maret Island
- a red alga of the genus *Ceramium*, collected at South Maret Island and Browse Island
- a red alga of the genus *Crouania*, collected at South Maret Island
- a red alga of the genus *Hypoglossum*, collected at Browse Island
- a red alga of the genus *Martensia*, collected at North Maret Island.

These species have also been collected at other locations and their formal descriptions have been prepared (and are being prepared) for publication (Huisman in press, Huisman in prep.).

Molluscs

Table 8-4 lists the intertidal molluscs recorded during reef walks at Browse Island, the Maret Islands, the Albert Islands, the Berthier Islands, West Montalivet Island and the East Montalivet Islands. A total of 321 macromollusc species of three classes were recorded during the surveys: 3 chitons, 75 bivalves, 235 prosobranch gastropods and 8 pulmonate gastropods.

Table 8-4: Inventory of the shelled macromollusc species recorded on intertidal reefs at Browse Island and at the Maret, Albert, Berthier and Montalivet island groups

Family	Species	Browse Island	Maret Islands	Albert Islands group	Berthier Islands group	West Montalivet Island	East Montalivet Islands group
Class Polyplacophora—chitons							
Chitonidae	*Acanthopleura gemmata*	–	✓	✓	✓	✓	✓
	Acanthopleura spinosa	–	✓	✓	✓	✓	✓
Cryptoplacidae	*Cryptoplax larvaeformis*	–	✓	✓	–	✓	✓
Class Bivalvia—bivalves							
Arcidae	*Arca avellana*	–	✓	–	–	✓	–
	Barbatia amygdalumtostum	✓	✓	✓	✓	✓	✓
	Barbatia coma	–	✓	–	–	–	–
Mytilidae	*Botula fusca*	–	✓	✓	–	✓	–
	Brachidontes ustulatus	–	✓	–	–	–	–
	Lithophaga hanleyana	✓	–	–	–	–	–
	Lithophaga sp. cf. *kuehnelti*	✓	–	–	–	–	–
	Lithophaga lima	–	✓	–	–	–	–
	Lithophaga malaccana	–	✓	✓	–	✓	✓
	Lithophaga obesa	–	✓	✓	–	✓	✓
	Lithophaga simplex	–	✓	✓	–	✓	✓
	Lithophaga teres	–	✓	✓	–	✓	✓
	Modiolus sp.	–	✓	–	✓	–	✓
	Septifer bilocularis	–	✓	–	✓	–	✓
Pteriidae	*Pinctada albina*	–	✓	–	✓	–	–
	Pinctada margaritifera	✓	✓	✓	–	✓	✓
	Pteria penguin	✓	–	–	–	–	–
	Pteria sp.	–	✓	–	–	–	–
Pinnidae	*Atrina pectinata*	–	–	–	✓	–	–
	Pinna deltodes	–	✓	✓	–	✓	✓
Pectinidae	*Chlamys acroporicola*	✓	–	✓	–	–	–
	Chlamys irregularis	–	–	✓	–	–	–
	Pedum sp.	✓	–	–	–	–	–
	Semipallium tigris	–	✓	–	–	–	–

Table 8-4: Inventory of the shelled macromollusc species recorded on intertidal reefs at Browse Island and at the Maret, Albert, Berthier and Montalivet island groups (continued)

Family	Species	Browse Island	Maret Islands	Albert Islands group	Berthier Islands group	West Montalivet Island	East Montalivet Islands group
Spondylidae	*Spondylus nicobaricus*	–	✓	–	–	✓	–
	Spondylus sp.	–	✓	–	–	✓	–
	Spondylus sp.	✓	–	–	–	–	–
Malleidae	*Malvufundus regula*	–	✓	✓	–	–	–
Isognomonidae	*Isognomon isognomon*	✓	✓	–	–	✓	–
	Isognomon legumen	✓	✓	–	–	–	–
	Isognomon nucleus	–	✓	–	✓	–	✓
Ostraeidae	*Saccostrea cucullata*	–	✓	–	✓	–	–
	Saccostrea echinata	–	✓	–	–	–	–
Lucinidae	*Codakia punctata*	✓	–	–	–	–	–
	Ctena bella	–	✓	✓	–	✓	✓
	Divaricella ornata	–	–	–	–	–	✓
	Lucinidae gen. et sp. indet.	✓	–	–	–	–	–
Carditidae	*Cardita preissii*	–	–	✓	–	–	–
	Cardita variegata	✓	✓	–	✓	✓	–
Cardiidae	*Acrosterigma alternatum*	–	✓	–	–	–	–
	Acrosterigma elongatum	✓	–	–	–	–	–
	Acrosterigma fultoni	–	✓	–	–	–	–
	Acrosterigma reeveanum	–	✓	✓	–	–	–
	Fragum hemicardium	–	–	✓	–	–	–
	Fragum unedo	–	✓	✓	✓	–	✓
	Fulvia aperta	–	✓	–	✓	–	–
Hemidonacidae	*Hemidonax australiensis*	–	✓	–	–	–	–
Tridacnidae	*Hippopus hippopus*	✓	–	–	–	–	–
	Tridacna maxima	✓	✓	✓	✓	–	–
	Tridacna squamosa	✓	✓	✓	–	✓	✓
Donacidae	*Donax cuneatus*	–	✓	–	✓	–	–
Mactridae	*Mactra dissimilis*	–	–	–	✓	–	–
Mesodesmatidae	*Atactodea striata*	–	✓	✓	✓	✓	–

Table 8-4: Inventory of the shelled macromollusc species recorded on intertidal reefs at Browse Island and at the Maret, Albert, Berthier and Montalivet island groups (continued)

Family	Species	Browse Island	Maret Islands	Albert Islands group	Berthier Islands group	West Montalivet Island	East Montalivet Islands group
Semelidae	*Semele* sp.	✓	–	–	–	–	–
Tellinidae	*Exotica assimilis*	–	–	–	✓	–	–
	Leporimetis sp.	–	✓	–	–	–	–
	Macalia bruguieri	–	–	–	✓	–	–
	Tellina rostrata	–	✓	–	–	–	–
	Tellina staurella	–	✓	–	✓	–	–
	Tellina sp.	–	✓	–	–	–	–
Psammobiidae	*Asaphis violascens*	–	✓	–	✓	✓	–
Trapeziidae	*Trapezium bicarinatum*	✓	✓	–	–	–	–
Petricolidae	*Petricola lapicida*	–	✓	–	–	–	–
	Petricola sp.	–	–	–	–	✓	–
Veneridae	*Antigona resticulata*	–	–	–	–	–	✓
	Anomalocardia squamosa	–	–	–	✓	–	–
	Gafrarium sp.	–	✓	–	–	–	–
	Lioconcha fastigiata	–	✓	✓	✓	–	✓
	Periglypta reticulata	✓	–	–	–	–	–
	Pitar sp.	–	–	–	✓	–	–
	Tapes deshayesii	–	✓	–	✓	–	–
	Ventricolaria embrithes	–	–	✓	–	–	–
Chamidae	*Chama* sp.	–	✓	–	–	✓	–
Gastrochaenidae	*Gastrochaena gigantea*	✓	✓	✓	–	✓	–
Clavagellidae	*Brechites australis*	–	–	–	✓	–	–
Class Gastropoda (subclass Prosobranchia)—prosobranch gastropods							
Patellidae	*Cellana radiata*	–	✓	–	✓	–	–
	Patella flexuosa	✓	✓	–	–	✓	✓
Acmaeidae	*Patelloida saccharina*	–	✓	–	✓	–	✓

Table 8-4: Inventory of the shelled macromollusc species recorded on intertidal reefs at Browse Island and at the Maret, Albert, Berthier and Montalivet island groups (continued)

Family	Species	Browse Island	Maret Islands	Albert Islands group	Berthier Islands group	West Montalivet Island	East Montalivet Islands group
Neritidae	*Nerita albicilla*	✓	✓	–	✓	✓	✓
	Nerita grossa	✓	–	–	–	–	–
	Nerita plicata	✓	–	–	–	–	–
	Nerita polita	–	✓	–	✓	–	✓
	Nerita reticulata	–	✓	–	✓	✓	✓
	Nerita undata	–	✓	✓	✓	✓	✓
Neritopsidae	*Neritopsis radula*	–	–	–	–	✓	–
Fissurellidae	?*Hemitoma* sp.	–	–	–	✓	–	–
Haliotidae	*Haliotis asinina*	–	✓	–	–	–	–
	Haliotis squamata	✓	✓	✓	✓	✓	✓
	Haliotis varia	–	✓	✓	✓	–	✓
Trochidae	*Calthalotia mundula*	–	✓	–	–	✓	✓
	Calthalotia strigata	–	✓	–	✓	–	–
	Clanculus atropurpureus	–	✓	–	–	✓	–
	Ethalia pulchella	–	–	–	✓	–	–
	Eurytrochus maccullochi	–	✓	–	✓	–	–
	Isanda coronata	–	–	–	✓	–	–
	Jujubinus gilberti	–	✓	–	✓	–	–
	Monodonta labio	–	✓	–	✓	–	✓
	Stomatella impertusa	✓	–	–	–	–	–
	Stomatia phymotis	–	✓	–	–	–	✓
	Tectus fenestratus	–	✓	–	–	✓	–
	Tectus pyramis	✓	✓	✓	–	✓	✓
	Trochus hanleyanus	–	✓	–	✓	✓	✓
	Trochus histrio	✓	–	–	–	–	–
	Trochus maculatus	✓	–	–	–	–	–
	Trochus niloticus	✓	–	–	–	–	–
Turbinidae	*Angaria delphinus*	–	✓	✓	✓	✓	✓
	Astralium pileolum	–	✓	–	–	–	–

Table 8-4: Inventory of the shelled macromollusc species recorded on intertidal reefs at Browse Island and at the Maret, Albert, Berthier and Montalivet island groups (continued)

Family	Species	Browse Island	Maret Islands	Albert Islands group	Berthier Islands group	West Montalivet Island	East Montalivet Islands group
Turbinidae (cont.)	*Astralium rhodostomum*	–	✓	✓	–	✓	–
	Astralium rotularium	–	✓	–	–	✓	–
	Liotina crassibassis	–	✓	–	–	–	–
	Munditia sp.	–	✓	–	–	–	–
	Phasianella solida	–	✓	–	✓	–	–
	Turbo argyrostomus	✓	–	–	–	–	–
	Turbo cinereus	–	✓	–	✓	–	–
	Turbo haynesi	–	✓	–	–	✓	–
	Turbo squamosus	–	✓	–	–	–	–
Stomatellidae	*Gena impertusa*	–	✓	–	–	–	–
Planaxidae	*Planaxis sulcatus*	–	✓	–	✓	✓	–
Modulidae	*Modulus tectum*	✓	✓	–	–	–	–
Cerithiidae	*Cerithium columna*	–	✓	–	–	–	–
	Cerithium echinatum	✓	✓	✓	–	✓	–
	Cerithium novaehollandiae	–	✓	✓	–	–	–
	Cerithium torresi	–	✓	✓	✓	–	–
	Cerithium sp. cf. *zonatum*	–	✓	–	–	–	–
	Cerithium sp.	–	✓	–	–	–	–
	Pseudovertagus aluco	–	✓	–	✓	✓	–
	Rhinoclavis brettinghami	–	✓	✓	–	✓	✓
	Rhinoclavis sinensis	✓	–	–	–	–	–
Littorinidae	*Littoraria filosa*	–	–	–	✓	–	–
	Littoraria pallescens	–	–	–	✓	–	–
	Littoraria undulata	–	✓	–	✓	✓	–
	Nodilittorina millegrana	–	✓	–	✓	✓	–
	Nodilittorina pyramidalis	–	✓	–	✓	✓	–
	Tectarius rusticus	–	✓	–	✓	–	–
Eulimidae	*Eulima* sp.	–	✓	–	–	–	–

Table 8-4: Inventory of the shelled macromollusc species recorded on intertidal reefs at Browse Island and at the Maret, Albert, Berthier and Montalivet island groups (continued)

Family	Species	Browse Island	Maret Islands	Albert Islands group	Berthier Islands group	West Montalivet Island	East Montalivet Islands group
Strombidae	*Lambis chiragra*	✓	–	–	–	–	–
	Lambis crocata	✓	–	–	–	–	–
	Lambis lambis	✓	✓	–	✓	–	–
	Strombus lentiginosus	✓	–	–	–	–	–
	Strombus luhuanus	✓	–	–	–	–	–
	Strombus mutabilis	✓	–	–	–	–	–
	Strombus urceus	–	✓	✓	✓	–	–
	Strombus variabilis	✓	–	–	–	–	–
Hipponocidae	*Antisabia* sp.	–	✓	–	–	–	–
	Hipponix ?conicus	✓	–	–	–	–	–
Calyptraeidae	*Cheilea equestris*	–	✓	–	✓	–	–
Capulidae	*Capulus* sp.	–	✓	✓	–	–	–
	Capulus sp.	✓	–	–	–	–	–
Vermetidae	*Dendropoma* sp.	–	✓	–	–	–	–
	Dendropoma sp.	✓	–	–	–	–	–
	Serpulorbis sp.	–	✓	–	–	–	–
	Serpulorbis sp.	✓	–	–	–	–	–
Triviidae	*Trivia oryza*	✓	✓	–	✓	–	–
	Trivia sp.	–	✓	–	–	–	–
Ovulidae	*Ovula ovum*	–	✓	–	–	–	–
	Prionovula sp.	–	–	–	✓	–	–
Cypraeidae	*Cypraea annulus*	✓	✓	✓	–	–	–
	Cypraea arabica	✓	–	✓	–	–	–
	Cypraea argus	–	✓	–	–	–	–
	Cypraea asellus	✓	–	–	–	–	–
	Cypraea bistrinotata	✓	–	–	–	–	–
	Cypraea caputserpentis	✓	–	–	–	–	–
	Cypraea carneola	✓	✓	–	–	–	–

Table 8-4: Inventory of the shelled macromollusc species recorded on intertidal reefs at Browse Island and at the Maret, Albert, Berthier and Montalivet island groups (continued)

Family	Species	Browse Island	Maret Islands	Albert Islands group	Berthier Islands group	West Montalivet Island	East Montalivet Islands group
Cypraeidae (cont.)	*Cypraea caurica*	✓	–	–	–	✓	–
	Cypraea cicercula	–	–	✓	–	–	–
	Cypraea cylindrica	–	✓	–	–	–	–
	Cypraea depressa	✓	–	–	–	–	–
	Cypraea eglantina	–	✓	–	✓	–	–
	Cypraea erosa	✓	✓	–	✓	–	–
	Cypraea errones	–	✓	✓	✓	–	–
	Cypraea fimbriata	✓	✓	–	–	–	–
	Cypraea flaveola	✓	–	–	–	–	–
	Cypraea gracilis	✓	✓	–	–	–	✓
	Cypraea helvola	✓	–	–	–	–	–
	Cypraea hirundo	–	–	–	✓	–	–
	Cypraea histrio	✓	–	–	–	–	–
	Cypraea isabella	✓	✓	✓	–	✓	–
	Cypraea lynx	✓	✓	–	–	–	–
	Cypraea mariae	✓	–	–	–	–	–
	Cypraea miliaris	–	–	✓	✓	–	–
	Cypraea moneta	✓	✓	–	–	–	–
	Cypraea nucleus	–	–	✓	–	–	–
	Cypraea pallidula	–	✓	–	–	–	–
	Cypraea scurra	✓	–	–	–	–	–
	Cypraea staphylaea	✓	–	✓	–	–	–
	Cypraea talpa	✓	✓	–	✓	–	–
	Cypraea teres	✓	–	–	–	–	–
	Cypraea testudinaria	✓	–	–	–	–	–
	Cypraea tigris	✓	–	–	–	–	–
	Cypraea ursellus	–	✓	–	–	–	–
	Cypraea vitellus	✓	✓	–	–	✓	–

Table 8-4: Inventory of the shelled macromollusc species recorded on intertidal reefs at Browse Island and at the Maret, Albert, Berthier and Montalivet island groups (continued)

Family	Species	Browse Island	Maret Islands	Albert Islands group	Berthier Islands group	West Montalivet Island	East Montalivet Islands group
Naticidae	*Natica euzona*	–	✓	–	✓	–	–
	Natica gualteriana	–	✓	–	✓	–	–
	Natica pseustes	–	–	✓	–	–	–
	Polinices mammilla	✓	–	–	–	–	–
	Polinices melanostomus	–	✓	–	✓	–	–
	Polinices simiae	–	✓	–	–	–	–
Bursidae	*Bursa* sp. 1	✓	–	–	–	–	–
	Bursa sp. 2	✓	–	–	–	–	–
	Tutufa rubeta	✓	–	–	–	–	–
Ranellidae	*Charonia tritonis*	✓	–	–	–	–	–
	Cymatium exaratum	–	✓	–	✓	–	–
	Cymatium labiosum	–	✓	–	–	–	–
	Cymatium mundum	✓	–	–	–	–	–
	Cymatium pileare	–	✓	–	–	–	–
	Cymatium nicobaricum	✓	–	–	–	–	–
Cassidae	*Casmaria erinacea*	✓	–	–	✓	–	–
Ficidae	*Ficus subintermedia*	–	–	–	✓	–	–
Tonnidae	*Malea pomum*	✓	–	–	–	–	–
	Tonna cepa	–	–	–	✓	–	–
	Tonna tessellata	–	–	–	✓	–	–
Janthinidae	*Janthina pallida*	–	–	–	✓	–	–
Muricidae	*Aspella* sp.	–	✓	–	–	–	–
	?Babelomurex sp.	–	✓	–	–	–	–
	Chicoreus microphyllus	–	✓	–	–	✓	–
	Cronia avellana	✓	✓	✓	✓	–	–
	Cronia crassulnata	–	✓	–	–	–	–
	Drupa morum	✓	–	–	–	–	–
	Drupa ricinus	✓	–	–	–	–	–
	Drupa rubusidaeus	✓	–	–	–	–	–
	Drupella cornus	✓	✓	–	–	–	–

Table 8-4: Inventory of the shelled macromollusc species recorded on intertidal reefs at Browse Island and at the Maret, Albert, Berthier and Montalivet island groups (continued)

Family	Species	Browse Island	Maret Islands	Albert Islands group	Berthier Islands group	West Montalivet Island	East Montalivet Islands group
Muricidae (cont.)	*Drupella rugosa*	✓	✓	–	–	✓	–
	Drupina grossularia	✓	✓	–	–	–	–
	Homalocantha anatomica	–	✓	–	✓	✓	–
	Morula biconica	✓	–	–	–	–	–
	Morula fiscella	–	–	–	–	✓	–
	Morula granulata	✓	✓	✓	–	–	–
	Morula margariticola	–	✓	–	–	✓	–
	Morula musiva	✓	–	–	–	–	–
	Morula spinosa	✓	✓	✓	–	✓	✓
	Morula uva	✓	–	–	–	–	–
	Nassa serta	✓	–	–	–	–	–
	Rapa bulbiformis	–	–	–	–	✓	–
	Thais aculeata	✓	✓	–	✓	✓	–
	Thais alouina	–	✓	–	–	✓	–
	Thais armigera	✓	–	–	–	–	–
	Thais echinata	–	✓	–	–	✓	✓
	Thais kieneri	✓	✓	–	✓	–	–
Nassariidae	*Nassarius albescens*	–	✓	✓	–	✓	–
	Nassarius glans	✓	✓	✓	✓	–	–
	Nassarius papillosus	✓	–	–	–	–	–
	Nassarius sp. cf. *papillosus*	–	✓	–	–	–	–
	Nassarius pauperus	–	✓	–	✓	–	–
Buccinidae	*Cantharus fumosus*	–	✓	–	–	–	–
	Cantharus undosus	✓	–	–	–	–	–
	Engina concinna	–	✓	✓	–	–	–
	Latirus belcheri	✓	–	–	–	–	–
	Latirus sp. cf. *belcheri*	–	✓	–	–	✓	✓
	Latirus polygonus	✓	–	–	–	–	–

Table 8-4: Inventory of the shelled macromollusc species recorded on intertidal reefs at Browse Island and at the Maret, Albert, Berthier and Montalivet island groups (continued)

Family	Species	Browse Island	Maret Islands	Albert Islands group	Berthier Islands group	West Montalivet Island	East Montalivet Islands group
Buccinidae (cont.)	*Peristernia fastigium*	✓	–	–	–	–	–
	Peristernia incarnata	✓	✓	✓	–	✓	–
	Peristernia sp.	✓	–	–	–	–	–
	Phos sculptilis	–	✓	–	–	–	–
	Phos senticosus	–	✓	–	–	–	–
	Pleuroploca filamentosa	✓	✓	–	–	✓	–
Columbellidae	*Pyrene* sp. cf. *scripta*	–	–	✓	–	–	–
	Pyrene testudinaria	–	✓	–	–	✓	–
	Pyrene varians	✓	✓	✓	✓	✓	–
Olividae	*Alocospira rosea*	–	✓	✓	✓	–	–
	Oliva annulata	✓	–	–	–	–	–
	Oliva australis	–	✓	✓	✓	–	✓
	Oliva caldania	–	–	–	✓	–	✓
	Oliva miniacea	–	✓	–	–	–	–
Harpidae	*Harpa amouretta*	✓	–	–	–	–	–
	Harpa articularis	✓	–	–	–	–	–
Volutidae	*Melo amphora*	✓	✓	✓	✓	✓	–
Mitridae	*Mitra ambigua*	–	✓	–	–	–	–
	Mitra stictica	✓	–	–	–	–	–
	Pterygia crenulata	–	✓	–	–	–	–
	Pterygia nucea	✓	–	–	–	–	–
	Scabricola sp.	–	✓	–	–	–	–
Cancellariidae	*Vexillum* sp.	–	✓	–	–	–	–
Vasidae	*Vasum ceramicum*	✓	–	–	–	–	✓
	Vasum turbinellum	✓	–	–	–	–	–
Conidae	*Conus arenatus*	–	✓	–	–	–	–
	Conus artoptus	–	–	–	–	✓	–
	Conus aulicus	✓	–	–	–	✓	–
	Conus catus	✓	–	–	–	–	–

Table 8-4: Inventory of the shelled macromollusc species recorded on intertidal reefs at Browse Island and at the Maret, Albert, Berthier and Montalivet island groups (continued)

Family	Species	Browse Island	Maret Islands	Albert Islands group	Berthier Islands group	West Montalivet Island	East Montalivet Islands group
Conidae (cont.)	*Conus coffeae*	–	✓	–	–	✓	✓
	Conus coronatus	✓	✓	✓	✓	✓	–
	Conus distans	✓	–	–	–	–	–
	Conus ebraeus	✓	✓	–	✓	✓	–
	Conus eburneus	–	✓	–	✓	–	–
	Conus flavidus	✓	–	–	–	–	–
	Conus frigidus	✓	–	–	–	–	–
	Conus geographus	✓	✓	–	✓	–	–
	Conus imperialis	✓	–	–	–	–	–
	Conus litteratus	✓	–	–	–	–	–
	Conus lividus	✓	–	–	–	–	–
	Conus miles	✓	✓	–	–	–	–
	Conus miliaris	✓	✓	–	–	✓	–
	Conus sp. cf. *miliaris*	✓	–	–	–	–	–
	Conus monachus	–	✓	✓	–	✓	–
	Conus musicus	✓	✓	–	–	–	–
	Conus mustelinus	–	✓	–	–	✓	✓
	Conus nussatella	–	✓	–	✓	–	–
	Conus obscurus	✓	–	–	–	–	–
	Conus pulicarius	✓	–	–	–	–	–
	Conus rattus	✓	–	–	–	–	–
	Conus striatus	✓	✓	–	–	✓	–
	Conus terebra	–	✓	–	–	✓	✓
	Conus textile	✓	✓	✓	✓	✓	–
	Conus varius	✓	–	–	–	–	–
	Conus sp. cf. *varius*	–	✓	–	–	–	–
	Conus vexillum	–	–	–	–	✓	–
	Conus virgo	✓	–	–	–	–	–
	Conus vitulinus	✓	–	–	–	–	–

Table 8-4: Inventory of the shelled macromollusc species recorded on intertidal reefs at Browse Island and at the Maret, Albert, Berthier and Montalivet island groups (continued)

Family	Species	Browse Island	Maret Islands	Albert Islands group	Berthier Islands group	West Montalivet Island	East Montalivet Islands group
Terebridae	*Hastula albula*	–	–	–	✓	–	–
	Terebra crenulata	✓	–	–	–	–	–
	Terebra felina	✓	–	–	–	–	–
Class Gastropoda (subclass Pulmonata)—pulmonate gastropods							
Siphonariidae	*Siphonaria* sp. 1	–	✓	✓	✓	–	✓
	Siphonaria sp. 2	–	✓	–	–	–	–
Ellobiidae	*Ophicardelus ornatus*	–	✓	–	✓	–	–
	Ophicardelus sp. indet. 1	–	✓	–	–	–	–
	Ophicardelus sp. indet. 2	–	✓	–	–	–	–
	?*Melosidula* sp.	–	✓	–	–	–	–
	Ellobiidae gen. et sp. indet. 1	–	✓	–	–	–	–
	Ellobiidae gen. et sp. indet. 2	–	✓	–	–	–	–
Total	**321**	**140**	**192**	**62**	**93**	**77**	**45**

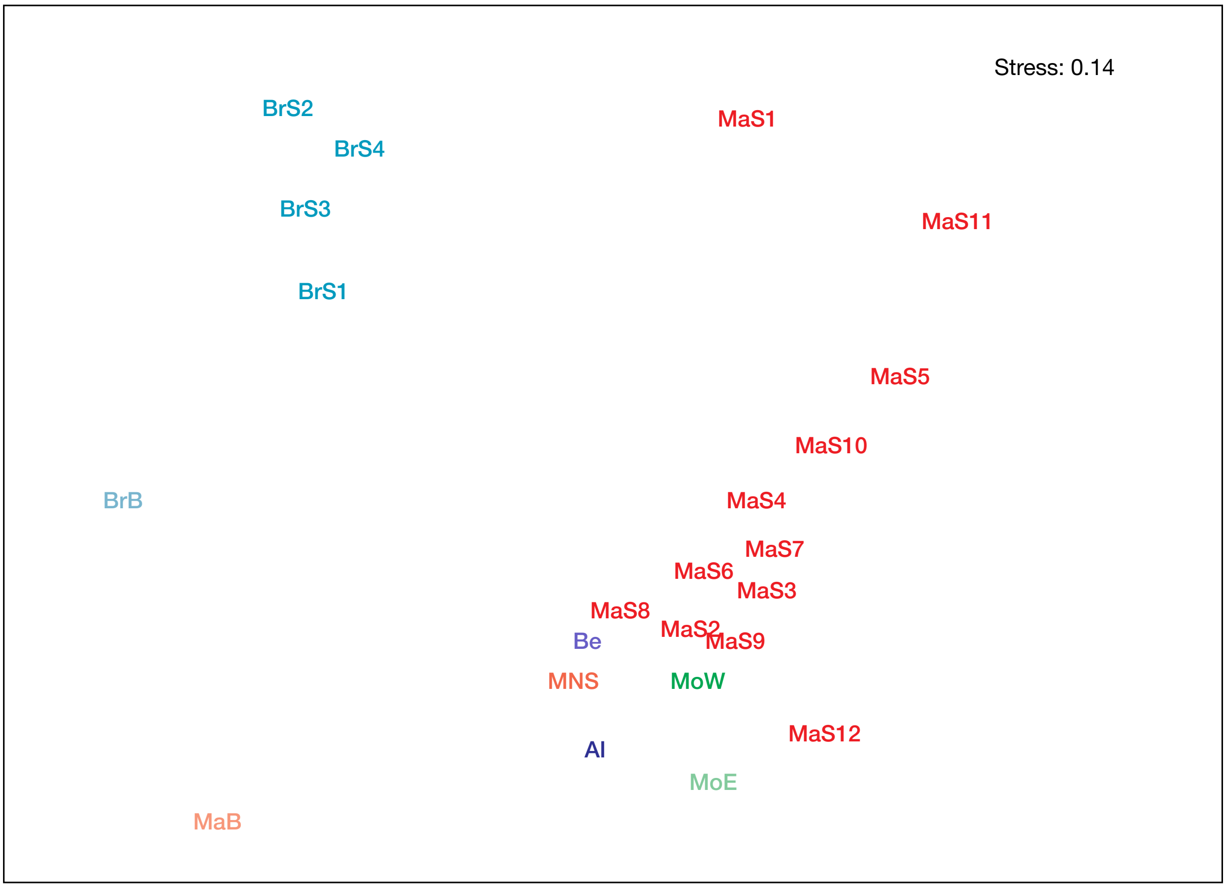

Figure 8-14: The multidimensional scaling plot of presence–absence data for macromolluscs recorded during surveys at the Maret Islands (Ma), all Maret Islands sites combined (MNS), Browse Island (Br), Albert Island (Al), Berthier Island (Be), East Montalivet Island (MoE) and West Montalivet Island (MoW)

Of the 140 Indo-West Pacific mollusc species recorded at Browse Island (which lies on the boundary of the North West Shelf and Oceanic Shoals bioregions) only 55 (39%) were also recorded at the Maret, Albert, Berthier and Montalivet island groups in the Bonaparte Archipelago (which forms part of the Kimberley Bioregion).

Presence–absence data for the molluscs collected during the reef-walk surveys were used to analyse the similarities or differences between the communities of macromolluscs found at Browse Island and those found around the surveyed island groups of the Bonaparte Archipelago. A one-way analysis of similarity (ANOSIM) indicated that the macromollusc assemblages at Browse Island were significantly different from those of the islands of the Bonaparte Archipelago (R = 0.836, P = 0.001).

The multidimensional scaling (MDS) plot shown in Figure 8-14 supported the ANOSIM result, with the Browse Island survey transects separated clearly from all of the other locations. No clear separation between the islands of the Bonaparte Archipelago is detectable. It is evident from the plot that both beach sites (at Browse Island and the Maret Islands) stand out as being different from their respective reef sites, although this separation in the cluster analysis is less clear for the Maret Islands beach site (MaB) than for the Browse Island beach site (BrB). The Maret Islands sites MaS1 (on the seaward side of the isthmus between North Maret Island and South Maret Island) and MaS11 (on the leeward side of the Maret Islands), were also different from the other sites.

Table 8-5 shows the numbers of intertidal macromollusc species recorded at Browse Island compared with the numbers recorded at the Bonaparte Archipelago sampling localities.

Table 8-5: Numbers of species of shelled macromolluscs recorded on intertidal reefs at Browse Island and at the Maret, Albert, Berthier and Montalivet island groups

Taxonomic group	Browse Island	Maret, Albert, Berthier and Montalivet island groups
Chitons	0 (0% of total)	3 (1% of total)
Bivalves	21 (15% of total)	64 (27% of total)
Prosobranch gastropods	119 (85% of total)	161 (68% of total)
Pulmonate gastropods	0 (0% of total)	8 (3% of total)
Total number of species	**140**	**235**

Differences in the composition of the molluscan assemblages were particularly evident for the predatory gastropod assemblages along the reef front and for the general molluscan assemblages of the upper littoral zone of rocky shores. The surface gastropods collected at Browse Island were generally prolific along the reef front. In equivalent habitats at the Maret and Montalivet islands, however, gastropods were few in number and low in diversity.

Table 8-6 lists the predatory gastropod species recorded from the seaward ramp and upper littoral zone of rocky shores on Browse Reef and the reefs on the Maret Islands and Montalivet Islands.

Table 8-6: Predatory gastropod assemblages of the seaward ramp of rocky shores at Browse Island and at the Maret and Montalivet island groups

Family	Species	Browse Island	Maret Islands	Montalivet Islands
Muricidae	*Cronia avellana*	✓	✓	–
	Drupa morum	✓	–	–
	Drupa ricinus	✓	–	–
	Drupa rubusidaeus	✓	–	–
	Drupina grossularia	✓	✓	–
	Morula biconica	✓	–	–
	Morula fiscella	–	–	✓
	Morula musiva	✓	–	–
	Morula spinosa	✓	✓	✓
	Morula uva	✓	–	–
	Thais alouina	–	✓	✓
	Thais armigera	✓	–	–
	Thais kieneri	✓	✓	–
Buccinidae	*Latirus belcheri*	✓	–	–
	Latirus polygonus	✓	–	–
Vasidae	*Vasum ceramicum*	✓	–	✓
	Vasum turbinellum	✓	–	–
Conidae	*Conus catus*	✓	–	–
	Conus coronatus	✓	✓	✓
	Conus distans	✓	–	–
	Conus ebraeus	✓	✓	✓
	Conus imperialis	✓	–	–
	Conus litteratus	✓	–	–
	Conus lividus	✓	–	–

Table 8-6: Predatory gastropod assemblages of the seaward ramp of rocky shores at Browse Island and at the Maret and Montalivet island groups (continued)

Family	Species	Browse Island	Maret Islands	Montalivet Islands
Conidae (cont.)	*Conus miles*	✓	✓	–
	Conus musicus	✓	✓	–
	Conus mustelinus	–	✓	✓
	Conus rattus	✓	–	–
	Conus vitulinus	✓	–	–

✓ = species recorded.

– = species not found.

Table 8-7 compares the mollusc assemblages recorded from the upper littoral rocky shore on Browse Island with those from the upper littoral rocky shores of the Maret Islands and Montalivet Islands.

Table 8-7: Mollusc assemblages of upper littoral rocky shores at Browse Island and at the Maret and Montalivet island groups

Family	Species	Browse Island	Maret Islands	Montalivet Islands
Chitonidae	*Acanthopleura gemmata*	–	✓	✓
	Acanthopleura spinosa	–	✓	✓
Isognomonidae	*Isognomon nucleus*	–	✓	✓
Patellidae	*Cellana radiata*	–	✓	–
	Patella flexuosa	✓	✓	✓
Acmaeidae	*Patelloida saccharina*	–	✓	✓
Neritidae	*Nerita albicilla*	✓	✓	✓
	Nerita grossa	✓	–	–
	Nerita plicata	✓	–	–
	Nerita polita	–	✓	✓
	Nerita reticulata	–	✓	✓
	Nerita undata	–	✓	✓
Trochidae	*Monodonta labio*	–	✓	✓
	Trochus hanleyanus	–	✓	✓
Turbinidae	*Turbo cinereus*	–	✓	–
Littorinidae	*Littoraria undulata*	–	✓	✓
	Nodilittorina millegrana	–	✓	✓
	Nodilittorina pyramidalis	–	✓	✓
	Tectarius rusticus	–	✓	–
Muricidae	*Cronia crassulnata*	–	✓	–
	Drupa morum	✓	–	–
	Morula granulata	✓	✓	–
	Thais aculeata	✓	✓	✓
	Thais kieneri	✓	✓	–
Vasidae	*Vasum ceramicum*	✓	–	✓
	Vasum turbinellum	✓	–	–
Siphonariidae	*Siphonaria* sp.	–	✓	✓

✓ = species recorded.

– = species not found.

8 MARINE ECOLOGY

Table 8-8 provides a comparison of the numbers of intertidal macromollusc species recorded at the Maret, Albert, Berthier, and Montalivet island groups. The reefs of these islands are considered to be representative of the reefs of the central part of the Bonaparte Archipelago.

Table 8-8: Numbers of species of shelled macromolluscs recorded on intertidal reefs at the Maret, Albert, Berthier, and Montalivet island groups

Taxonomic group	Maret Islands	Albert Islands group	Berthier Islands group	West Montalivet Island	East Montalivet Islands group
Chitons	3 (2% of total)	3 (5% of total)	2 (2% of total)	3 (4% of total)	3 (7% of total)
Bivalves	49 (25% of total)	22 (35% of total)	23 (25% of total)	20 (26% of total)	16 (36% of total)
Prosobranch gastropods	132 (69% of total)	36 (58% of total)	66 (71% of total)	54 (70% of total)	25 (55% of total)
Pulmonate gastropods	8 (4% of total)	1 (2% of total)	2 (2% of total)	0 (0% of total)	1 (2% of total)
Total number of species	**192**	**62**	**93**	**77**	**45**

8 MARINE ECOLOGY

Coral assemblages at the Maret, Montalivet and Berthier island groups

Coral abundance and diversity were determined by reef-walk surveys. A total of 275 scleractinian coral species representing 15 families and 59 genera were recorded from 31 locations in the intertidal reefs of the Maret Islands[6] (12 locations), the Montalivet Islands[7] (10 locations) and the Berthier Islands[8] (9 locations). Although the coral fauna was less extensively surveyed at Browse Island, it was apparent that coral species richness was much lower on the intertidal reef around this offshore island than on the inshore islands of the Bonaparte Archipelago, with only 27 scleractinian species found; all of these species were also recorded at the Bonaparte Archipelago.

At the Maret Islands, 221 species were recorded, while 179 species were recorded at the Montalivet Islands (West Montalivet Island and the East Montalivet Islands group), and 187 at the Berthier Islands group. These differences may however be attributable to differences in sampling effort over the three island groups.

One hundred and twenty-three species were common to all three island groups. The Maret Islands, however, had 52 species that were not found at the other island groups, while the Montalivet Islands had 14 such species and the Berthier Islands had 19.

A list of the scleractinian coral families, genera and species found during surveys at the Maret, Montalivet and Berthier island groups is presented in Table 8-9.

6 The Maret Islands group consists of North Maret Island and South Maret Island.

7 The Montalivet Islands in Table 8-9 are taken to be West Montalivet Island, East Montalivet Island, Walker Island (and three adjacent unnamed islets off its north-west coast), Patricia Island, and Don Island (and an unnamed islet off its south-west coast.

8 The Berthier Islands group is usually taken to consist of four islands, Berthier Island itself, together with three smaller unnamed islets off its north-west coast. In Table 8-9 below, however, the group is taken to consist of Berthier Island with its three satellite islands as well as the Albert Islands group and Turbin Island.

Table 8-9: Inventory of the coral species of the order Scleractinia recorded at the Maret, Montalivet and Berthier island groups

Family	Species	Maret Islands group* (12 sites)	Montalivet Islands group† (10 sites)	Berthier Islands group‡ (9 sites)
		Number of sites where the species was recorded		
Astrocoeniidae	*Stylocoeniella armata*	–	–	1
	Stylocoeniella guentheri	2	1	2
Pocilloporidae	*Pocillopora damicornis*	12	9	8
	Pocillopora meandrina	2	–	2
	Pocillopora verrucosa	4	1	4
	Seriatopora aculeata	1	4	4
	Seriatopora caliendrum	1	6	6
	Seriatopora hystrix	12	9	7
	Stylophora pistillata	10	9	9
	Stylophora subseriata	6	1	5
Acroporidae	*Acropora abrotanoides*	–	–	1
	Acropora aculeus	8	–	–
	Acropora acuminata	–	5	2
	Acropora anthocercis	–	2	1
	Acropora aspera	12	8	8
	Acropora austera	–	5	5
	Acropora brueggemanni	12	6	6
	Acropora bushyensis	5	2	–
	Acropora cerealis	11	4	3
	Acropora clathrata	9	8	5
	Acropora crateriformis	–	4	–
	Acropora cytherea	10	7	–
	Acropora dendrum	–	1	–
	Acropora digitifera	12	4	9
	Acropora divaricata	2	5	–
	Acropora donei	–	2	–
	Acropora elseyi	–	–	1
	Acropora florida	9	6	7
	Acropora formosa	9	9	8
	Acropora gemmifera	7	5	5
	Acropora glauca	2	3	2
	Acropora grandis	6	2	–
	Acropora humilis	11	8	7
	Acropora hyacinthus	12	8	9
	Acropora insignis	2	–	–
	Acropora latistella	5	5	5
	Acropora loripes	–	5	4
	Acropora lutkeni	–	3	1
	Acropora microclados	11	–	–
	Acropora microphthalma	9	7	2

Table 8-9: Inventory of the coral species of the order Scleractinia recorded at the Maret, Montalivet and Berthier island groups (continued)

Family	Species	Maret Islands group* (12 sites)	Montalivet Islands group† (10 sites)	Berthier Islands group‡ (9 sites)
		Number of sites where the species was recorded		
Acroporidae (cont.)	*Acropora millepora*	12	9	7
	Acropora monticulosa	–	3	–
	Acropora nana	8	1	4
	Acropora nasuta	11	9	6
	Acropora nobilis	11	8	7
	Acropora orbicularis	3	8	–
	Acropora palifera	3	3	–
	Acropora palmerae	7	–	1
	Acropora papillare	1	4	1
	Acropora polystoma	–	1	–
	Acropora prostrata	5	–	–
	Acropora pulchra	7	8	8
	Acropora robusta	7	3	4
	Acropora samoensis	10	8	7
	Acropora sarmentosa	5	1	4
	Acropora secale	–	1	3
	Acropora selago	2	4	4
	Acropora solitaryensis	2	2	1
	Acropora spicifera	–	7	5
	Acropora striata	–	–	2
	Acropora subulata	10	2	3
	Acropora tenuis	9	6	5
	Acropora tortuosa	2	–	–
	Acropora valida	11	7	8
	Acropora verweyi	6	2	4
	Acropora yongei	6	7	–
	Astreopora listeri	2	–	1
	Astreopora myriophthalma	12	7	4
	Astreopora ocellata	5	–	–
	Montipora aequituberculata	8	8	4
	Montipora australiensis	5	–	–
	Montipora calcarea	6	–	6
	Montipora caliculata	6	1	1
	Montipora capricornis	2	–	–
	Montipora crassituberculata	–	7	3
	Montipora danae	2	–	–
	Montipora delicatula	–	–	2
	Montipora digitata	8	2	–
	Montipora efflorescens	7	1	–
	Montipora foliosa	2	–	6
	Montipora foveolata	–	3	1
	Montipora gaimardi	6	–	–
	Montipora grisea	3	–	3
	Montipora hispida	7	–	–

Table 8-9: Inventory of the coral species of the order Scleractinia recorded at the Maret, Montalivet and Berthier island groups (continued)

Family	Species	Maret Islands group* (12 sites)	Montalivet Islands group† (10 sites)	Berthier Islands group‡ (9 sites)
		Number of sites where the species was recorded		
Acroporidae (cont.)	*Montipora hoffmeisteri*	3	–	–
	Montipora incrassata	5	1	4
	Montipora mollis	2	–	–
	Montipora monasteriata	7	–	4
	Montipora nodosa	4	–	–
	Montipora peltiformis	6	–	–
	Montipora spongodes	6	–	–
	Montipora spumosa	7	1	–
	Montipora tuberculosa	7	4	–
	Montipora turgescens	7	8	5
	Montipora undata	–	–	1
	Montipora venosa	1	2	1
	Montipora verrucosa	1	5	–
Euphyllidae	*Catalaphyllia jardinei*	1	5	–
	Euphyllia ancora	–	–	4
	Euphyllia glabrescens	7	2	4
	Physogyra lichtensteini	2	–	–
Oculinidae	*Galaxea astreata*	12	8	9
	Galaxea fascicularis	12	9	8
	Galaxea longisepta	–	1	–
	Galaxea paucisepta	–	–	1
Siderastreidae	*Coscinaraea columna*	5	2	1
	Coscinaraea exesa	3	3	–
	Coscinaraea monile	–	–	1
	Psammocora contigua	6	6	4
	Psammocora digitata	4	–	–
	Psammocora haimeana	1	1	–
	Psammocora nierstraszi	–	–	2
	Psammocora profundacella	8	3	1
	Psammocora superficialis	5	–	3
	Pseudosiderastrea tayami	4	4	–
Agariciidae	*Coeloseris mayeri*	10	5	6
	Gardineroseris planulata	–	–	1
	Pachyseris gemmae	–	1	1
	Pachyseris rugosa	7	–	1
	Pachyseris speciosa	7	–	2
	Pavona cactus	–	2	–
	Pavona danai	1	–	–
	Pavona decussata	12	5	6
	Pavona varians	11	1	2
	Pavona venosa	11	4	5
Fungiidae	*Ctenactis crassa*	1	1	–
	Ctenactis echinata	1	1	–
	Cycloseris cyclolites	–	1	–

Table 8-9: Inventory of the coral species of the order Scleractinia recorded at the Maret, Montalivet and Berthier island groups (continued)

Family	Species	Maret Islands group* (12 sites)	Montalivet Islands group† (10 sites)	Berthier Islands group‡ (9 sites)
		Number of sites where the species was recorded		
Fungiidae (cont.)	*Fungia concinna*	8	–	–
	Fungia fungites	11	1	6
	Fungia granulosa	2	–	–
	Fungia klunzingeri	1	–	1
	Fungia paumotensis	1	–	–
	Fungia repanda	6	5	3
	Fungia scruposa	7	–	1
	Fungia scutaria	–	–	3
	Heliofungia actiniformis	–	–	1
	Herpolitha limax	–	–	1
	Herpolitha weberi	–	1	–
	Lithophyllon mokai	1	–	–
	Lithophyllon undulatum	5	–	2
	Podabacia crustacea	4	3	4
	Podabacia motuporensis	3	–	–
	Polyphyllia talpina	–	1	1
Pectiniidae	*Echinophyllia aspera*	1	1	3
	Echinophyllia echinata	1	–	–
	Mycedium elephantotus	2	2	6
	Oxypora glabra	1	–	–
	Oxypora lacera	–	–	1
	Pectinia lactuca	2	1	3
	Pectinia paeonia	8	1	3
Merulinidae	*Hydnophora exesa*	6	5	8
	Hydnophora grandis	4	–	–
	Hydnophora microconos	11	8	4
	Hydnophora pilosa	8	1	3
	Hydnophora rigida	5	5	3
	Merulina ampliata	11	4	5
	Merulina scabricula	6	4	6
Dendrophylliidae	*Turbinaria bifrons*	7	1	1
	Turbinaria conspicua	3	–	–
	Turbinaria frondens	–	1	–
	Turbinaria mesenterina	10	2	–
	Turbinaria peltata	1	3	1
	Turbinaria radicalis	8	2	–
	Turbinaria reniformis	2	2	3
	Turbinaria stellulata	6	–	–
Mussidae	*Acanthastrea brevis*	–	1	–
	Acanthastrea echinata	7	7	4
	Acanthastrea hemprichii	8	8	6
	Acanthastrea lordhowensis	–	2	2
	Lobophyllia corymbosa	5	8	7
	Lobophyllia diminuta	5	5	2

Table 8-9: Inventory of the coral species of the order Scleractinia recorded at the Maret, Montalivet and Berthier island groups (continued)

Family	Species	Maret Islands group* (12 sites)	Montalivet Islands group† (10 sites)	Berthier Islands group‡ (9 sites)
		Number of sites where the species was recorded		
Mussidae (cont.)	*Lobophyllia flabelliformis*	–	–	9
	Lobophyllia hataii	1	–	–
	Lobophyllia hemprichii	11	9	9
	Scolymia australis	–	1	1
	Symphyllia agaricia	9	4	5
	Symphyllia radians	12	5	7
	Symphyllia recta	11	10	9
	Symphyllia valenciennesii	10	5	–
Faviidae	*Barabattoia amicorum*	1	–	3
	Caulastrea furcata	–	4	4
	Caulastrea tumida	9	–	–
	Cyphastrea chalcidicum	10	2	4
	Cyphastrea microphthalma	10	4	5
	Diploastrea heliopora	4	–	2
	Echinopora ashmorensis	2	–	–
	Echinopora gemmacea	12	2	2
	Echinopora lamellosa	12	7	8
	Favia favus	11	5	4
	Favia lizardensis	1	–	2
	Favia maritima	–	4	3
	Favia marshae	1	–	–
	Favia matthaii	10	6	6
	Favia maxima	1	1	2
	Favia pallida	12	4	8
	Favia rosaria	5	–	–
	Favia rotumana	–	–	7
	Favia rotundata	10	4	4
	Favia speciosa	11	5	7
	Favia stelligera	12	4	4
	Favia truncatus	2	–	–
	Favia veroni	6	–	1
	Favites abdita	12	9	7
	Favites chinensis	6	2	8
	Favites complanata	10	5	3
	Favites flexuosa	12	5	7
	Favites halicora	12	10	7
	Favites paraflexuosa	–	2	1
	Favites pentagona	12	7	5
	Favites russelli	12	–	1
	Favites spinosa	2	–	–
	Goniastrea aspera	12	8	8
	Goniastrea australensis	12	5	5
	Goniastrea edwardsi	10	4	6
	Goniastrea favulus	12	7	8

Table 8-9: Inventory of the coral species of the order Scleractinia recorded at the Maret, Montalivet and Berthier island groups (continued)

Family	Species	Maret Islands group* (12 sites)	Montalivet Islands group† (10 sites)	Berthier Islands group‡ (9 sites)
		Number of sites where the species was recorded		
Faviidae (cont.)	*Goniastrea pectinata*	11	4	6
	Goniastrea ramosa	–	3	1
	Goniastrea retiformis	12	9	8
	Goniastrea sp. (honeycomb)	–	4	4
	Leptastrea aequalis	4	–	–
	Leptastrea bewickensis	1	–	–
	Leptastrea pruinosa	–	–	7
	Leptastrea purpurea	12	5	8
	Leptastrea transversa	6	3	6
	Leptoria phrygia	12	8	5
	Montastrea annularis	–	1	–
	Montastrea annuligera	4	1	1
	Montastrea curta	12	10	6
	Montastrea magnistellata	11	4	4
	Montastrea valenciennesi	6	3	1
	Moseleya latistellata	1	3	1
	Oulastrea crispata	2	3	2
	Oulophyllia bennettae	2	1	3
	Oulophyllia crispa	7	4	2
	Platygyra acuta	9	6	7
	Platygyra daedalea	11	7	7
	Platygyra lamellina	10	4	6
	Platygyra pini	12	3	7
	Platygyra ryukyuensis	12	6	6
	Platygyra sinensis	12	9	8
	Platygyra verweyi	–	5	–
	Plesiastrea versipora	7	–	1
Trachyphylliidae	*Trachyphyllia geoffroyi*	–	1	–
Poritidae	*Alveopora spongiosa*	5	–	1
	Alveopora tizardi	6	–	–
	Goniopora columna	7	–	3
	Goniopora djiboutiensis	–	1	2
	Goniopora eclipsensis	1	–	–
	Goniopora lobata	7	5	–
	Goniopora minor	4	–	–
	Goniopora pendulus	2	–	–
	Goniopora somaliensis	–	1	1
	Goniopora stutchburyi	6	2	2
	Goniopora tenuidens	1	7	3
	Machadoporites tantillus	1	–	–
	Porites annae	1	–	5
	Porites aranetai	2	–	3
	Porites attenuata	2	–	–
	Porites australiensis	2	3	5

Table 8-9: Inventory of the coral species of the order Scleractinia recorded at the Maret, Montalivet and Berthier island groups (continued)

Family	Species	Maret Islands group* (12 sites)	Montalivet Islands group† (10 sites)	Berthier Islands group‡ (9 sites)
		Number of sites where the species was recorded		
Poritidae (cont.)	*Porites cylindrica*	7	7	7
	Porites deformis	2	–	–
	Porites divaricata	5	–	–
	Porites evermanni	1	–	–
	Porites latistella	2	–	–
	Porites lichen	–	2	2
	Porites lobata	6	5	7
	Porites lutea	7	8	3
	Porites monticulosa	3	–	–
	Porites nigrescens	6	–	1
	Porites rus	6	–	4
	Porites sillimaniana	3	–	–
	Porites solida	4	–	–
	Porites stephensoni	5	–	–
	Stylaraea punctata	–	–	1
Total	**275**	**221**	**179**	**187**

Note: Species highlighted in yellow are new records for the Kimberley region of Western Australia.
Species highlighted in green are new records for Australia.

* The Maret Islands group consists of North Maret Island and South Maret Island.

† The Montalivet Islands group in this table are taken to be West Montalivet Island, East Montalivet Island, Walker Island (and three adjacent unnamed islets off its north-west coast), Patricia Island, and Don Island (and an unnamed islet off its south-west coast.

‡ The Berthier Islands group, in the case of this table only, is taken to consist of Berthier Island (with three smaller unnamed islets off its north-west coast) together with the Albert Islands group and Turbin Island.

The high number of new records from the surveys—54 for the Kimberley Bioregion, two of which are new records for Australia—reflects the relative lack of research effort in the region prior to 2006.

The 27 scleractinian coral species found at Browse Island are listed in Table 8-10. All of these species were also found in the study island groups of the Bonaparte Archipelago.

Table 8-10: The coral species of the order Scleractinia recorded at the Browse Island reef complex

Family	Species
Pocilloporidae	*Pocillopora damicornis*
	Pocillopora verrucosa
	Seriatopora hystrix
Acroporidae	*Acropora aculeus*
	Acropora acuminata
	Acropora aspera
	Acropora bushyensis
	Acropora digitifera
	Acropora nana
	Acropora palifera
	Acropora papillare
	Acropora robusta
	Acropora samoensis
	Acropora spicifera
Acroporidae (cont.)	*Montipora venosa*
Oculinidae	*Galaxea fascicularis*
Agariciidae	*Coeloseris mayeri*
	Pavona venosa
Merulinidae	*Hydnophora exesa*
	Hydnophora pilosa
Faviidae	*Cyphastrea microphthalma*
	Favites abdita
	Goniastrea aspera
	Platygyra verweyi
Poritidae	*Goniopora* sp.
	Porites cylindrica
	Porites lutea

Fishes

Table 8-11 contains the list of fish species recorded at the 11 intertidal rock pools sampled at Browse Island (one site) (see Figure 8-6), the Maret Islands (six sites) (see Figure 8-2), West Montalivet Island (one site) (see Figure 8-5) and Patricia Island in the East Montalivet Islands group (three sites) (see Figure 8-4). A total of 97 species from 32 families were recorded during the surveys.

Table 8-11: Inventory of the fish species recorded at Browse Island, the Maret Islands, West Montalivet Island and the East Montalivet Islands group

Family	Species	Browse Island	Maret Islands	West Montalivet Island	East Montalivet Islands group
Muraenidae (moray eels)	*Echidna nebulosa* (starry moray)	–	–	✓	–
	Gymnothorax zonipectis (bartail moray)	–	✓	–	–
	Gymnothorax sp. (moray)	✓	–	–	–
Ophichthidae (snake eels)	*Pisodonophis cancrivorus* (burrowing snake eel)	–	✓	✓	–
	Pisodonophis sp. A (unidentified snake eel)	–	–	✓	–
	Pisodonophis sp. B (unidentified snake eel)	–	–	✓	–
Synodontidae (lizardfishes)	*Synodus variegatus* (variegated lizardfish)	–	✓	–	✓
Ariidae (forktail catfishes)	*Arius* sp. (unidentified catfish)	–	✓	–	–
Plotosidae (eeltail catfishes)	*Plotosus lineatus* (striped catfish)	–	–	–	✓
	Paraplotosus sp. (unidentified catfish)	–	✓	–	✓
Batrachoididae (frogfishes)	*Apogon coccineus* (ruby cardinalfish)	–	–	–	✓
	Batrachomoeus dahli (Dahl's frogfish)	–	✓	–	–
	Batrachomoeus trispinosus (threespined frogfish)	–	–	–	✓
Bythitidae (live-bearing cusks)	*Ogilbia* sp. (unidentified brotula)	✓	–	✓	–
Ophidiidae (cusk eels)	*Ophidion muraenolepis* (blackedge cusk)	✓	✓	–	–
Syngnathidae (pipefishes)	*Choeroichthys brachysoma* (Pacific shortbody pipefish)	–	✓	–	–
	Micrognathus micronotopterus (tidepool pipefish)	–	–	–	✓
	Trachyrhamphus longirostris (straightstick pipefish)	–	✓	–	–
Scorpaenidae (scorpionfishes)	*Scorpaenopsis diabolus* (false stonefish)	✓	–	–	–
	Scorpaenopsis venosa (raggy scorpionfish)	–	✓	✓	–
Platycephalidae (flatheads)	*Inegocia harrisii* (Harris's flathead)	–	✓	–	–
	Inegocia japonica (rusty flathead)	✓	–	–	–

Table 8-11: Inventory of the fish species recorded at Browse Island, the Maret Islands, West Montalivet Island and the East Montalivet Islands group (continued)

Family	Species	Browse Island	Maret Islands	West Montalivet Island	East Montalivet Islands group
Serranidae (rockcods)	*Cephalopholis argus* (peacock rockcod)	✓	–	–	–
	Cephalopholis boenak (brownbarred rockcod)	–	✓	–	✓
	Epinephelus coioides (goldspotted rockcod)	–	✓	–	–
	Epinephelus fasciatus (blacktip rockcod)	–	✓	✓	✓
	Epinephelus merra (birdwire rockcod)	–	✓	–	–
	Epinephelus quoyanus (longfin rockcod)	–	✓	–	✓
	Plectropomus maculatus (barcheek coral trout)	–	–	–	✓
Grammistidae (soapfishes)	*Grammistes sexlineatus* (lined soapfish)	✓	–	–	–
Pseudochromidae (dottybacks)	*Assiculus punctatus* (bluespotted dottyback)	✓	–	–	–
	Pseudochromis tapeinosoma (blackmargin dottyback)	✓	–	–	–
	Pseudochromis sp. (dottyback)	✓	–	–	–
Apogonidae (cardinalfishes)	*Apogon doederleini* (fourline cardinalfish)	–	✓	–	–
	Apogon pallidofasciatus (palestriped cardinalfish)	–	✓	–	–
	Apogonichthyoides timorensis (Timor cardinalfish)	–	✓	–	–
	Fowleria aurita (crosseye cardinalfish)	–	✓	✓	✓
	Fowleria variegata (variegated cardinalfish)	–	✓	–	–
	Ostorhinchus angustatus (broadstriped cardinalfish)	–	✓	✓	✓
Lutjanidae (tropical snappers)	*Lutjanus carponotatus* (stripey snapper)	–	✓	–	–
	Lutjanus decussatus (chequered snapper)	✓	–	–	–
	Lutjanus russellii (Moses's snapper)	–	–	✓	–
Nemipteridae (threadfin breams)	*Nemipterus* sp. A (threadfin bream)	✓	–	–	–
	Scaevius milii (coral monocle bream)	–	✓	✓	✓
	Scolopsis bilineata (two-line monocle bream)	–	✓	–	–
Lethrinidae (emperors)	*Lethrinus* sp. (unidentified emperor)	–	✓	–	–
Mullidae (goatfishes)	*Parupeneus indicus* (yellowspot goatfish)	–	✓	–	✓
	Parupeneus trifasciatus (doublebar goatfish)	✓	–	–	–

Table 8-11: Inventory of the fish species recorded at Browse Island, the Maret Islands, West Montalivet Island and the East Montalivet Islands group (continued)

Family	Species	Browse Island	Maret Islands	West Montalivet Island	East Montalivet Islands group
Chaetodontidae (butterflyfishes)	*Chaetodon lunula* (raccoon butterflyfish)	✓	–	–	–
	Chelmon marginalis (margined coralfish)	–	✓	–	–
Pomacentridae (damselfishes)	*Abudefduf septemfasciatus* (banded sergeant)	–	✓	✓	✓
	Abudefduf vaigiensis (Indo-Pacific sergeant)	✓	–	–	–
	Dischistodus fasciatus (yellow-banded damsel)	–	–	✓	–
	Plectroglyphidodon leucozonus (whiteband damsel)	✓	–	–	–
	Pomacentrus coelestis (neon damsel)	–	✓	✓	✓
	Pomacentrus milleri (Miller's damsel)	–	✓	✓	✓
	Stegastes lividus (bluntsnout gregory)	–	✓	–	–
	Stegastes nigricans (dusky gregory)	–	✓	–	–
Labridae (wrasses)	*Choerodon cyanodus* (blue tuskfish)	–	✓	–	✓
	Halichoeres biocellatus (false-eyed wrasse)	–	✓	–	–
	Halichoeres margaritaceus (pearly wrasse)	✓	✓	✓	✓
	Halichoeres marginatus (dusky wrasse)	✓	✓	–	–
	Halichoeres nebulosus (cloud wrasse)	✓	✓	✓	✓
	Halichoeres nigrescens (bubblefin wrasse)	–	✓	✓	✓
	Labroides dimidiatus (common cleanerfish)	–	✓	–	–
	Leptojulis cyanopleura (shoulderspot wrasse)	–	✓	✓	✓
	Leptojulis sp. (unidentified wrasse)	–	✓	–	–
	Macropharyngodon ornatus (ornate leopard wrasse)	–	✓	–	–
	Pteragogus flagellifer (cocktail wrasse)	–	✓	✓	✓
	Stethojulis bandanensis (redspot wrasse)	–	✓	–	–
	Stethojulis interrupta (brokenline wrasse)	–	✓	✓	✓
	Stethojulis strigiventer (silverstreak wrasse)	–	✓	✓	–
	Thalassoma hardwicke (sixbar wrasse)	✓	–	–	–
	Thalassoma jansenii (Jansen's wrasse)	✓	–	–	–

Table 8-11: Inventory of the fish species recorded at Browse Island, the Maret Islands, West Montalivet Island and the East Montalivet Islands group (continued)

Family	Species	Browse Island	Maret Islands	West Montalivet Island	East Montalivet Islands group
Blenniidae (blennies)	*Blenniella periophthalmus* (bluestreaked rockskipper)	✓	✓	–	✓
	Cirripectes filamentosus (filamentous blenny)	✓	✓	✓	✓
	Cirripectes variolosus (redspeckled blenny)	✓	–	–	–
	Ecsenius oculatus (ocular combtooth blenny)	✓	–	–	–
	Salarias fasciatus (banded blenny)	–	✓	✓	✓
	Salarias sexfilum (Spalding's blenny)	–	✓	–	–
Notograptidae (bearded eel blennies)	*Notograptus guttatus* (spotted eel blenny)	–	✓	–	–
Gobiidae (gobies)	*Bathygobius fuscus* (dusky frillgoby)	–	✓	–	–
	Callogobius sp. (unidentified goby)	–	–	✓	–
	Glossogobius circumspectus (mangrove flathead goby)	–	✓	–	–
	Istigobius decoratus (decorated sandgoby)	–	✓	✓	✓
	Priolepis semidoliata (halfbarred reefgoby)	–	–	✓	✓
Acanthuridae (surgeonfishes)	*Acanthurus dussumieri* (pencil surgeonfish)	–	–	–	✓
	Acanthurus grammoptilus (inshore surgeonfish)	–	✓	–	–
	Acanthurus nigrofuscus (dusky surgeonfish)	✓	–	–	–
	Acanthurus sp. (surgeonfish)	✓	–	–	–
Siganidae (rabbitfishes)	*Siganus canaliculatus* (whitespotted rabbitfish)	–	✓	–	–
	Siganus virgatus (doublebar rabbitfish)	–	✓	–	✓
Soleidae (soles)	*Zebrias craticulus* (wicker-work sole)	–	✓	–	–
Balistidae (triggerfishes)	*Balistoides viridescens* (titan triggerfish)	✓	–	–	–
Monacanthidae (leatherjackets)	Unidentified leatherjacket	✓	–	–	–
Tetraodontidae (pufferfishes)	Unidentified pufferfish	✓	–	–	–
Diodontidae (porcupinefishes)	*Diodon liturosus* (blackblotched porcupinefish)	✓	–	–	–
Total no. of families = 32	**Total no. of species = 97**	**31**	**59**	**27**	**31**

* The taxonomic order of the families in this table follows Yearsley, Last and Hoese (2006).

✓ = species recorded.

– = species not found.

Intertidal and subtidal habitat maps

Habitat maps were created for Browse Island and for several islands or island groups of the Bonaparte Archipelago using aerial photographs, remote-sensing data, and data collected from reef walks. The maps are as follows: North Maret Island (Figure 8-15); South Maret Island (Figure 8-16); the Albert Islands group (Figure 8-17); the four main islands of the East Montalivet Islands group (East Montalivet Island, Patricia Island, Don Island and Walker Island) (Figure 8-18); West Montalivet Island (Figure 8-19); and Browse Island (Figure 8-20).

The levels of accuracy of these maps are a function of the intensity of the ground-truthing effort from reef walks and this varied from island to island.

Maps were not prepared for other islands in the archipelago, for example Berthier Island and Turbin Island, because the aerial imagery was not of suitable standard or they were insufficiently surveyed to support detailed mapping.

The descriptions of the different habitats for the Bonaparte Archipelago habitat maps are presented in Table 8-12. The descriptions for Browse Island are presented on the Browse Island habitat map itself.

Each island investigated in the Bonaparte Archipelago had extensive reef flats on its western side and a steep reef slope on its eastern side. The Maret Islands and the Albert Islands also had numerous lagoons in their intertidal zones.

The intertidal and subtidal habitats of Browse Island were quite different from those found in the Bonaparte Archipelago in that there is an extensive reef system surrounding the whole island.

Table 8-12: Geomorphic and biotic descriptions for the intertidal and subtidal habitat maps prepared for the eight surveyed islands in the Bonaparte Archipelago

Geomorphic description		Biotic description	Habitat type
Upper littoral subzone			
Rocky shore	Laterite boulders broken away from the slope above.	Mollusc–barnacle community (including oysters, limpets and chitons).	1
	Basalt bedrock and/or boulders.	Mollusc–barnacle community.	2
	Sandstone bedrock and/or boulders.	Mollusc–barnacle community.	2a
Beach	Sloping beach of coarse carbonate sand with some patches of exposed beachrock.	Bivalves, crabs and other infaunal elements.	3
	Beachrock of a consolidated sand matrix, sometimes bare but periodically buried.	None.	4
Midlittoral subzone			
Reef flat or platform	Perched pools that maintain a water level above that of the low-tide mark.	Mixed coral community, with medium cover (10–50%) and with algae and cryptic invertebrates.	5
	Deep lagoon, often sublittoral within lagoon.	Diverse communities, dominated by either live corals (e.g. *Porites* or *Acropora*) or macroalgae growing on coral rubble.	6
	Shallow sandy lagoon, often as a gutter adjacent to the break of beach slope.	Bare sand with scattered low-density *Halophila* seagrass (<10% cover) and limited invertebrate infauna.	7
	Limestone platform, sometimes with shallow pools.	Medium-biomass macroalgae with low coral cover (<10%) and epifaunal invertebrates.	8
	Limestone platform, often with pools and sand and rubble.	Low-biomass macroalgal turf and small patches of seagrass; normally with mixed cryptic fauna and invertebrate epifauna; low-density corals (<10%).	9
	Sandbanks.	Infauna community.	10
	Accumulation of coral rubble.	Usually *Acropora* coral rubble with epiphytes and cryptic invertebrates.	11
	Fringing coral reef.	Bank of high-cover (>50%) staghorn corals (*Acropora*), with sea urchins (*Diadema*), limited epiphytic algae and cryptic invertebrates.	12

Table 8-12: Geomorphic and biotic descriptions for the intertidal and subtidal habitat maps prepared for the eight surveyed islands in the Bonaparte Archipelago(continued)

Geomorphic description		Biotic description	Habitat type
Reef crest	Boulder area.	Dead coral boulders, usually heavily bored by invertebrates, with mixed coral communities and some pools; low turfing macroalgal biomass among the boulders.	13
	Small boulders, small pools, sand and rubble.	Mixed coral assemblages and turfing macroalgae, often rich in cryptic invertebrates.	14
Lower littoral subzone			
Reef front	Seaward ramp, slightly sloping.	Dominated by faviid colonies, with normally high coral cover (>50%) and diversity, with crustose coralline algae between the corals; limited invertebrate epifauna.	15
		High cover (>50%) of mixed corals, usually faviids and *Acropora* with crustose coralline algae between the corals; limited invertebrate epifauna.	16
		Dominated by *Acropora*, with high coral cover (>50%) and diversity, with crustose coralline algae between the corals.	17
		Dominated by crustose coralline algae, with low coral cover (<10%).	18
	High terrace.	High-cover (>50%) coral community dominated by the families Faviidae and Mussidae.	27
Sublittoral subzone			
Reef slope	Bombora on gentle slope (<20°).	*Porites* bombora-dominated community on the reef slope or wall, off the edge of the intertidal platform.	19
	Steeply sloping (>45°) reef.	Mixed coral reef community (high cover and high diversity) on the reef slope or reef wall, off the edge of the intertidal platform.	20
Seafloor	Fine to medium sand.	Infauna community.	21
	Pavement reef with sand veneer.	High-cover (>70%) filter-feeding communities, including sponges, gorgonians, soft corals, sea whips, hydroids, bryozoans, fan worms and polychaetes.	22
		Medium-cover (40–70%) filter-feeding communities, including sponges, gorgonians, soft corals, sea whips, hydroids, bryozoans, fan worms and polychaetes.	23
	Silty mud.	Silty mud with heavy bioturbation, indicating the presence of annelids, polychaetes and bivalves.	24
	Pavement reef with sand veneer.	Low-cover (<40%) filter-feeding communities including sponges, gorgonians, soft corals, sea whips, hydroids, bryozoans, fan worms and polychaetes.	25
		Generally dense macroalgae-dominated community.	26

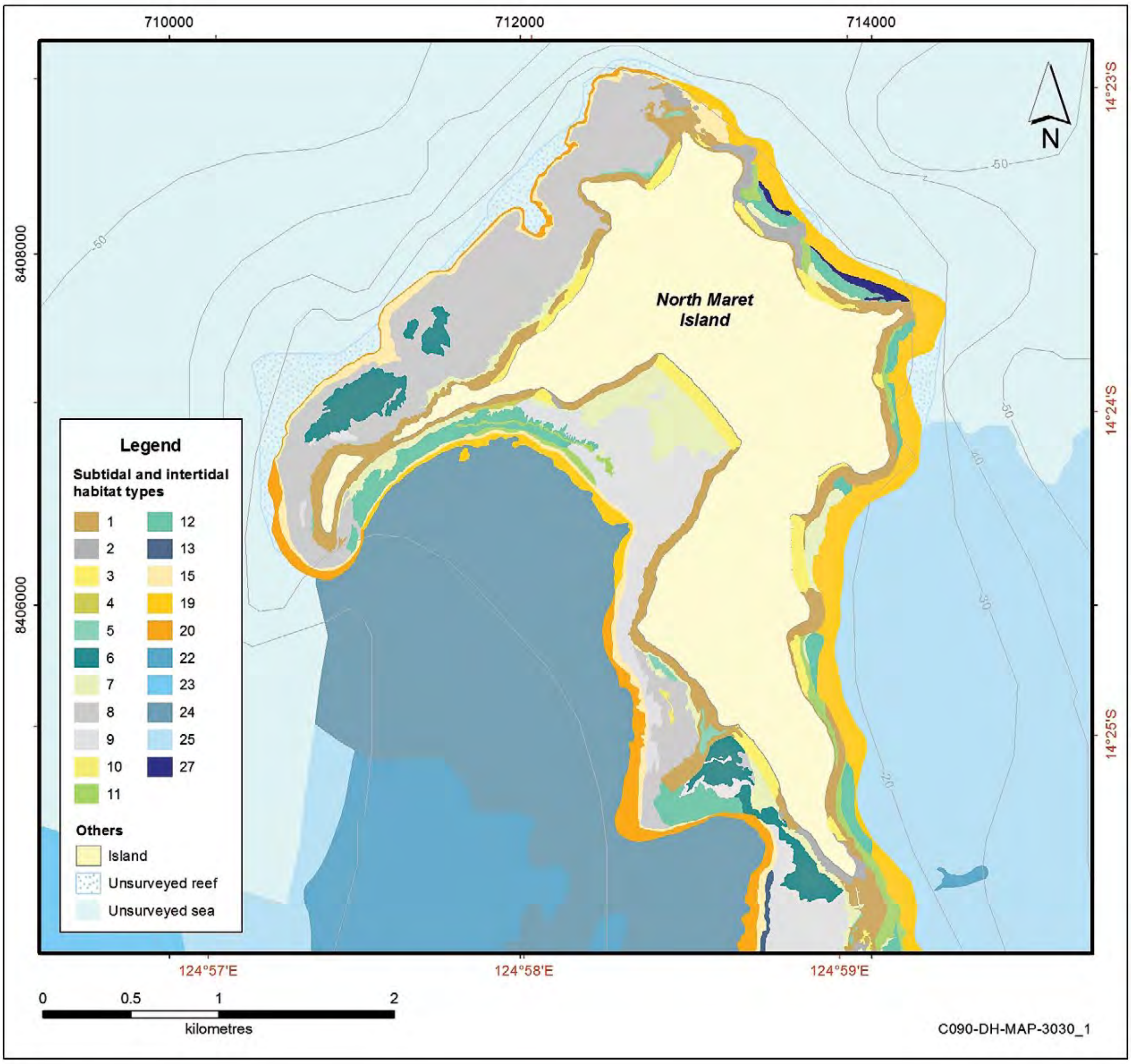

Figure 8-15: Intertidal and subtidal habitats of North Maret Island

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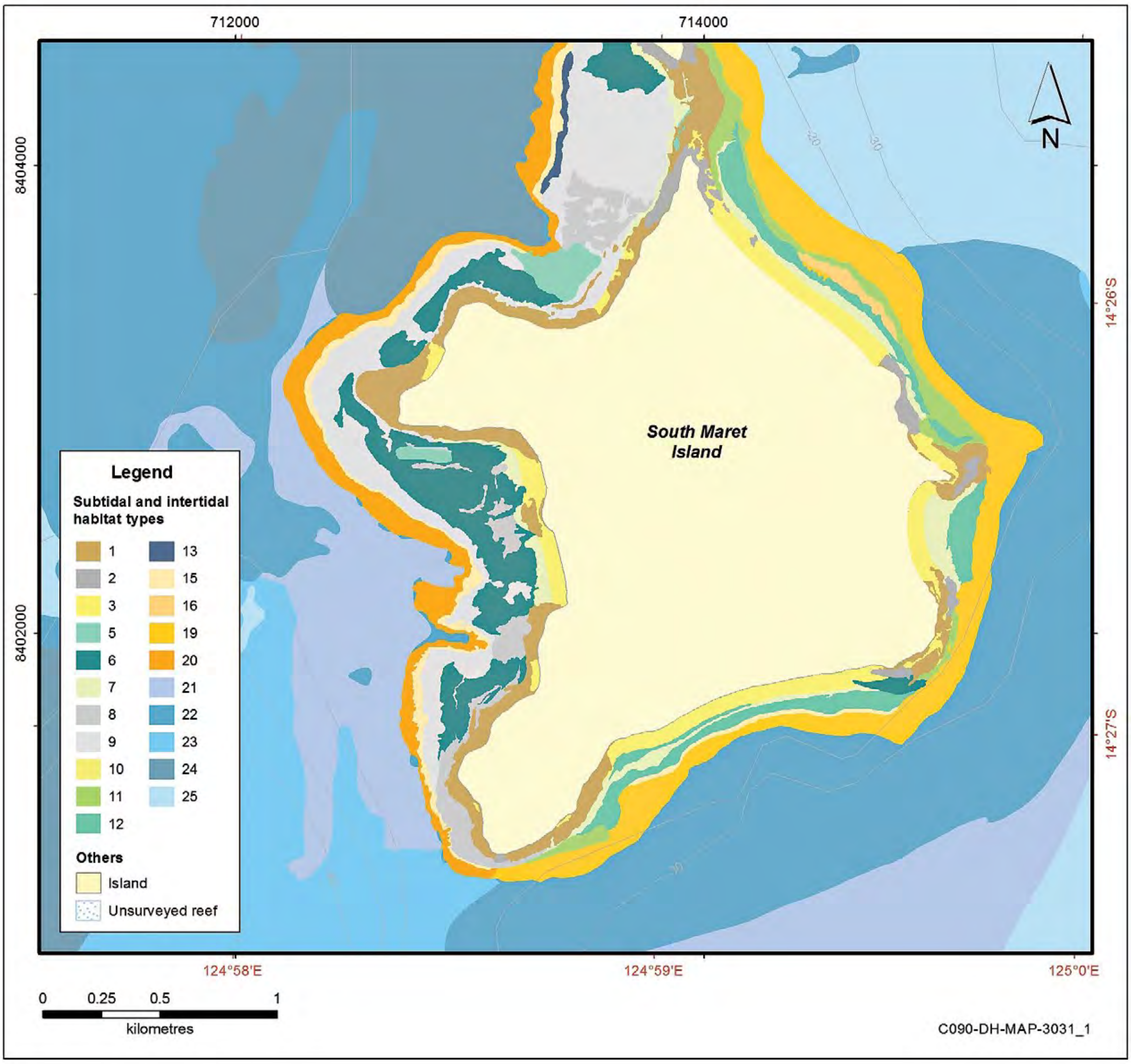

Figure 8-16: Intertidal and subtidal habitats of South Maret Island

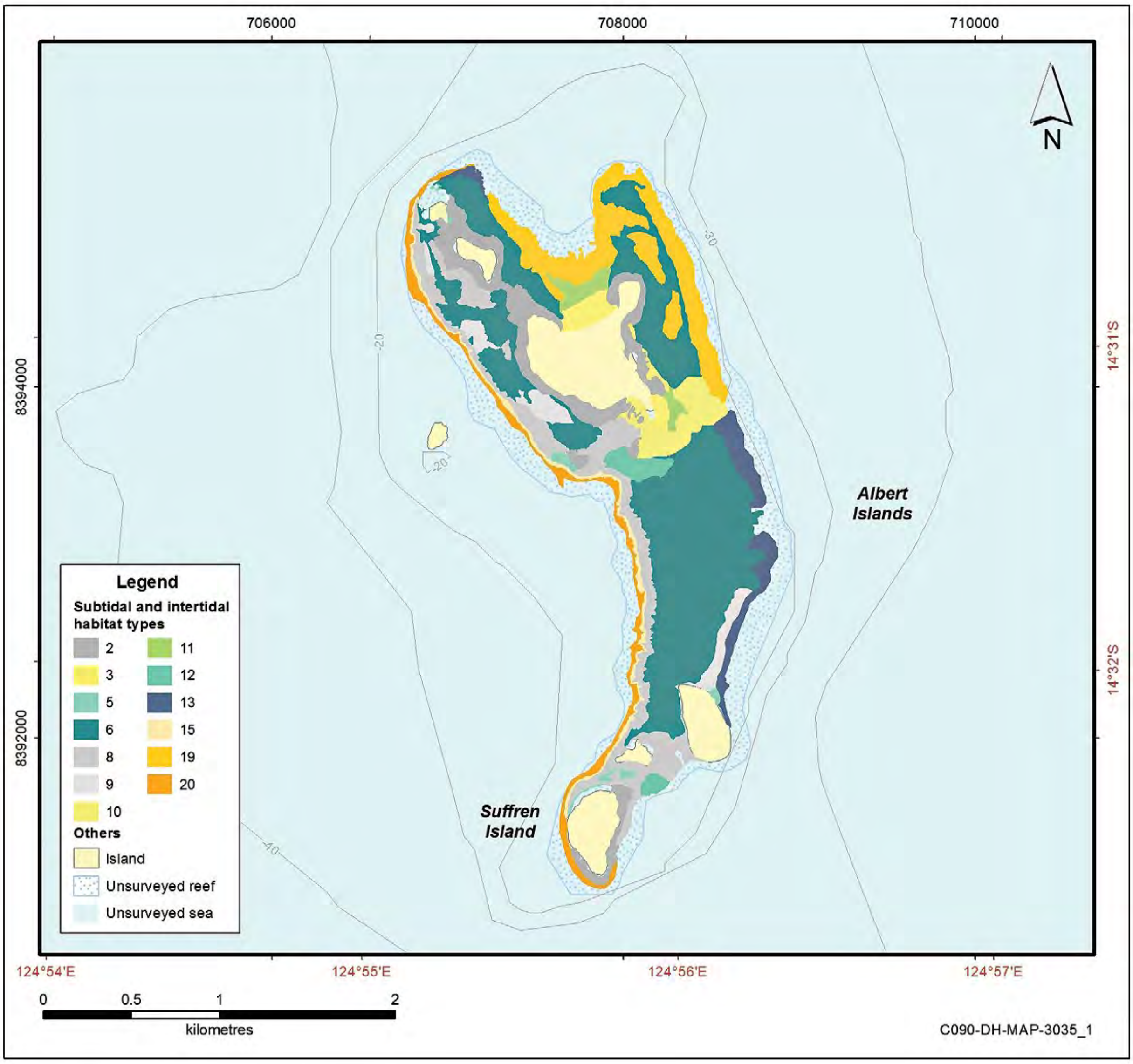

Figure 8-17: Intertidal and subtidal habitats in the Albert Islands group

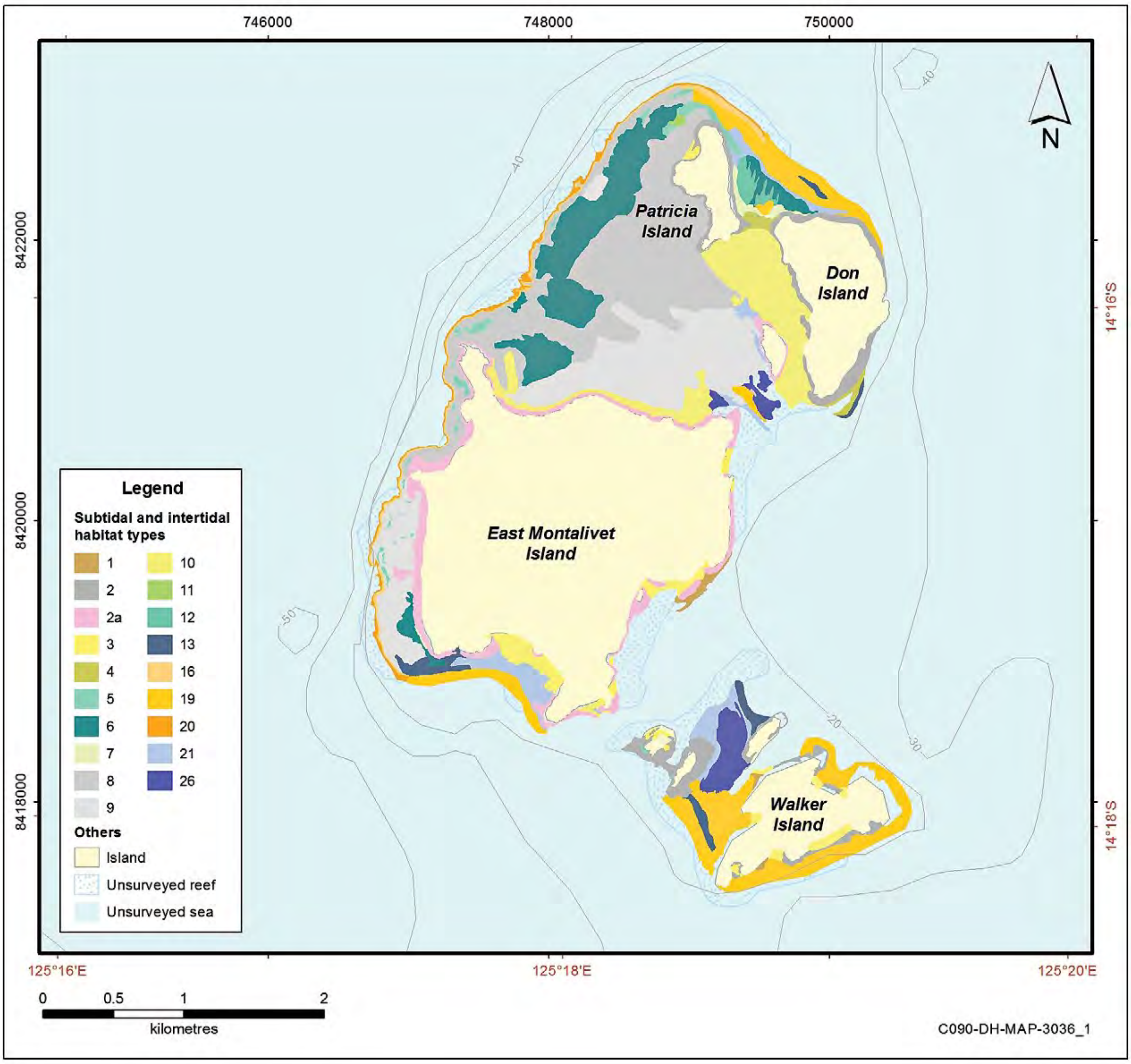

Figure 8-18: Intertidal and subtidal habitats of the East Montalivet Islands group

8 MARINE ECOLOGY

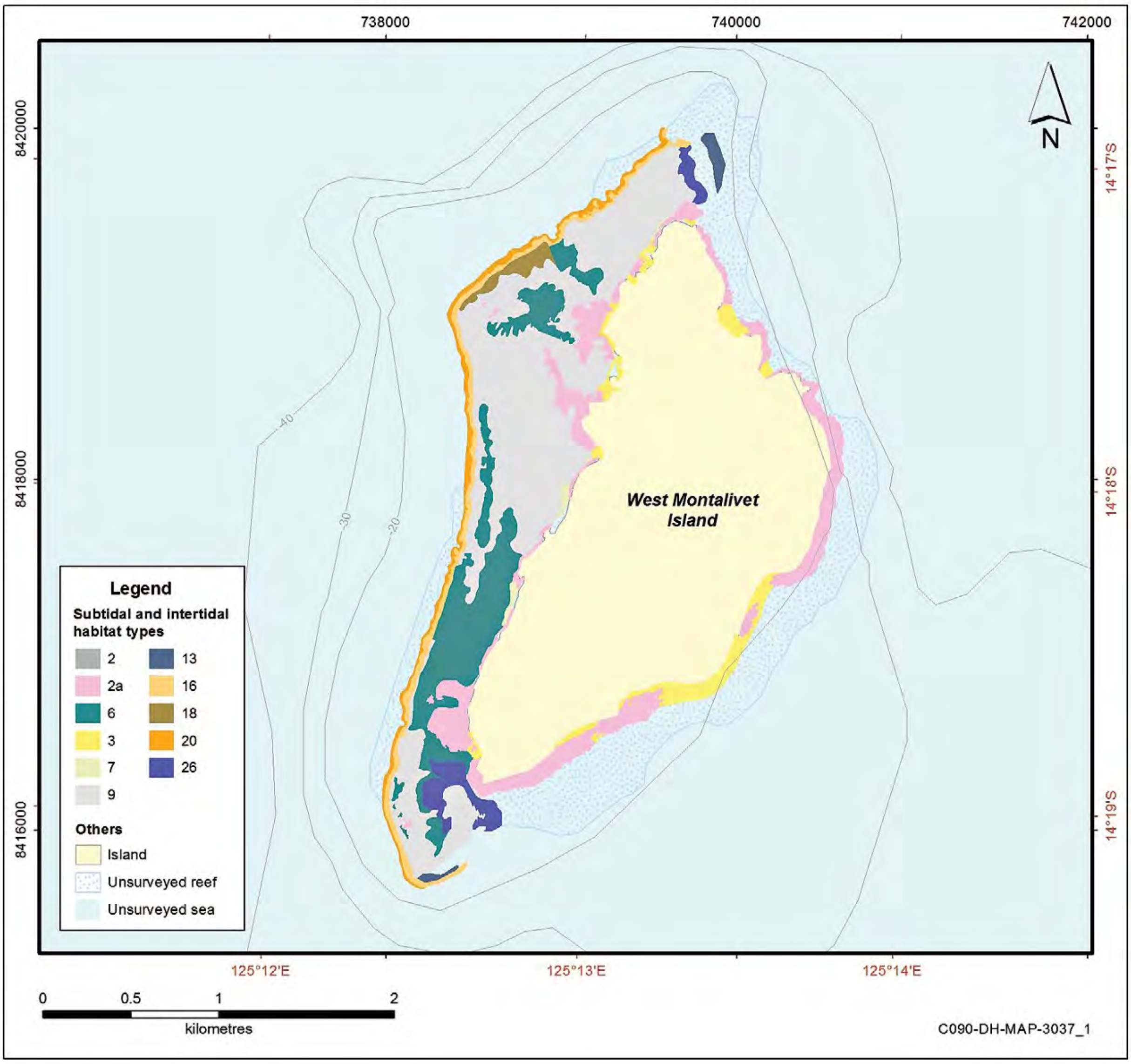

Figure 8-19: Intertidal and subtidal habitats of West Montalivet Island

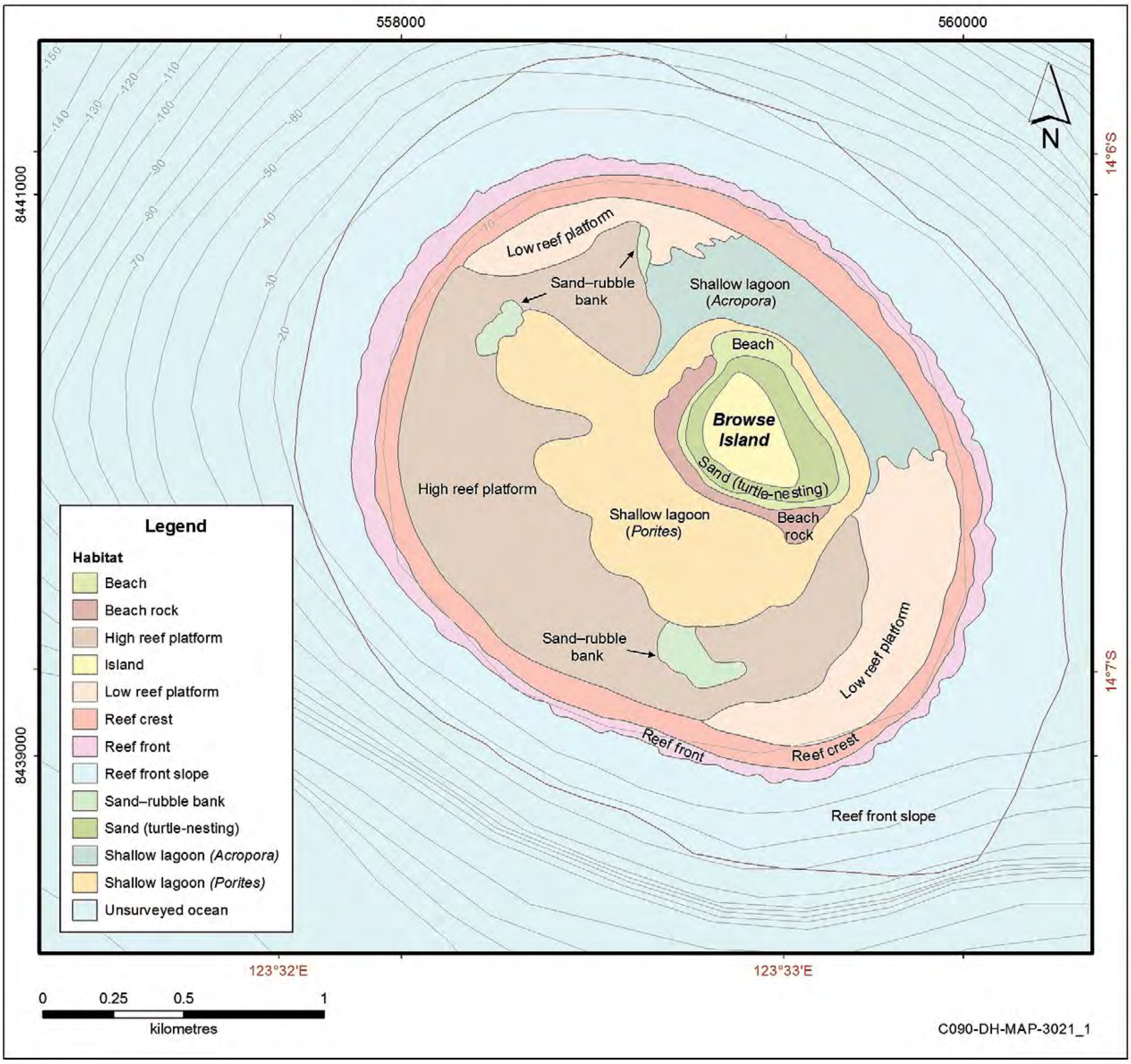

Figure 8-20: The habitats of the Browse Island reef complex

Intertidal surveys—detailed results

The Maret Islands

Intertidal habitats

Intertidal habitats were examined during reef walks at 12 different locations around North Maret Island and South Maret Island in October and November 2006 and in January and March 2007. Descriptions of the 12 sites are provided in Table 8-13 and their localities are shown in Figure 8-2.

Table 8-13: Intertidal habitat descriptions for the 12 sites at the Maret Islands surveyed in October–November 2006 and January and March 2007

Site	Location	Description
1	Southern end of Brunei Bay on North Maret Island	At this site a steep sand beach, Brunei Bay Beach, plunges to a sandflat estimated to be about 400 m wide from the top of the beach to the reef edge. The survey could not be extended into the lower littoral zone because of a rising tide. In the upper littoral and midlittoral zones three distinct subzones were recognised: 1. an upper littoral beach composed of coarse carbonate sand 2. a midlittoral sandflat 3. a midlittoral subzone of coral rubble, the outer limit of which deepened into a shallow pool with corals.
2	North-western side of the isthmus between North Maret Island and South Maret Island	The transect on this site traversed a reef platform with five distinct subzones: 1. an upper littoral basalt rock slope with an upper littoral subzone of mixed basalt boulders and exogenous laterite that encompassed a 0.5 m deep pool 2. an upper littoral pavement covered with sand-encrusted turf algae 3. a reef flat believed to be of coralgal limestone over a basalt base 4. a low reef crest only several centimetres higher than the reef flat, with small boulders (mostly less than 60 cm in diameter) and many shallow pools 5. a lower littoral seaward ramp with a ragged reef edge and poorly developed transverse gutters.
3	Eastern side of the isthmus between the two islands	The transect was carried out along a 90° bearing across a narrow leeward fringing reef on the eastern side of the rocky isthmus between the Maret Islands. Three subzones were identified: 1. an upper littoral basalt rock and boulder slope that was covered in rock oysters and had exogenous laterite boulders in the lower part 2. a midlittoral rock platform with many shallow pools and loose stones 3. a lower littoral ramp incorporating the reef flat that had little slope and no distinct edge.
4	North-facing reef on North Maret Island	This site extended along the shore on the north side of the rocky peninsula forming the northern boundary of Brunei Bay and leading to the the small unnamed islet forming the western extremity of North Maret Island. This reef was made up of a wide rock platform running at an angle of approximately 325° from an upper littoral rocky shore across a reef flat to the coral-dominated lower reef edge. The platform had a distinct edge (but no distinct reef crest or boulder subzone) and an almost level but irregular surface with large mid-flat lagoons. Four distinct subzones were recognised: 1. an upper littoral rocky shore with large laterite boulders 2. an inner midlittoral reef flat with pools dissected by transverse gutters 30–60 cm deep 3. a midlittoral reef flat with loose stones and shallow pools 4. a lower littoral reef front with very little slope and no distinct edge. Site 4 could not be comprehensively examined because of a rising tide.
5	North Maret Island reef and Little Brunei Bay	This site extended along the shore on the south side of the rocky peninsula between Little Brunei Bay and the small unnamed islet forming the western extremity of North Maret Island. Four subzones were recognised: 1. an upper littoral rocky shore of large lateritic boulders at the base of a scree slope with a small beach at the eastern end (Little Brunei Bay Beach) 2. a midlittoral lagoon varying between 10 m and 25 m in width and having a depth of less than 40 cm 3. a midlittoral *Acropora* bank 4. a lower littoral reef front with an indistinct reef edge that was not accessed because of a rising tide.

Table 8-13: Intertidal habitat descriptions for the 12 sites at the Maret Islands surveyed in October–November 2006 and January and March 2007 (continued)

Site	Location	Description
6	Southern end of South Maret Island	This site lay along the shore between rocky points at the western and eastern ends of South Beach and consisted of a narrow fringing reef dominated by an *Acropora* rubble subzone, which was largely unconsolidated and crumbly with minor live corals, including *Acropora* washed from deeper water. Six subzones were recognised: 1. an upper littoral beach of coarse sand, small coral and laterite stones 2. an upper littoral rocky shore with a laterite boulder slope fronted by a rock platform 3. an upper littoral subzone of laterite and coral stones with small pools 4. a midlittoral lagoon approximately 50 cm deep and 5–20 m wide 5. a midlittoral reef platform with some sandy pools 6. a lower-littoral reef front with an indistinct edge that was not closely examined because of relatively high water during the survey.
7	Western side of North Maret Island (north of an islet)	This site consisted of a wide rock platform on the northern side of a small rocky causeway between a rocky shore and a small islet. The transect either passed through or was adjacent to five distinguishable subzones: 1. an upper littoral rocky shore of conglomerate with laterite boulders and pisolitic stones embedded in a hard matrix with a large perched pool 2. a high inner midlittoral reef flat adjacent to the rocky shore 3. a midlittoral reef flat with no distinct reef crest or boulder subzone 4. a midlittoral reef front with a large tidal pool at the centre that was not examined because of a rising tide 5. a lower littoral reef front that was not closely examined because of a rising tide.
8	Western side of North Maret Island (south of an islet)	This site consisted of a rock platform on the southern side of a small rocky causeway between a rocky shore and a small islet. Seven subzones were recognised: 1. an upper littoral beach of coarse sand and beachrock 2. an upper littoral rocky shore that was not investigated 3. a midlittoral sandflat 4. a midlittoral lagoon more than 1 m deep that was not investigated 5. a midlittoral reef platform with many loose stones and shallow pools and no distinct reef crest; also two lower littoral reef front subzones 6. the western reef front, which was an *Acropora* bank that was closer to the beach 7. the eastern reef front adjacent to the end of the islet, which was a reef-front ramp with massive corals.
9	North-western side of South Maret Island	This site encompassed a seaward rock platform approximately 100 m wide along the shore of a double rocky headland (south of Site 2). Six subzones were recognised: 1. an upper littoral rocky shore comprising laterite boulders extending around the shores of both headlands 2. an upper littoral to midlittoral reef flat 3. a midlittoral low reef flat grading into a shallow lagoon 4. a lower littoral lagoon more than 1 m deep 5. a lower littoral *Acropora* bank 6. a lower littoral reef front with a ragged reef edge and no reef crest or boulder subzone.
10	Western bays of South Maret Island	This site consisted of a seaward rock platform, approximately 100 m wide, around the shores of a large bay on the western side of South Maret Island offshore Kingfisher Beach and Sandpiper Beach. Eight subzones were recognised but subzones 1, 2 and 3 were not investigated because of a rising tide: 1. an upper littoral rocky shore made up of laterite boulders 2. an upper littoral beach 3. an upper littoral sandy gutter 4. an upper midlittoral reef flat separated by Subzone 2 at the centre of the bay and Subzone 8 in the southern part 5. a midlittoral reef flat with no distinct crest but a moderately developed boulder subzone with evidence of heavy bio-erosion 6. a midlittoral lagoon more than 1 m deep 7. a lower littoral *Acropora* bank 8. a lower littoral reef-front ramp with a moderate slope and a distinct but ragged reef edge with high coral diversity.

Table 8-13: Intertidal habitat descriptions for the 12 sites at the Maret Islands surveyed in October–November 2006 and January and March 2007 (continued)

Site	Location	Description
11	North-eastern side of North Maret Island	This site is the southernmost of two small bays on the north-eastern side of North Maret Island, offshore Pandanus Beach. It lies below laterite cliffs with vine-thicket scree slopes, a steep beach and a narrow fringing reef between rocky headlands. The southern headland is composed of laterite, while the northern headland is composed of basalt with superficial laterite boulders. The lower littoral was flooded at the time of the survey and examination of this fringing reef was only cursory. The northern bay of the two, offshore Heron Beach, was not examined at low tide but appeared to be similar, except that both its bounding headlands were basalt. Further south, offshore from two more small bays with sandy beaches, there were also narrow fringing reefs with similar zoning patterns. The latter were not examined but were mapped from photo-interpretation and extrapolation. Six subzones were recognised: 1. an upper littoral rocky headland of basalt, with broad, smooth, sloping ramps with some shallow pools and gutters 2. an upper littoral beach of coarse sand 3. a midlittoral sandy gutter 4. a midlittoral reef flat 5. a midlittoral *Acropora* bank 6. a lower littoral reef front with little slope and no distinct reef edge. The fauna of subzones 3 and 4 was not investigated.
12	Northern end of North Maret Island	The northern end of the island is a basalt headland complex below a laterite escarpment and scree slopes. The north-eastern corner of the complex is a high cliff of columnar basalt with a terraced seaward profile, dropping off into deep water with no fringing reef. The northern corner is a long basalt point projecting northwards from a field of large laterite boulders at the base of the cliffs. Between the north-eastern headland and the northern point there was a small sand–rubble beach and a narrow rock flat fringed with coral along its irregular seaward edge. Site 12 was on the western side of the northern point where there was a wide rocky area of laterite–basalt conglomerate with shallow perched rock pools in the upper littoral zone and a high midlittoral rock flat. The reef edge was flooded by the tide and was not examined. Two subzones were examined before the flooding tide prevented further work: 1. a midlittoral to upper littoral basalt rocky shore, with many shallow pools and deep crevices 2. an upper littoral to upper midlittoral reef flat with perched pools and an adjacent, wide, upper midlittoral reef flat.

In addition to these sites, three locations were chosen to conduct reef-profile investigations, six locations were chosen to conduct fish surveys in intertidal rock pools and twelve locations were chosen to conduct coral assemblage studies.

The supralittoral and upper littoral zones of the shores of the Maret Islands were either beach or rock, both of which substrates were fronted by intertidal fringing reefs. Intertidal sandflats were restricted to inner midlittoral sandy subzones of some fringing reef platforms. Wide mudflats and mangals were not found at the Maret Islands and in this respect these shores are unlike those of larger islands closer to the coast and on the Kimberley mainland.

Reef profiles

The shores of the Maret Islands were found to have four different types of profile, three of which were assessed quantitatively. All were interpreted as being of Holocene age, but their geomorphic forms and biotic assemblages varied according to their exposure to prevailing winds and ocean swells.

- *Seaward fringing reefs with a wide rock platform*

Seaward fringing reefs with wide rock platforms were found on the western and northern sides of the islands that were exposed to the prevailing westerly swell (sites 2, 4, 7, 9 and the southern half of Site 10 (Figure 8-2)). A profile of this reef type is shown in Figure 8-21.

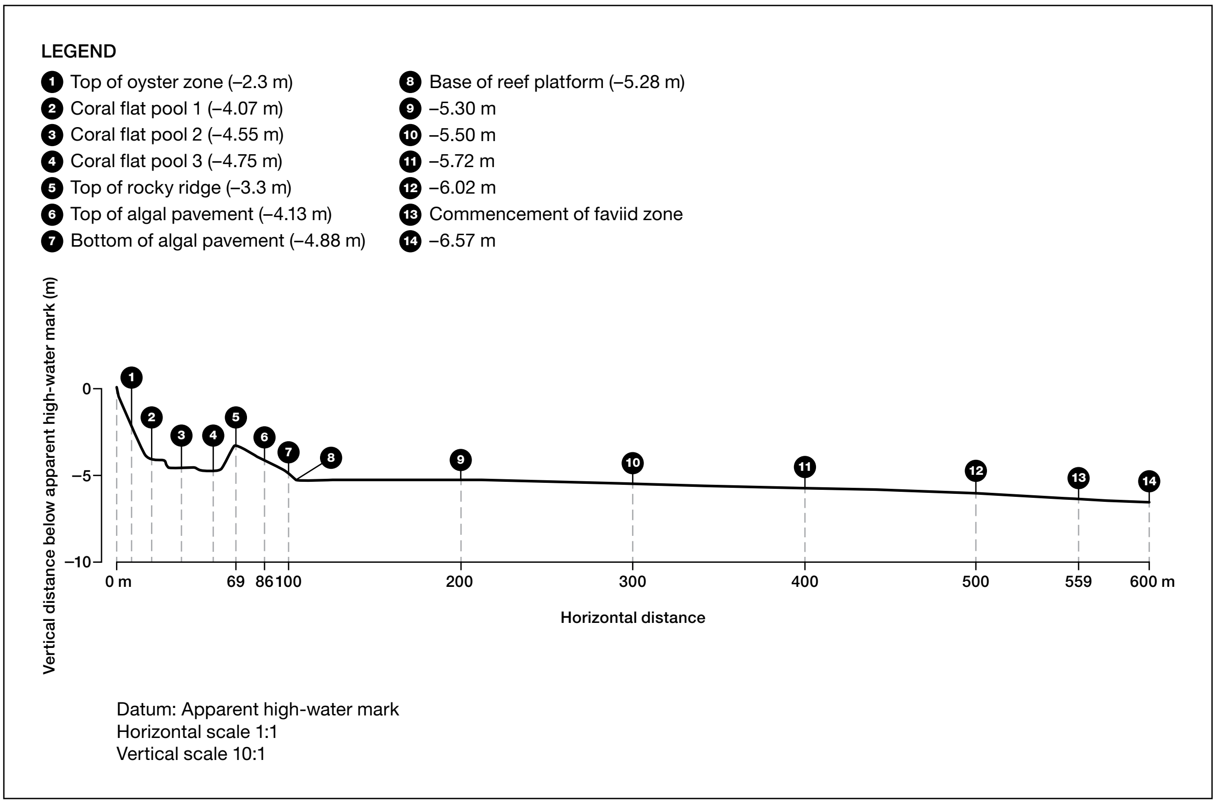

Figure 8-21: Profile of a seaward fringing reef with a wide rock platform at the Maret Islands

Figure 8-22: The vertical seaward face of the reef-front slope at low tide, at Site 2 on North Maret Island

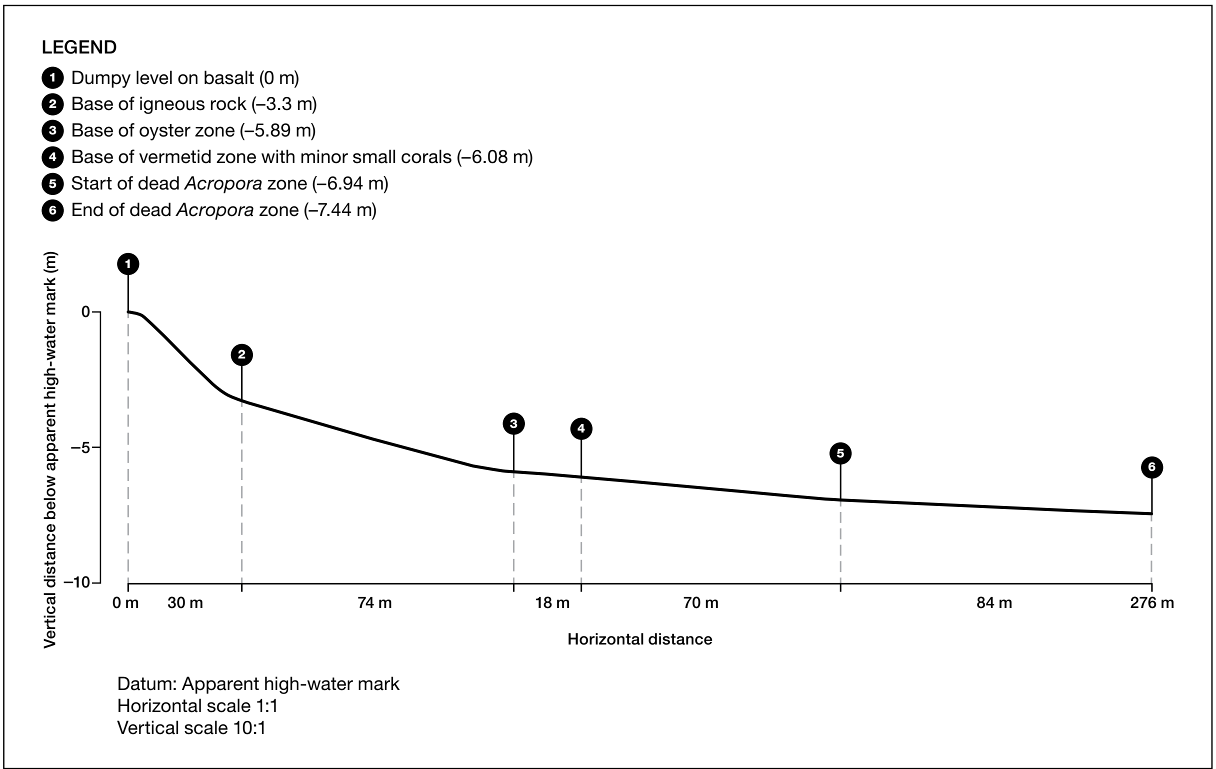

Figure 8-23: Profile of a typical leeward fringing reef with *Acropora* banks in front of sandy beaches at the Maret Islands

The inner section of the midlittoral zone generally had a narrow sandy gutter less than 10 m wide at the slope break of the adjacent upper littoral beach or rocky shore. The gutters were 20 to 50 cm deep at low tide and had a poor faunal assemblage. There were sometimes small patches of seagrass (*Thalassia hemprichii*) in the gutters and nearby shallow pools, but seagrass meadows were not present.

There was a low reef crest in the outer midlittoral zone with a boulder subzone that was weakly developed, if at all. The midlittoral rock platforms behind the reef crest were up to 400 m wide with the higher parts covered with a dense algal turf and few corals. There were many pools in the less-elevated sections, supporting diverse corals around their margins with dense growths of leafy brown algae, predominantly of the genus *Sargassum*. There was a moderately diverse community of surface-dwelling and cryptic invertebrates.

The sublittoral fore-reef slope was steep, generally dropping off into a depth of 15–20 m; it supported a diverse coral community. The reef edge was distinct, though ragged, and often had a near-vertical seaward face (Figure 8-22).

It lacked a prominent spur and grooved drainage system. These reefs had a well-developed, gently sloping reef-front ramp, the outer part supporting abundant and relatively diverse coral communities dominated by domal faviids.

The inner part of the ramp had fewer corals and was covered with a low algal turf.

- *Fringing reefs with* Acropora *banks in front of sandy beaches*

Fringing reefs on leeward southern and eastern shores of the Maret Islands (Figure 8-23) supported banks of branching *Acropora*, with a nearly level top just above the level of Lowest Astronomical Tide.

In some places the *Acropora* thickets were predominantly alive, while in others much of the *Acropora* was dead but still attached. Two variations of leeward fringing reef of this kind can be distinguished:

1. Reefs without a prominent edge and no rock platform, but with a wide lower littoral *Acropora* bank sloping irregularly into the subtidal *Porites* bombora subzone. There are sometimes narrow sandy gutters between the *Acropora* bank and the beach (sites 3, 5 and 6).

Figure 8-24: An *Acropora* bank and lagoon at low tide, at the northern end of Site 8 on North Maret Island

Figure 8-25: The beach at high tide, at Site 1 in Brunei Bay on North Maret Island

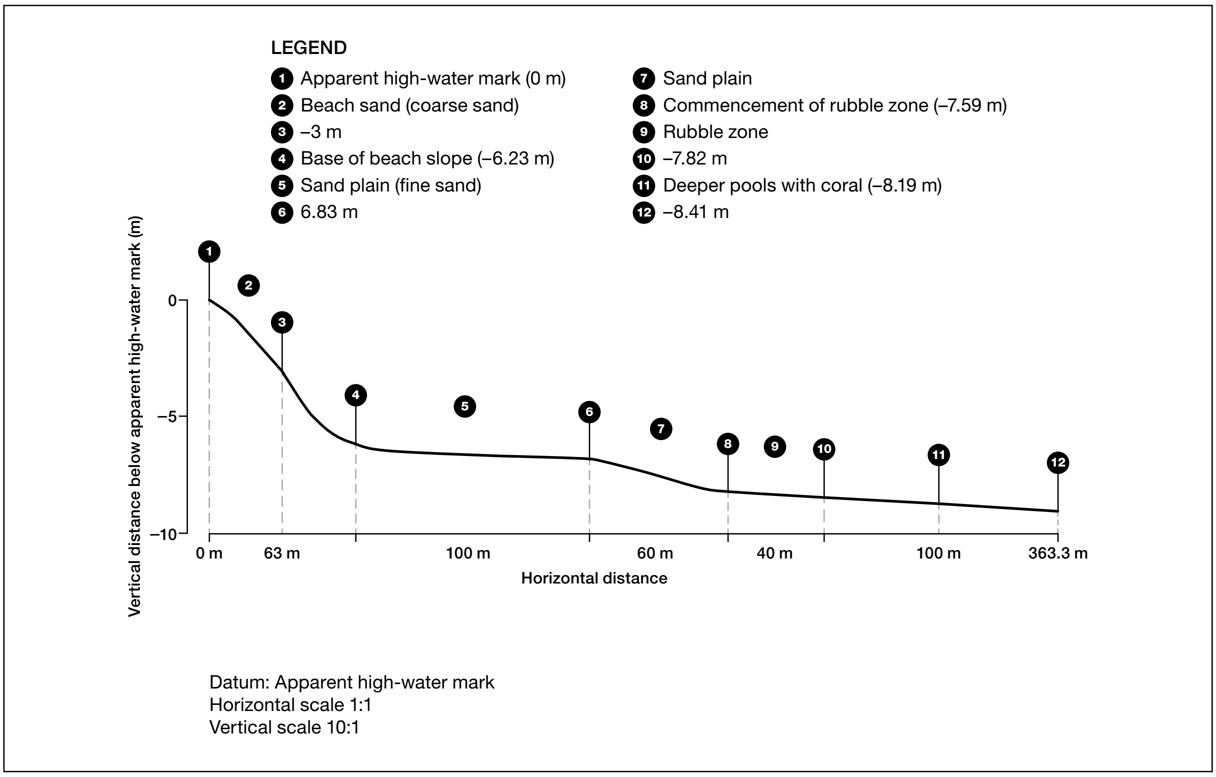

Figure 8-26: Profile of a sheltered-bay reef with sand–rubble flats—Site 1 (Brunei Bay) on North Maret Island

2. Reefs with an edge of massive corals (mostly *Goniastrea retiformis*) along a narrow reef front but with no rock platform. There is often a gutter in the lower littoral zone separating the reef front from a narrow lower littoral *Acropora* bank and sometimes a wide, shallow (less than 1 m deep at low tide) inner lagoon with scattered corals on a sand–rubble floor (sites 11 and 12).

There was low coral diversity over much of the area of the *Acropora* banks. Several *Acropora* species were present, most notably the arborescent *Acropora aspera*, *Acropora nobilis* and *Acropora pulchra*. Other corals were sparse although there were patches of domal faviids and a few other species. A feature of the sloping *Acropora* banks was the presence of populations of echinoids (*Diadema*) and tridacnine clams (*Tridacna squamosa*). There was a greater variety of corals along the leeward reef front and in the lagoons of these reefs, but few other macroinvertebrates.

- *Fringing reefs with* Acropora *banks in front of semi-sheltered rocky shores*

Reefs on the sheltered sides of the peninsulas on seaward shores (Site 8 on North Maret Island and the northern end of Site 10 on South Maret Island) were also made up of dense *Acropora* banks (Figure 8-24) that were often partly dead but still attached. They also lacked a distinct reef edge and merged seaward into the higher-diversity sublittoral *Porites* subzone. They were separated from the shore by a wide and relatively deep lagoon (less than 1 m deep at low tide) that supported moderately diverse coral assemblages and a dense growth of brown algae, mainly of *Sargassum* species.

- *Sheltered-bay reef with sand–rubble flats*

The single example of this fringing reef type observed at the Maret Islands was the reef in Brunei Bay on North Maret Island (Site 1) (Figure 8-25). There was a wide midlittoral sand and rubble flat, without corals, that merged seaward into a rich coral community in the lower littoral, apparently growing on a semi-consolidated rubble base. There was no exposed rock pavement or distinct reef edge. The lower littoral coral community sloped down into the diverse *Porites* subzone of the sublittoral (Figure 8-26).

The abundance of invertebrate infaunal animals in the inner sandflats was low, but was slightly greater than in the lower midlittoral where there were many loose stones.

Algal and seagrass assemblages

There were no seagrass meadows in the intertidal zone at the Maret Islands, although the seagrasses *Thalassia hemprichii* (Figure 8-27) and *Halophila ovalis* were commonly found in pools, lagoons and sandy flats near the backs of reef platforms.

Figure 8-27: The most common seagrass on the intertidal reef, *Thalassia hemprichii*

Figure 8-28: The encrusting coralline red alga *Hydrolithon reinboldii*, widespread on the reef crest of North Maret Island

At the reef crest, the encrusting coralline red alga *Hydrolithon reinboldii* was common (Figure 8-28). Further shoreward on the reef flats were various species of red, green and brown algae, for example *Laurencia similis*, *Galaxaura rugosa*, *Caulerpa lentillifera*, *Caulerpa racemosa* (Figure 8-29), *Caulerpa sertularioides*, *Halimeda opuntia*, *Cladophoropsis vaucheriiformis* (Figure 8-30) and *Padina australis*. In rock pools and "lagoonal" habitats, the genus *Sargassum* dominated, as it did in many habitats; algae of this genus were the most common components of drifting algae. Eight species were recorded and voucher specimens were collected.

Figure 8-29: The green alga *Caulerpa racemosa* on the reef flats of North Maret Island

Figure 8-30: The green alga *Cladophoropsis vaucheriiformis*, common on the reef flats of the Maret Islands

On relatively sheltered, sandy shores with boulder fields, the boulders were commonly covered with the green alga *Ulva flexuosa* (Figure 8-31) and, less commonly, with *Boergesenia forbesii*. In many shallow pools, the red algae *Liagora ceranoides* and *Hommersandiophycus borowitzkae* were very common (Figure 8-32).

Figure 8-31: The green alga *Ulva flexuosa* growing on boulders on a sheltered sandy shore on North Maret Island

Figure 8-32: The red alga *Hommersandiophycus borowitzkae* was very common in shallow pools on sandy shores on North Maret Island

Intertidal invertebrate assemblages

Around the shores of the Maret Islands, intertidal habitats and the communities of invertebrates inhabiting them were found to be moderately diverse.

- *Upper littoral beach assemblages*

Beaches in the upper littoral zone normally have characteristic meiofaunal[9] communities and assemblages of larger invertebrates.

At the Maret Islands, the most conspicuous invertebrate in the upper part of the beach was a ghost crab of the genus *Ocypode* which maintains burrows near high-water mark and forages both on the beach and in the supralittoral fore-dunes. At many Kimberley coastal locations, there is an assemblage of burrowing venerid and donacid bivalves low in the profile close to the break of slope, but at the Maret Islands this assemblage was depauperate, being represented by only one donacid, *Donax cuneatus*.

- *Upper littoral rocky-shore assemblages*

On the shores of the Maret Islands, the upper littoral subzone was dominated by basalt or laterite rocks with a characteristic assemblage of molluscs and barnacles (Figure 8-33). Beachrock was present at some sites, but it was almost barren or had restricted rocky-shore assemblages.

In the upper part of this subzone there were four species of littorinid; the largest of them, *Tectarius rusticus*, is endemic to the Kimberley coast. There were also four *Nerita* species and one of these, *Nerita reticulata*, is also a Kimberley endemic. Two patellid limpets, two siphonarians, two species of rock oyster (*Saccostrea*) and the very common bivalve *Isognomon nucleus* occurred in clusters in rock crevices.

Figure 8-33: Basalt rocky shore and perched pools in Subzone 1 at Site 12 at the north-eastern end of North Maret Island

9 The term meiofauna is here descriptive of small benthic invertebrates between 0.1 mm and 1.0 mm in size.

There were also large colonies of the furrowed clusterwink *Planaxis sulcatus* in pools and wet gutters. Two large chitons, *Acanthopleura gemmata* and *Acanthopleura spinosa*, were conspicuous on the rocks in the lower half of the subzone. Rock surfaces in the lower part of this subzone, below the rock oyster subzone, were often covered with mats of adherent gastropods of the worm-shell family Vermetidae, probably *Dendropoma*. Feeding on these were the muricids *Thais aculeata*, *Cronia crassulnata* and *Morula granulata*. The large grazing gastropods *Turbo cinereus*, *Monodonta labio* and *Trochus hanleyanus* were also common in the lower part of this subzone. Vertical zonation of this upper littoral assemblage appeared to be typical of rocky shores across northern Australia.

- *Midlittoral reef-crest assemblages*

At the Maret Islands the reef crest is hardly evident and the boulder subzone is mostly poorly developed. The only location with a significant reef-crest boulder subzone at the Maret Islands was Site 2, where the coral rock boulders were heavily bored by the barnacle *Lithotrya valentiana* and the boring bivalves, *Gastrochaena gigantea*, *Lithophaga obesa*, *Lithophaga malaccana* and *Lithophaga teres*.

The common muricids feeding on the borers in this subzone were *Thais alouina*, *Morula spinosa*, *Morula margariticola* and *Homalocantha anatomica*. A large number of small coral stones and shallow pools were present here along with a variety of cryptic invertebrates commonly found sheltering under stones. This assemblage was very similar to that on the midlittoral platform closer to shore.

- *Midlittoral reef-flat assemblages*

The midlittoral reef flat had the most diverse assemblage of molluscs and other invertebrates, but abundance was generally low. The herbivorous gastropods *Lambis lambis*, *Angaria delphinus* and *Turbo haynesi* were conspicuous.

The cerithiid detritivores *Cerithium echinatum*, *Cerithium novaehollandiae* and *Rhinoclavis brettinghami* were generally common, crawling in sandy patches on the reef surface. *Pseudovertagus aluco* was found in colonies in muddier places. *Conus coronatus* and *Conus ebraeus* were the most common surface-crawling predatory gastropods. The only common bivalves were byssally attached species living under stones (e.g. *Isognomon* and *Barbatia*) and a *Chama* species that cements to bare rock surfaces. There was a cryptic fauna of molluscs, crustaceans and several species of ophiuroid and crinoid sheltering under the stones.

- *Lower littoral reef-front assemblages*

Invertebrates other than corals were sparse on the lower littoral reef front and no echinoderms were present on the reef surface. Only one large herbivorous trochoid, *Tectus pyramis*, was found. There were few cowries on the reef surface. Predatory gastropods that are normally a feature of coral reef fronts were sparse. *Morula spinosa* was the most common muricid. *Conus ebraeus*, *Conus coronatus*, and *Conus mustelinus* were the only cone shells, none of them abundant.

Bivalve molluscs were also poorly represented, with the occasional *Tridacna maxima*, the *Chama* species mentioned above, and the byssally attached mytilid *Septifer bilocularis* being the only common surface-dwelling species. The crustose algal matrix between the reef-front corals was extensively bored, principally by a *Gastrochaena* species and by lithophagine bivalves. The most abundant macroinvertebrate in the reef-front subzone was the large, cryptic, wormlike chiton, *Cryptoplax larvaeformis.* However this species was only revealed when the algal crust was broken up. There were also small molluscs, crustaceans, polychaetes, colonial ascidians, bryozoans, sponges and hydrozoans within spaces in the reef.

Coral assemblages

In the intertidal zone of the Maret Islands, 221 species of corals from 52 genera were collected or identified. Of these, 29 were new records for the Kimberley region and two of these, *Platygyra acuta* and *Machadoporites tantillus*, were new records for Australia, both being recorded at several sites around the Maret Islands.

Because the reefs were surveyed at different stages of the tidal cycle, there were minor differences in sampling effort. The species counts are therefore only representative and are not comparable between sites.

The highest species counts were generally obtained from the most exposed reef sites, such as the reef fronts on the north-western side of South Maret Island (163 species), the two sites on the edge of the south-west side of North Maret Island (153 and 138 species), and on the north-west side of North Maret Island (140 species).

The sheltered reef community at the western end of South Beach on South Maret Island also produced a relatively high species count (142 species), mainly because of the small pockets of diverse assemblages that have developed within the arborescent *Acropora* community there.

Intertidal coral assemblages fell into two broad groups, reflecting the differences between exposed and sheltered areas.

Exposed areas on the northern and western sides of the islands are subject to moderate but persistent wave energy, especially during the winter months when long-period westerly swells prevail. Sheltered areas in the lee of peninsulas and on the southern and eastern coasts of both islands are less affected by wave energy; the coral communities in these areas are generally dominated by fast-growing species that are capable of rapid colonisation but are not able to withstand the assault of the winter swells and occasional cyclonic storms.

- *Exposed areas*

The northern shores of North Maret Island and the western shores of both North Maret Island and South Maret Island are the most exposed to swell. The survey found that the reef fronts of their fringing reefs were generally dominated by massive corals that were able to withstand the wave regime. In such exposed areas, species of *Acropora* were usually represented by stunted forms that are less fragile than conspecifics found in more protected areas. Massive domal corals of the family Faviidae usually dominated the species-rich lower intertidal zones but *Coeloseris mayeri* (family Agariciidae) and the helioporacean octocoral *Heliopora coerulea* (family Helioporidae) (Figure 8-34) were also common. Other common genera were *Porites*, *Montipora*, *Stylophora*, *Pocillopora*, *Merulina*, *Hydnophora*, *Pavona*, *Pectinia*, *Goniastrea* and *Alveopora*.

Photograph courtesy of Zoe Richards (Western Australian Museum)

Figure 8-34: *Heliopora coerulea*, an octocoral commonly found in exposed areas of the Maret Islands

Low reef flats that are exposed for shorter periods and pools that retain water at low tide provide more benign conditions. These habitats supported a different suite of coral species from that found at the reef front, including a diverse array of *Acropora* species and a wide range of coral species not often observed on the raised reef front; these included representatives of the genera *Porites*, *Montipora*, *Astreopora*, *Goniopora*, *Galaxea*, *Hydnophora* and *Merulina*.

The seaward edge of the reef on the north-facing coast of North Maret Island comprises vertical faces, overhanging reef edges, and steep fore-reef slopes with a high cover of massive, branching and foliose corals. The octocoral *Heliopora coerulea* was a dominant species on the edge of the northern reef flat and provided strength and stability to the reef structure. Other common corals there included digitate or encrusting *Acropora*, *Montipora*, *Pocillopora*, *Stylophora* and *Seriatopora* species. These are fast-growing corals, their rapid growth appearing to be the cause of the overhanging edges along the seaward reef front.

The reef platforms along the western sides of the islands are less exposed to the energy of the open sea and are characterised by less steep fore-reef slopes.

The fore-reef slopes and lower littoral zones of the west coast fringing reefs were found to support the highest coral species richness of any intertidal area investigated at the Maret Islands.

- *Sheltered areas*

Low-energy coral habitats fringe the entire east coast of the Maret Islands, the south side of South Maret Island (South Beach) and the protected shore on the northern side of Brunei Bay on North Maret Island. The Brunei Bay and South Beach intertidal zones were found to be very similar in community composition and zonation. Branching *Acropora* species were dominant, forming wide, high-density coral banks. These were generally low-diversity coral communities dominated by staghorn corals such as *Acropora aspera* and *Acropora pulchra*, with other *Acropora* species such as *Acropora florida* and *Acropora robusta* present, but less abundant. The mussid *Lobophyllia hemprichii* was generally the most common non-acroporid coral. These communities were also characterised by large populations of the long-spined sea urchin *Diadema setosum* and the giant clam *Tridacna squamosa*. Small patches of mixed corals occurred within the *Acropora* banks and, although limited in area, the coral communities of these areas were often diverse.

Large banks of loosely consolidated staghorn *Acropora* rubble reflected the effects of cyclonic activity in the area. *Acropora* corals are among the fastest-growing of the scleractinians but are very susceptible to storm damage. These rubble banks supported only a few live corals, mainly small acroporids, fungiids and faviids.

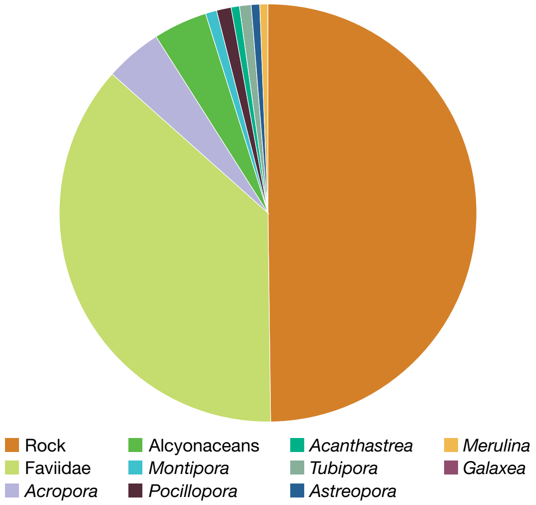

Figure 8-35: Mean coral-community composition from four replicate video transects at Site 2, on the western side of the isthmus between North Maret Island and South Maret Island

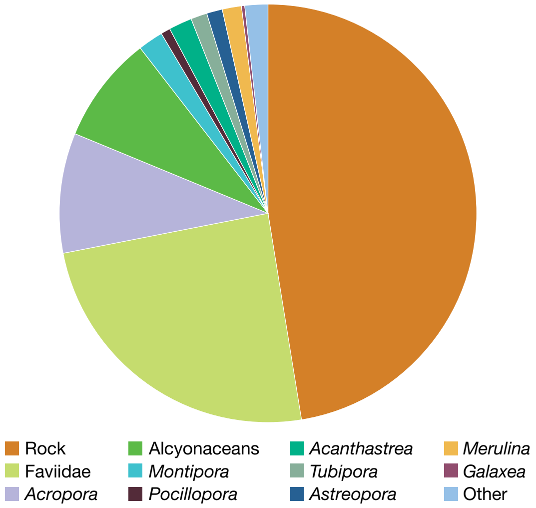

Figure 8-36: Mean coral-community composition from six replicate video transects at Site 4, on the north-west side of North Maret Island

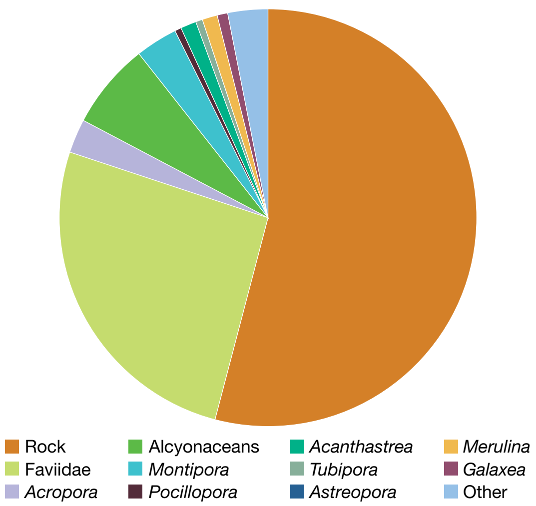

Figure 8-37: Mean coral-community composition from eight replicate video transects at Site 7, on the western side of North Maret Island

Coral-community composition

Live coral cover at all sites on the Maret Islands was estimated to range between 10% and 95%. High cover was frequently encountered in patches in the staghorn *Acropora* thickets on the leeward sides of the islands and on the outer reef edge in exposed areas. The coral reef assemblages were heterogeneous over small spatial scales (hundreds of square metres) in both coral cover and community composition.

Video transects along the reef front at Site 2 (on the western side of the isthmus between North Maret Island and South Maret Island), Site 4 (on the north-west side of North Maret Island), and Site 7 (on the western side of North Maret Island) were used to obtain an estimate of coral-community composition and abundance in the lower littoral zone.

All three reef-front sites were dominated by corals of the family Faviidae. Species of *Acropora* and soft corals were the next most common taxa. Site 2 recorded the lowest number of genera (Figure 8-35); Site 4 had the highest coral cover of the three sites and also had the largest number of genera (Figure 8-36), while Site 7 had the lowest percentage coral cover (Figure 8-37).

Fish assemblages

At North Maret Island, 12 species of fishes from 9 families were collected from an intertidal pool, approximately 14 m^2 in area and 0.5 m deep, during a spring low tide in March 2007 (Figure 8-2, Table 8-14). The most abundant fish species were *Halichoeres nigrescens* (family Labridae), *Ostorhinchus angustatus* (family Apogonidae) and *Pomacentrus milleri* (family Pomacentridae); the least abundant were *Inegocia harrisii* (family Platycephalidae) and *Salarias fasciatus* (family Blenniidae). All of the species found are common in the Indo-Pacific region.

Table 8-14: Numbers of individuals of each fish species collected from an intertidal pool at the south-west corner of North Maret Island

Family*	Species	Number of individuals
Ophichthidae (snake eels)	*Pisodonophis cancrivorus* (burrowing snake eel)	2
Scorpaenidae (scorpionfishes)	*Scorpaenopsis venosa* (raggy scorpionfish)	7
Platycephalidae (flatheads)	*Inegocia harrisii* (Harris's flathead)	1
Serranidae (rockcods)	*Epinephelus quoyanus* (longfin rockcod)	8
Apogonidae (cardinalfishes)	*Fowleria aurita* (crosseye cardinalfish)	9
	Ostorhinchus angustatus (broadstriped cardinalfish)	19
Pomacentridae (damselfishes)	*Abudefduf septemfasciatus* (banded sergeant)	9
	Pomacentrus milleri (Miller's damsel)	11
Labridae (wrasses)	*Halichoeres nigrescens* (bubblefin wrasse)	31
Blenniidae (blennies)	*Salarias fasciatus* (banded blenny)	1
Gobiidae (gobies)	*Bathygobius fuscus* (dusky frillgoby)	6
	Istigobius decoratus (decorated sandgoby)	4
Total no. of families = 9	**Total no. of species = 12**	**108**

* The taxonomic order of the families in this table follows Yearsley, Last and Hoese (2006).

At South Maret Island, 58 species of fishes from 24 families were collected from five intertidal pools, ranging in approximate area between 9 m^2 and 68 m^2 and in depth between 0.3 m and 0.6 m, during a spring low tide in March 2007 (Figure 8-2, Table 8-15). The pools ranged from upper intertidal pools dominated by *Sargassum* species to mid-to-lower intertidal pools with rock, coarse sand and other macroalgae. The most abundant fish species were *Halichoeres nigrescens* (family Labridae), *Ostorhinchus angustatus* (family Apogonidae) and *Pomacentrus milleri* (family Pomacentridae), which occurred in large numbers in all five pools.

Table 8-15: Numbers of individuals of each fish species collected from five intertidal pools on the western coast of South Maret Island

Family*	Species	Number of individuals					
		Pool 1	Pool 2	Pool 3	Pool 4	Pool 5	Total
Muraenidae (moray eels)	*Gymnothorax zonipectis* (bartail moray)	–	1	–	–	–	**1**
Ophichthidae (snake eels)	*Pisodonophis cancrivorus* (burrowing snake eel)	1	–	–	1	–	**2**
Synodontidae (lizardfishes)	*Synodus variegatus* (variegated lizardfish)	–	3	–	–	–	**3**
Ariidae (forktail catfishes)	*Arius* sp. (unidentified catfish)	5	–	–	–	–	**5**
Plotosidae (eeltail catfishes)	*Paraplotosus* sp. (unidentified catfish)	–	–	2	–	2	**4**
Batrachoididae (frogfishes)	*Batrachomoeus dahli* (Dahl's frogfish)	–	–	–	1	1	**2**
Ophidiidae (cusk eels)	*Ophidion muraenolepis* (blackedge cusk)	3	–	–	–	–	**3**
Syngnathidae (pipefishes)	*Choeroichthys brachysoma* (Pacific shortbody pipefish)	–	1	–	–	–	**1**
	Trachyrhamphus longirostris (straightstick pipefish)	–	1	–	–	–	**1**
Scorpaenidae (scorpionfishes)	*Scorpaenopsis venosa* (raggy scorpionfish)	3	1	–	2	3	**9**
Serranidae (rockcods)	*Cephalopholis boenak* (brownbarred rockcod)	–	3	–	–	–	**3**
	Epinephelus coioides (goldspotted rockcod)	1	–	–	–	–	**1**

Table 8-15: Numbers of individuals of each fish species collected from five intertidal pools on the western coast of South Maret Island (continued)

Family*	Species	Number of individuals					
		Pool 1	Pool 2	Pool 3	Pool 4	Pool 5	Total
Serranidae (rockcods) (cont.)	*Epinephelus fasciatus* (blacktip rockcod)	1	3	3	1	5	**13**
	Epinephelus merra (birdwire rockcod)	2	–	–	1	–	**3**
	Epinephelus quoyanus (longfin rockcod)	2	3	–	–	–	**5**
Apogonidae (cardinalfishes)	*Apogon doederleini* (fourline cardinalfish)	–	2	–	–	–	**2**
	Apogon pallidofasciatus (palestriped cardinalfish)	2	–	–	–	–	**2**
	Apogonichthyoides timorensis (Timor cardinalfish)	2	–	–	–	–	**2**
	Fowleria aurita (crosseye cardinalfish)	–	–	2	–	1	**3**
	Fowleria variegata (variegated cardinalfish)	11	4	–	–	–	**15**
	Ostorhinchus angustatus (broadstriped cardinalfish)	14	7	24	9	27	**81**
Lutjanidae (tropical snappers)	*Lutjanus carponotatus* (stripey snapper)	–	1	–	–	–	**1**
Nemipteridae (threadfin breams)	*Scaevius milii* (coral monocle bream)	–	2	–	–	–	**2**
	Scolopsis bilineata (two-line monocle bream)	–	1	–	–	–	**1**
Lethrinidae (emperors)	*Lethrinus* sp. (unidentified emperor)	–	3	–	–	–	**3**
Mullidae (goatfishes)	*Parupeneus indicus* (yellowspot goatfish)	2	–	–	–	–	**2**
Chaetodontidae (butterflyfishes)	*Chelmon marginalis* (margined coralfish)	–	1	–	–	–	**1**
Pomacentridae (damselfishes)	*Abudefduf septemfasciatus* (banded sergeant)	1	2	–	–	–	**3**
	Pomacentrus coelestis (neon damsel)	–	12	–	–	–	**12**
	Pomacentrus milleri (Miller's damsel)	9	26	7	10	30	**82**
	Stegastes lividus (bluntsnout gregory)	21	–	–	–	–	**21**
	Stegastes nigricans (dusky gregory)	5	–	–	–	–	**5**
Labridae (wrasses)	*Choerodon cyanodus* (blue tuskfish)	–	–	1	–	–	**1**
	Halichoeres biocellatus (false-eyed wrasse)	6	–	–	–	–	**6**
	Halichoeres margaritaceus (pearly wrasse)	–	–	37	1	–	**38**
	Halichoeres marginatus (dusky wrasse)	3	–	–	–	–	**3**
	Halichoeres nebulosus (cloud wrasse)	–	–	3	3	8	**14**

Table 8-15: Numbers of individuals of each fish species collected from five intertidal pools on the western coast of South Maret Island (continued)

Family*	Species	Number of individuals					
		Pool 1	Pool 2	Pool 3	Pool 4	Pool 5	Total
Labridae (wrasses) (cont.)	*Halichoeres nigrescens* (bubblefin wrasse)	5	13	5	7	38	**68**
	Labroides dimidiatus (common cleanerfish)	–	2	–	–	–	**2**
	Leptojulis cyanopleura (shoulderspot wrasse)	6	–	–	–	–	**6**
	Leptojulis sp. (unidentified wrasse)	–	–	18	–	–	**18**
	Macropharyngodon ornatus (ornate leopard wrasse)	–	3	–	–	2	**5**
	Pteragogus flagellifer (cocktail wrasse)	–	1	1	4	14	**20**
	Stethojulis bandanensis (redspot wrasse)	–	2	3	–	2	**7**
	Stethojulis interrupta (brokenline wrasse)	4	11	13	6	18	**52**
	Stethojulis strigiventer (silverstreak wrasse)	2	–	–	–	–	**2**
Blenniidae (blennies)	*Blenniella periophthalmus* (bluestreaked rockskipper)	6	–	–	–	–	**6**
	Cirripectes filamentosus (filamentous blenny)	–	1	–	–	–	**1**
Blenniidae (blennies)	*Salarias fasciatus* (banded blenny)	–	4	–	1	2	**7**
	Salarias sexfilum (Spalding's blenny)	4	–	–	–	–	**4**
Notograptidae (bearded eel blennies)	*Notograptus guttatus* (spotted eel blenny)	–	3	–	–	–	**3**
Gobiidae (gobies)	*Bathygobius fuscus* (dusky frillgoby)	–	–	–	–	2	**2**
	Glossogobius circumspectus (mangrove flathead goby)	–	–	–	1	–	**1**
	Istigobius decoratus (decorated sandgoby)	6	–	–	–	–	**6**
Acanthuridae (surgeonfishes)	*Acanthurus grammoptilus* (inshore surgeonfish)	1	–	–	–	–	**1**
Siganidae (rabbitfishes)	*Siganus canaliculatus* (whitespotted rabbitfish)	1	6	–	–	–	**7**
	Siganus virgatus (doublebar rabbitfish)	–	8	–	–	–	**8**
Soleidae (soles)	*Zebrias craticulus* (wicker-work sole)	–	1	–	–	–	**1**
Total no. of families = 24	**Total no. of species = 58**	**129**	**132**	**119**	**48**	**155**	**583**

* The taxonomic order of the families in this table follows Yearsley, Last and Hoese (2006).

✓ = species recorded.

– = species not found.

8 MARINE ECOLOGY

Another labrid, *Stethojulis interrupta*, was also abundant with 52 individuals recovered across the five pools, while the serranid *Epinephelus fasciatus* was less common with only 13 individuals collected across the pools.

The family Syngnathidae was represented by two species, *Trachyrhamphus longirostris* and *Choeroichthys brachysoma*, with one specimen each, both collected from Pool 2. *Choerodon cyanodus* (family Labridae) and *Cirripectes filamentosus* (family Blenniidae) were also seemingly rare with only one individual of each species recorded.

The Albert Islands

The Albert Islands group is made up of several small basalt islands and islets, mostly linked by a limestone platform reef. The group is about 4 km long with a north–south alignment, lying about 7 km west of Berthier Island. The largest island is unofficially known as Albert Island and it is located towards the northern end of the island complex, connected by the reef to several smaller islands, including Suffren Island at the southern end.

The island complex has an atoll-like structure with reefs on the western and eastern sides enclosing a subtidal central lagoon that is up to 400 m wide and generally deeper than 1.5 m at low tide. The reef complex is bordered on both sides by ocean with no terrestrial shore, other than the islands at either end. As a consequence, it is structured differently from other west-facing reefs in the area. The reef is assumed to be of Holocene coralgal origin and its present form is the result of coalescence of fringing reefs growing around the rocky shores of the islands or on submerged banks.

The reef on the western side is exposed to moderate ocean-swell energy. It is continuous, with a platform ranging between 30 m and 100 m wide that is emergent at low tide. The eastern rim of the reef was not examined closely. This side of the reef complex is less affected by the prevailing swell but is exposed to easterly winds and moderate wave action during the winter months.

Reef walks were conducted at three locations in the Albert Islands group in April 2007. These locations are shown in Figure 8-3 and are described in Table 8-16.

Table 8-16: Intertidal habitat descriptions for the three sites at the Albert Islands group surveyed in April 2007

Site	Location	Description
1	South and south-east of Albert Island	The sandflats at this site were on the western side of a high sand spit at the southern end of the largest island of the group, Albert Island, with coarse sand and a sparse infauna. The reef platform was immediately north of an emergent basalt outcrop with a well-developed algal turf and shallow pools but very few live corals. The reef front was slightly sloping and approximately 50 m wide. The inner margin of this subzone abutted on an emergent basalt outcrop. The reef edge had many drainage channels and gutters and was rough and irregular but distinct, dropping off abruptly into a steep sublittoral fore-reef subzone.
2	North-western side of an islet north-north-west of Albert Island	The islet has a basalt base and a laterite cap, the shore being mostly basalt but with laterite boulders in some places. There was a narrow fringing reef and lagoon, terminating at the end of the islet but widening to the south along the western side of Albert Island. The lagoon was less than 0.5 m deep at low tide and about 100 m wide at the study site, widening to the south. The reef front was narrow (approximately 70 m wide), sloping and cavernous with a poorly developed reef crest. The outer edge was irregular and rough, dropping off abruptly into the subtidal subzone that was deeply dissected by drainage gutters, some of which were tunnel-like. These originated in deep pools 10 m to 20 m from the edge, exiting below low-water mark on the reef front. The inner edge was less distinct and sloped into the lagoon. The invertebrate fauna in the lagoon was not examined because of a rapidly incoming tide.
3	Reef platform and lagoon north-east of Suffren Island	This reef platform and lagoon is about 30 m wide and lies immediately adjacent to the rocky shore at the north-eastern side of a small island north-east of Suffren Island. There was a platform of hard limestone with a prominent boulder subzone of large coral blocks, with sandy pools and algal turf between the boulders. The lagoon was less than 1 m deep at low tide and about 150 m wide at the study site with a bed of sand and rubble over a rock pavement and a prolific growth of long-stemmed *Sargassum.* The reef front was slightly sloping, approximately 30 m wide and moderately dissected by drainage gutters. The reef crest and boulder subzone were lacking and the reef edge was indistinct and irregular with a sloping subtidal fore reef. The inner margin of this subzone sloped into the lagoon with no distinct inner edge.

Intertidal invertebrate and algal assemblages

Four categories of intertidal zone were distinguished at the Albert Islands study sites: upper littoral beaches, upper littoral rocky shores, midlittoral reef flats, and lower littoral reef fronts. The molluscan fauna in all zones was similar to that found at the Maret Islands.

- *Upper littoral beach assemblages*

Upper littoral sandflats were only found at Site 1. A colony of a gastropod, *Oliva* sp. cf. *australis*, was present, along with the cone *Conus coronatus*, the olivid *Alocospira rosea* and the naticids *Natica gualteriana* and *Natica pseustes*. No living bivalves were observed. There was no evidence of burrowing polychaete or echiuroid worms.

- *Upper littoral rocky-shore assemblages*

The upper littoral subzone at Site 2 had a thin veneer of filamentous green algae and few invertebrates.

The lower ledges had patches of the rock oyster *Saccostrea cucullata*, as well as *Nerita undata*, *Morula granulata* and the barnacle *Amphibalanus amphitrite*. The lowest ledges and rocks of the subzone were occupied by *Turbo cinereus*, *Monodonta labio*, *Thais aculeata* and individuals of the genus *Acanthopleura*. The pools and narrow rock platform at the base of the rocks along the inner margin of the lagoon had a prolific growth of *Sargassum* species (Figure 8-38).

Figure 8-38: An extensive sward of *Sargassum* species in the midlittoral lagoon at Site 2, off the north-west side of an islet north of Albert Island

- *Midlittoral reef-flat assemblages*

On the reef platform at Site 1 south of Albert Island, *Holothuria atra* was very common but no other echinoderms were observed. Surface molluscs were sparse: those seen included *Conus ebraeus*, *Conus mustelinus*, *Lambis lambis*, *Tectus pyramis* and *Cerithium echinatum.* The cones *Conus striatus*, *Conus terebra* and *Conus textile* were found under stones.

At Site 3 north-east of Suffren Island, the reef-platform boulders were heavily bored by the barnacle *Lithotrya valentiana* and the bivalves *Lithophaga obesa*, *Lithophaga teres*, *Lithophaga malaccana*, *Botula fusca* and *Gastrochaena gigantea.* Live *Goniastrea* colonies were riddled with the boreholes of the bivalve *Lithophaga simplex*. Flooding tide conditions did not permit observation of other invertebrates.

- *Lower littoral reef-front assemblages*

The reef front at Site 1 was made up of friable crustose algal material (most likely *Hydrolithon onkodes*) and did not have a hard surface. There were a few dead coral boulders 20 m or so from the reef edge but no distinct reef-crest subzone.

The most conspicuous surface molluscs were *Tridacna maxima*, *Pinctada margaritifera* and a cemented clam species of the genus *Chama*. Surface invertebrates other than corals were sparse. Boulders had some barnacles, including the rock-boring *Lithotrya valentiana* and the gastropod predators *Thais alouina* and *Morula spinosa*. The boulders were also heavily bored by the mussel *Lithophaga obesa*, identified by its characteristic burrows.

The reef surface at Site 2 between the corals consisted of friable crustose algae with a cover of low algal turf. The surface was heavily bored by the barnacle *Lithotrya valentiana* and the bivalves *Lithophaga obesa*, *Lithophaga teres* and *Gastrochaena gigantea.* The chiton *Cryptoplax larvaeformis* was common in crevices and spaces within the matrix. Other than corals, surface invertebrates were lacking. The reef flat also had a lagoon less than 1 m deep at low tide and about 150 m wide at the study site with a bed of sand and rubble over a rock pavement and prolific growth of long-stemmed *Sargassum*. Few corals or other invertebrates other than *Holothuria atra* and the bivalve *Pinna deltodes* were seen.

The lower littoral reef front at Site 3 north of Suffren Island had a surface of crustose algae with a low algal turf between the corals and was heavily bored by the bivalves *Lithophaga obesa* and *Gastrochaena gigantea.*

The predatory muricids *Thais alouina* and *Morula spinosa* were present, but rare.

Coral assemblages

The coral community on the outer reef front along the west coast of the reef near Albert Island was generally dominated by large domal faviids, with approximately 20% cover by live colonies. Large rocky or sandy pools contained many coral species and *Acropora* species were particularly dominant. The narrow midlittoral flat supported a sparse coral assemblage dominated by encrusting species, with a live coral cover of approximately 5%.

At the southern end of the island group, in the vicinity of Suffren Island, there was a rich assemblage of corals, especially in a series of large shallow pools that contained diverse corals with approximately 70% live cover. Many scleractinian families were represented and no single genus or morphological type was dominant. *Scolymia australis*, a rare species, was recorded in these pools. The staghorn reef, while heavily dominated (90%) by arborescent *Acropora aspera* and *Acropora pulchra*, had a small, diverse assemblage of corals within and beneath the *Acropora*. These included fungiid and agariciid corals.

The reef front on the eastern side of Suffren Island included a ragged spur and groove system supporting arborescent *Acropora* beds that contained at least 23 species of coral. The outer reef flat supported a diverse coral assemblage dominated particularly by *Acropora pulchra* and *Acropora nasuta*. Some of the acroporids on this reef were not recorded on other reefs in the archipelago during the study; these included *Acropora striata*, which was common on this outer reef flat, and *Acropora microclados*. Fungiids and faviids, including large colonies of *Goniastrea retiformis* and various *Favia* species, were also abundant at this locality.

Photograph courtesy of David Abdo

Figure 8-39: A reef-building stony coral of the genus *Favia* (family Faviidae)

The East Montalivet Islands

The islands of the East Montalivet Islands group lie around three rock types that were exposed in places around the shores of the islands in this group: the unconformities of the underlying King Leopold Sandstone, the columnar basalt of the Carson Volcanics and remnants of the overlying Tertiary laterite. Most of the shores are basalt, although at a few locations boulders had fallen from the laterite cap. A small islet of King Leopold Sandstone is emergent on the intertidal flats between Patricia and East Montalivet islands. The long headland forming the north-western corner of East Montalivet Island is also composed of King Leopold Sandstone.

Three sites around Patricia Island and Don Island in the East Montalivet Islands group were examined during reef walks (Figure 8-4, Table 8-17), but not to the same level of detail as the intertidal sites at the Maret Islands. Logistic and time constraints meant that different parts of the littoral zone were examined at different sites. Rocky-shore communities were examined only at one locality and narrow fringing reefs on the eastern and southern coasts were not examined. No reef walk was carried out immediately adjacent to East Montalivet Island itself, but the reef platforms of the islands are connected.

Fringing reefs, presumed to be coralgal structures of Holocene age, were well developed on the north-western and north-eastern shores of the island group.

The intertidal platform and fringing reefs of the islands had many features that differed from those of other islands in the Bonaparte Archipelago. There were, for example, upper midlittoral mud- and sandflats between East Montalivet, Don and Patricia islands which connected these islands at low tide.

Offshore the north-eastern corner of East Montalivet Island and south of Patricia Island (Site 2) there was a wide fringing reef with a large central lagoon and a distinctly terraced midlittoral platform. The western fringing reef had an orientation similar to that of the reefs of the Maret Islands but with lower coral diversity and abundance on the reef front.

At the northern end of Patricia Island (Site 1) there was a marked change in the character of the fringing reef and its biota. There was no central lagoon and the reef front graded directly across a narrow midlittoral platform to abut on the rocky shore. The reef front supported a rich coral community dominated by *Acropora.* A variety of corals and other invertebrates occurred in shallow pools on the inner part of the midlittoral platform.

Along the south-eastern coast of Patricia Island and the north coast of Don Island (Site 3) there was a narrow fringing reef with very little midlittoral platform and a narrow lagoon with diverse corals abutting on the rocky shore. In this sector the reef front was dominated by diverse massive and encrusting corals and there were few *Acropora* species.

Intertidal invertebrate and algal assemblages

The rocky-shore community of the East Montalivet Islands group was examined at one site on the eastern side of Don Island, where the rocks are basalt and there is a substantial upper littoral invertebrate fauna assemblage. This assemblage was made up of the same species found in equivalent habitats at the Maret Islands.

Table 8-17: Intertidal habitat descriptions for the three sites at the East Montalivet Islands group surveyed in March 2007

Site	Location	Description
1	North-western side of Patricia Island	Site 1 is a north-west-facing, high-energy fringing reef around the north-western side of Patricia Island. There was little slope on the reef front and no reef crest, the reef front merging with a low midlittoral reef flat with coral-lined pools that ran up to the base of the rocky shore on the northern headland of Patricia Island. There was no lagoon, but approximately 100 m to the south-west this site met the northern end of the lagoon of Site 2.
2	Reef flat south of Patricia Island	On the outer reef there was a ragged but distinct reef edge with drainage gutters and subsurface tunnels. No slope was perceptible on the reef front and there was no reef crest or boulder subzone, except at the northern end (adjacent to Site 1) where there were a few large coral blocks 10 to 20 m behind the reef edge. For most of its length, the reef front graded directly into the central lagoon. The lagoon, estimated to be 200 m wide at the centre and 1–2 m deep at low tide, extended along the whole length of the reef from Patricia Island to the north-east corner of East Montalivet Island. Along the inner margin of the lagoon, there was a pronounced terrace, like a second “reef edge”, approximately 0.5–1.0 m high, trending roughly north-east to south-west. It had a ragged edge dissected by numerous drainage channels and was composed of hard limestone.
3	Northern side of Don Island to the eastern side of Patricia Island	At this site the fringing reef was narrow and separated from the basalt rocky shore by a band of coral rubble and a shallow lagoon and sandy gutters. The narrow lower littoral reef front had a ragged, dissected edge. The lagoon was less than 0.5 m deep at low tide and contained mainly dead *Acropora* (in situ) and rubble. This site was not closely investigated because of an incoming tide and poor light.

- *Patricia Island*

At Site 1 directly north of Patricia Island, the reef bore a multi-species *Acropora* community fronting a basalt rocky shore (Figure 8-40).

Live coral cover was high, at approximately 80%. *Acropora* diversity was high, with at least 20 species observed; small tabular and digitate forms were the most common. Scattered faviids, *Montipora* and *Merulina* were among the *Acropora*. There were few molluscs and other invertebrates but a comprehensive search was not made because of an incoming tide.

The reef-front surface at Site 1 consisted of a crust of calcareous algae with very little algal turf and few corals. No echinoderms were seen and the only predatory gastropod was *Vasum ceramicum*, two live specimens of which were found. Unusually there were apparently no *Tridacna maxima*.

The surface crust was friable underneath, heavily bio-eroded by sponges, sipunculids, the barnacle *Lithotrya* and the lithophagid mussels *Lithophaga teres* and *Lithophaga obesa*. In the cavities of the rock mass were a variety of invertebrates, including sponges, ascidians, bryozoans, polychaetes, the bivalves *Malvufundus regula* and *Barbatia amygdalumtostum*, the chiton *Cryptoplax larvaeformis* and the gastropod *Trivia oryza*.

- *Don Island*

The lagoon at Site 2 was examined near its centre where it had a rocky bed with a thin sand veneer, some *Sargassum*, and many areas of dead coral. There were few live corals and few surface-dwelling invertebrates. The only conspicuous molluscs found were *Lambis lambis* and *Tridacna squamosa*.

The lagoon at Site 3 contained mainly in situ dead *Acropora* and rubble. The echinoid *Diadema* was common and the clam *Tridacna squamosa* nestled in the live and dead *Acropora* thickets.

Coral assemblages

At the East Montalivet Islands group, corals were investigated at Patricia Island and Walker Island. Descriptions for this diverse coral community are presented below.

The inner reef flats at Walker Island were commonly dominated by branching *Acropora*, *Porites* microatolls, *Favites pentagona* and the blue octocoral *Heliopora coerulea.* Live coral cover was approximately 20%. The outer reef flats around Walker Island were dominated by *Favites abdita* and *Goniastrea retiformis*. Overall coral cover in this area ranged between 55% and 70%. Three species of *Montipora* that were absent from the inner reef flat were recorded on the outer reef flat.

Species encountered in low numbers around Walker Island included *Leptoria phrygia*, *Hydnophora microconos*, *Psammocora contigua*, *Euphyllia glabrescens*, *Stylocoeniella guentheri*, *Pavona varians*, *Turbinaria frondens* and *Podabacia crustacea*.

Figure 8-40: The *Acropora* fringing reef on the midlittoral reef platform at Site 1 at the north end of Patricia Island

Parts of the shore at Walker Island consisted of low rocky shelves supporting a rich assemblage of encrusting and massive faviids. *Oulastrea crispata* was present on the rocky faces of these shelves among abundant faviid recruits. The faviid *Platygyra acuta* (Figure 8-41) was recorded at Walker Island, the first record of this species in Australia; it was also found at the Maret Islands and at the Berthier Islands group. The widespread but usually subtidal genera *Pectinia* and *Pachyseris* were present in small numbers in these intertidal zones.

The sandy and rocky shore of Patricia Island is fringed with a reef flat approximately 200 m in width, made up of an inner midlittoral reef flat, a mid-reef flat, and an outer reef front. The inner midlittoral reef flat is a mixture of sandy channels and consolidated low platforms, with a low coral cover (less than 1%) and no obviously dominant species. The middle part of the midlittoral reef flat is an elevated platform that was dominated by faviids, with a low coral cover (approximately 10%) of small encrusting faviids and digitate acroporids. The narrow outer reef front and fore-reef slope supported a diverse coral assemblage, with a high cover of live coral (more than 60%) dominated by corymbose and digitate acroporids as well as by massive and encrusting faviids.

Photograph courtesy of Zoe Richards (Western Australian Museum)

Figure 8-41: The faviid stony coral *Platygyra acuta*, the first record of this species in Australia, was found at the Maret, Montalivet and Berthier island groups

The reef front was heavily dominated by arborescent, corymbose and tabular acroporids. Some of the *Acropora* species recorded at Patricia Island, including *Acropora abrotanoides*, *Acropora divaricata*, *Acropora loripes* and *Acropora selago*, were not found elsewhere in the East Montalivet Islands group.

Fish assemblages

At Patricia Island in the East Montalivet Islands group, 31 species of fishes from 14 families were collected from three intertidal pools, approximately 0.5 m deep and ranging in area from 6 m^2 to 15 m^2, during a spring low tide in March 2007 (Figure 8-4, Table 8-18). The three pools were in the midlittoral zone and contained a low coverage of corals and macroalgae. As with the suite of fishes caught at West Montalivet Island, the most abundant fish species were *Halichoeres nebulosus* and *Stethojulis interrupta* (family Labridae) and *Pomacentrus coelestis* and *Pomacentrus milleri* (family Pomacentridae). Fishes of the family Serranidae were the least represented among the collections with only one individual of each of two species sampled (*Epinephelus fasciatus* and *Epinephelus quoyanus*). One member of the family Syngnathidae (*Micrognathus micronotopterus*) was recorded.

Table 8-18: Numbers of individuals of each fish species collected from three intertidal pools on the west coast of Patricia Island

Family*	Species	Number of individuals			
		Pool 1	Pool 2	Pool 3	Total
Synodontidae (lizardfishes)	*Synodus variegatus* (variegated lizardfish)	–	–	1	**1**
Plotosidae (eeltail catfishes)	*Plotosus lineatus* (striped catfish)	2	–	–	**2**
	Paraplotosus sp. (unidentified catfish)	–	1	1	**2**
Batrachoididae (frogfishes)	*Apogon coccineus* (ruby cardinalfish)	1	–	–	**1**
	Batrachomoeus trispinosus (threespined frogfish)	–	1	–	**1**
Syngnathidae (pipefishes)	*Micrognathus micronotopterus* (tidepool pipefish)	–	–	1	**1**
Serranidae (rockcods)	*Cephalopholis boenak* (brownbarred rockcod)	1	1	2	**4**
	Epinephelus fasciatus (blacktip rockcod)	1	–	–	**1**
	Epinephelus quoyanus (longfin rockcod)	1	–	–	**1**
	Plectropomus maculatus (barcheek coral trout)	1	–	–	**1**
Apogonidae (cardinalfishes)	*Fowleria aurita* (crosseye cardinalfish)	3	1	–	**4**
	Ostorhinchus angustatus (broadstriped cardinalfish)	9	1	–	**10**
Nemipteridae (threadfin breams)	*Scaevius milii* (coral monocle bream)	1	–	–	**1**
Mullidae (goatfishes)	*Parupeneus indicus* (yellowspot goatfish)	2	–	–	**2**
Pomacentridae (damselfishes)	*Abudefduf septemfasciatus* (banded sergeant)	1	3	2	**6**
	Pomacentrus coelestis (neon damsel)	1	6	4	**11**
	Pomacentrus milleri (Miller's damsel)	5	6	–	**11**

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Table 8-18: Numbers of individuals of each fish species collected from three intertidal pools on the west coast of Patricia Island (continued)

Family*	Species	Number of individuals			
		Pool 1	Pool 2	Pool 3	Total
Labridae (wrasses)	*Choerodon cyanodus* (blue tuskfish)	–	1	–	**1**
	Halichoeres margaritaceus (pearly wrasse)	–	1	1	**2**
	Halichoeres nebulosus (cloud wrasse)	4	4	5	**13**
	Halichoeres nigrescens (bubblefin wrasse)	–	1	5	**6**
	Leptojulis cyanopleura (shoulderspot wrasse)	7	3	–	**10**
	Pteragogus flagellifer (cocktail wrasse)	5	–	–	**5**
	Stethojulis interrupta (brokenline wrasse)	7	1	5	**13**
Blenniidae (blennies)	*Blenniella periophthalmus* (bluestreaked rockskipper)	–	1	1	**2**
	Cirripectes filamentosus (filamentous blenny)	–	3	–	**3**
	Salarias fasciatus (banded blenny)	3	1	2	**6**
Gobiidae (gobies)	*Istigobius decoratus* (decorated sandgoby)	–	1	–	**1**
	Priolepis semidoliata (halfbarred reefgoby)	1	–	1	**2**
Acanthuridae (surgeonfishes)	*Acanthurus dussumieri* (pencil surgeonfish)	1	–	–	**1**
Siganidae (rabbitfishes)	*Siganus virgatus* (doublebar rabbitfish)	1	1	–	**2**
Total no. of families = 14	**Total no. of species = 31**	**58**	**38**	**31**	**127**

* The taxonomic order of the families in this table follows Yearsley, Last and Hoese (2006).

West Montalivet Island

West Montalivet Island has a base of King Leopold Sandstone with a central cap of Tertiary laterite. Its rocky shores comprise bedded and strongly jointed sandstone–quartzite, with a fringing reef and a wide Holocene limestone rock platform along the western and northern sides. An area on the north-western corner was examined during morning and late-afternoon low tides on 18 March 2007 (Figure 8-5).

At the study site, there is a wide fringing reef with a complex structure. The outer reef edge is of irregular outline with major embayments. The lower littoral reef front varied from a few metres wide at the northern end to approximately 150 m wide in the south of the study area. It had little if any slope, that is, it was not ramped, and was separated by a shallow gutter from a second terraced edge, 30 cm high, marking the beginning of the midlittoral reef flat.

The surface of the reef front near the edge was composed of crustose calcareous algae with little algal turf.

A rocky outcrop was visible on the reef edge south of the study area, presumed to be composed of sandstone. The reef crest was poorly defined, although there were a few small coral boulders representing a narrow boulder subzone.

The boulders were heavily bored by bivalves and barnacles of the same species as at other localities. There were also many shallow pools (more than 30 cm deep) with small loose stones, a variety of scleractinian and soft corals, and a moderately diverse cryptic fauna of molluscs and other invertebrates.

The wide midlittoral platform had little relief and was covered in a sandy, matted algal turf. Along the inner margin of the platform, there was a narrow, sandy lagoon that was, in places, almost filled with branching *Acropora* and other corals.

The adjacent upper littoral rocky-shore fauna was typical of the equivalent subzone encountered on the shores of the Maret Islands, even though the geology was sandstone rather than basalt or laterite.

Intertidal invertebrate and algal assemblages

- *Upper littoral rocky shore*

The upper littoral rocky shore is composed of blocky sandstone–quartzite with strong jointing cracks and weathered surfaces; during the survey it had the appearance of having been subjected recently to heavy scouring. Barnacles and limpets were present (Figure 8-42). The rocky-shore invertebrate community was typical of the bioregion, but patchy.

Figure 8-42: Barnacles and limpets on the upper littoral rocky shore at West Montalivet Island

- *Midlittoral lagoon*

Along the inner margin of the platform in the inner part of the midlittoral reef flat there was a narrow *Acropora*-filled lagoon or moat.

- *Midlittoral reef flat*

The midlittoral reef-flat pavement has little relief and is covered with a sandy, matted algal turf and zoanthid mats. Macroalgae were diverse and abundant and included species of the genera *Caulerpa*, *Halimeda*, *Sargassum*, *Ulva*, *Padina* and *Turbinaria*, numerous crustose coralline algae and small red and brown algae.

A cemented bivalve of the genus *Chama* was common on areas of exposed pavement, while *Tridacna maxima* was present but not common. The predatory gastropods *Conus coronatus*, *Conus ebraeus* and *Conus mustelinus* were present but not abundant. Present on the pavement surface in low numbers were the herbivorous gastropods *Angaria delphinus*, *Astralium rotularium* and *Tectus pyramis*; the grazing and detritus-feeding gastropods *Cerithium echinatum* and *Cerithium novaehollandiae*; and the cowrie *Cypraea moneta*.

Under stones and slabs there was a sparse cryptic fauna. *Cypraea eglantina*, *Conus striatus*, *Conus terebra* and *Conus textile* were present but uncommon. One specimen of *Conus geographus* was recorded under a stone.

The holothurians *Stichopus chloronotus*, *Holothuria atra* and an unidentified synaptid were present in shallow pools on the platform surface; *Stichopus chloronotus* was particularly abundant. *Holothuria hilla*, *Holothuria impatiens* and four species of brittlestar were found under stones. Occasionally, specimens of *Diadema* were found in pools.

There were numerous shallow pools (less than 20 cm deep) in which leafy macroalgae (mainly *Sargassum* species) were dominant, with a moderate diversity of corals including *Favia*, *Montipora*, *Hydnophora*, *Montastraea*, *Psammocora*, *Platygyra*, *Acropora*, *Pocillopora*, *Echinopora*, *Oxypora*, *Symphyllia*, *Coeloseris*, *Leptoria*, *Porites*, *Lobophyllia*, *Astreopora* and the octocoral *Heliopora coerulea*. Soft corals of the genus *Sinularia* were very common.

- *Midlittoral reef crest*

Between the boulders, the reef pavement had a veneer of shallow sand and rubble and a well-developed algal turf. *Halimeda* was abundant about 30 m shoreward from the reef edge.

There was a much greater variety of invertebrates here compared with the reef platform in Subzone 3. The herbivorous gastropods *Lambis lambis* and *Tectus pyramis* and the clam *Tridacna maxima* were all common on the reef surface. Large numbers of the holothurian *Stichopus chloronotus* were present with up to five individuals per square metre. *Holothuria atra* was also present but was much less common. A moderate assemblage of cryptic invertebrates was present under stones and *Acropora* slabs, including *Haliotis asinina*, *Haliotis squamata*, *Conus terebra*, *Malvufundus regula* and a *Spondylus* species.

The boulders of this subzone were heavily bored by sipunculids, the barnacle *Lithotrya valentiana*, three lithophagid bivalves, *Lithophaga obesa*, *Lithophaga teres* and *Lithophaga malaccana*, and a bivalve of the genus *Gastrochaena*. A few specimens of the barnacle *Amphibalanus amphitrite* were present on the rock surfaces on which the muricid gastropod *Thais alouina* was feeding. Another predatory muricid *Morula fiscella* was also present.

- *Lower littoral seaward ramp*

The pavement surface was largely covered by crustose algae and corals while algal turf was sparse. Other than corals, few invertebrates were present on the surface. The only predatory gastropod seen was *Conus mustelinus*, but it was uncommon.

No observations of surface herbivores or of suspension-feeding molluscs were made.

Below the hardened crust of the surface not covered by corals, the pavement was spongy and friable, riddled with spaces occupied by the browsing chiton *Cryptoplax larvaeformis*, as well as by *Trivia oryza* and a variety of bryozoans, sponges and ascidians. The byssally attached bivalves *Barbatia amygdalumtostum* and *Malvufundus regula* were also common.

Harder rock and dead coral were heavily bored by sponges, sipunculids and the barnacle *Lithotrya valentiana*. There were also occasional individuals of the boring bivalves *Lithophaga teres*, *Lithophaga obesa* and *Lithophaga malaccana* and a *Gastrochaena* species.

Coral assemblages

The wide reef flat on the north-western side of West Montalivet Island consisted of an inner flat, a mid-flat, and an outer reef flat and crest. The inner flat had a coral cover of approximately 20% and supported scattered large (4–5 m) *Porites* microatolls, branching *Acropora*, and several small elevated reef platforms. The elevated platforms were dominated by large colonies of massive corals and small, encrusting faviids. Digitate acroporids were present around the microatolls and included the uncommon *Acropora papillare*. The mid-flat was composed of low-profile limestone with very little (approximately 1%) living coral cover dominated by a few hardy species of faviids. A pronounced lower platform was present in the outer flat which had a relatively high (approximately 50%) cover of live corals and a large number of arborescent and corymbose acroporids, massive and encrusting faviids, and a variety of subdominant coral taxa.

Fish assemblages

At West Montalivet Island, 27 species of fishes from 12 families were collected from an intertidal pool, approximately 14 m^2 in area and 0.6 m deep, during a spring low tide in March 2007 (Figure 8-5, Table 8-19). The pool substrate consisted of rock, coral rubble and sand with macroalgae. The most abundant fish species were *Halichoeres nebulosus* and *Stethojulis interrupta* (family Labridae) and *Pomacentrus coelestis* and *Pomacentrus milleri* (family Pomacentridae), which is similar to the assemblage found at Patricia Island in the East Montalivet Islands group.

Other than from these two families, a proportionate decrease in numbers of individuals was noted in the other families, with *Epinephelus fasciatus* (family Serranidae), *Scorpaenopsis venosa* (family Scorpaenidae) and *Istigobius decoratus* (family Gobiidae) being the least abundant.

Table 8-19: Numbers of individuals of each fish species collected from an intertidal pool at the north-west corner of West Montalivet Island

Family*	Species	Number of individuals
Muraenidae (moray eels)	*Echidna nebulosa* (starry moray)	1
Ophichthidae (snake eels)	*Pisodonophis cancrivorus* (burrowing snake eel)	4
	Pisodonophis sp. A (unidentified snake eel)	2
	Pisodonophis sp. B (unidentified snake eel)	2
Bythitidae (live-bearing cusks)	*Ogilbia* sp. (unidentified brotula)	2
Scorpaenidae (scorpionfishes)	*Scorpaenopsis venosa* (raggy scorpionfish)	1
Serranidae (rockcods)	*Epinephelus fasciatus* (blacktip rockcod)	1
Apogonidae (cardinalfishes)	*Fowleria aurita* (crosseye cardinalfish)	3
	Ostorhinchus angustatus (broadstriped cardinalfish)	11
Lutjanidae (tropical snappers)	*Lutjanus russellii* (Moses's snapper)	2
Nemipteridae (threadfin breams)	*Scaevius milii* (coral monocle bream)	1
Pomacentridae (damselfishes)	*Abudefduf septemfasciatus* (banded sergeant)	4
	Dischistodus fasciatus (yellow-banded damsel)	1
	Pomacentrus coelestis (neon damsel)	42
	Pomacentrus milleri (Miller's damsel)	21
Labridae (wrasses)	*Halichoeres margaritaceus* (pearly wrasse)	2
	Halichoeres nebulosus (cloud wrasse)	34
	Halichoeres nigrescens (bubblefin wrasse)	3
	Leptojulis cyanopleura (shoulderspot wrasse)	5
	Pteragogus flagellifer (cocktail wrasse)	1
	Stethojulis interrupta (brokenline wrasse)	27
Labridae (wrasses)	*Stethojulis strigiventer* (silverstreak wrasse)	2
Blenniidae (blennies)	*Cirripectes filamentosus* (filamentous blenny)	2
	Salarias fasciatus (banded blenny)	14

Table 8-19: Numbers of individuals of each fish species collected from an intertidal pool at the north-west corner of West Montalivet Island (continued)

Family*	Species	Number of individuals
Gobiidae (gobies)	*Callogobius* sp. (unidentified goby)	1
	Istigobius decoratus (decorated sandgoby)	1
	Priolepis semidoliata (halfbarred reefgoby)	2
Total no. of families = 12	**Total no. of species = 27**	**192**

* The taxonomic order of the families in this table follows Yearsley, Last and Hoese (2006).

Coral assemblages at the Berthier Islands group (including Turbin Island)

Coral assemblage surveys were also carried out at the Berthier Islands group and Turbin Island. Fifty-two genera with 187 species of coral were recorded from the western side of Berthier Island and the northern and southern sides of Turbin Island.

Corals at the Berthier Islands group

The reefs on the western side of Berthier Island were similar in appearance and species composition to the reefs on the western sides of the Maret Islands. The coral fauna on the reef front was highly diverse. A number of *Acropora* species with a low-growing semi-hispidose form were seen, including *Acropora polystoma* and *Acropora florida*.

The faviid boulder subzone behind the reef front had an outer border of cone-shaped *Goniastrea retiformis* boulders. The midlittoral reef flat had a mixed faviid assemblage and mussids, merulinids and the digitate acroporid *Acropora brueggemanni* were abundant. The inner part of the midlittoral reef flat was slightly deeper and supported a mixed assemblage, including small *Acropora* thickets and various fungiids.

Corals at Turbin Island

The southern side of Turbin Island supported a coral assemblage similar in species composition and richness to the reef at the western end of South Beach on South Maret Island. The outer reef flat, although dominated by *Acropora*, was also extremely rich in other genera.

The reef front on the northern side of Turbin Island had a well-developed spur and groove system with wide spaces between the tops of the spurs. The spurs were slightly below reef-front height. Their coral cover was dominated by *Acropora* but included many genera not found on the reef flat, including *Lithophyllon*, *Podabacia*, *Diploastrea*, *Echinophyllia*, *Euphyllia*, *Pectinia*, *Alveopora*, the octocoral *Tubipora* and the hydrozoan *Millepora*.

The lower littoral reef front supported a diverse coral assemblage, dominated by large faviid colonies, especially of *Goniastrea retiformis*, *Goniastrea favulus*, *Platygyra pini* and species of *Leptastrea* as well as an agariciid of the genus *Coeloseris*. Small colonies of various faviids, mussids, *Goniopora* and *Porites* were also present, together with encrusting forms and the blue octocoral *Heliopora coerulea*. The inner reef flat was slightly lower and supported a distinctive coral fauna dominated by solitary fungiids and plating *Montipora*, with subdominant species such as *Moseleya latistellata* and various pocilloporids. There were large areas of branching *Acropora* in a nearshore lagoon.

Photograph courtesy of David Abdo

Figure 8-43: A close-up of the tentacles of a large-polyp stony coral of the genus *Euphyllia*

The Browse Island reef complex

The reef around Browse Island is a biohermic[10] structure rising steeply from the outer shelf at a depth of approximately 200 m. It is a flat-topped, oval-shaped, planar platform reef, with its greatest diameter being about 2.2 km. Browse Island itself is an off-centre, triangular, vegetated sandy cay that stands on the reef platform just a few metres above high-water mark; it measures approximately 700 m × 400 m (Figure 8-20).

Reef habitats around Browse Island were found not to be diverse. Rocky shore habitat was represented only by exposed beachrock, and there were no intertidal sandflats. The lagoon habitat was poorly developed, with poor water circulation, and showed evidence of recent infill and high mortality. The reef platform, especially on the western side, was high and conspicuously barren in many places. Only the reef crest and seaward ramp habitats around the edge of the reef were found to support moderately rich assemblages of molluscs. The shallow subtidal zone was narrow, and supported relatively small areas of well-developed coral assemblages.

[10] A bioherm is a body of rock built up by or composed mainly of the remains of sedentary organisms such as corals, molluscs and algae.

The intertidal habitats of the reef platform surrounding Browse Island were examined during the spring low tide from 6 to 13 September 2006 (Table 8-20). Heavy swell limited the extent of this work. Constraints imposed by unsafe landing conditions allowed only four transects across the reef to be accomplished (Figure 8-6).

Teichert and Fairbridge (1948) illustrated the geomorphology of Browse Reef based on aerial photograph interpretation. Field observations made during this study were consistent with their account.

Table 8-20: Intertidal habitat descriptions for the four survey transects at the Browse Island reef complex surveyed in September 2006

Transect	Location	Description
1	North-north-east	This transect was on a bearing of approximately 20° across the reef platform from the high-water mark at the top of the beach slope to the reef edge; it was 440 m long. Five distinct subzones were recognised: 1. a steep beach slope of coarse coral sand and sandy gutter with coral rubble immediately below the break of slope 2. a shallow lagoon less than 1 m deep at low tide with sandy spaces between mostly dead coral 3. a shallow coral-rich lagoon 4. a reef crest with an abundance of loose coral slabs and stones and a few standing coral boulders (less than 1.5 m high); there were some shallow pools and some sand–rubble gutters 5. a reef-front ramp, slightly sloping with a rough surface but few pools, a ragged outer reef edge and no major drainage gutters.
2	East-south-east	This transect was on a bearing of approximately 100° across the reef platform from the break of slope of the beach to the reef edge; it was approximately 450 m long. The eastern end of the southern beachrock is adjacent to (south of) the beginning of the transect. Four distinctive subzones were recognised: 1. a shallow sandy lagoon less than 1 m deep at low tide, beginning immediately below the beach break of slope with coral rubble and low live coral cover (less than 5% 2. a midlittoral reef platform 3. a reef crest with very little elevation and numerous loose coral stones and slabs but no upstanding boulders 4. a reef-front ramp with very little slope and a ragged edge; the ramp had no major drainage gutters but had some shallow pools. Transect 2 was not comprehensively studied because of a tidal influx.
3	South	This transect began at the top edge of the beachrock on a bearing of approximately 190° and proceeded in a series of “dog-legs” across the southern reef platform to the reef edge; it was approximately 1030 m long. Five distinctive subzones were recognised: 1. sloping beachrock (approximately 60 m wide) with ridges parallel to the shore up to 2 m high and pools in between 2. a shallow lagoon 0.5–1 m deep at low tide and 400 m wide, dominated by sand and rubble (approximately 70%) 3. a high reef platform approximately 340 m wide with some bare coral rock exposure and shallow barren pools, sand and rubble 4. a low and approximately 70 m wide reef crest with shallow sandy pools 5. a reef-front ramp (approximately 60 m wide) that sloped distinctly with a rough coral rock pavement, a ragged reef-front edge and a weakly developed drainage groove system. The beachrock and reef platform subzones were not examined carefully as the incoming current became too strong for safety by the time these subzones were reached.
4	West-south-west	This transect was on a bearing of approximately 265° across the western reef platform from the top edge of the beachrock to the reef edge; it was approximately 1130 m long. Five distinctive subzones were recognised: 1. an upper littoral beachrock zone with ridges up to 2 m high, parallel and interspersed with shallow perched pools 2. a shallow lagoon 855 m wide consisting of a matrix of sandy pools with irregular depth (less than 0.5 m) among patches of rock flat 3. a high rock platform approximately 95 m wide, generally exposed at low tide but with a few very shallow (less than 10 cm) pools 4. a reef crest approximately 60 m wide with large numbers of upstanding dead coral boulders (up to 1.5 m high), numerous loose stones, dead *Acropora* slabs and shallow pools 5. a reef-front ramp approximately 60 m wide with a distinct slope seaward, low relief and some narrow drainage gutters.

- *Intertidal invertebrate assemblages*

During the survey it was found that the reef habitats at Browse Island were not diverse. Rocky-shore habitat was represented only by exposed beachrock and there were no intertidal sandflats. The lagoon habitat was also poorly developed, but was represented by shallow pools on the inner part of the reef platform which showed evidence of recent sediment infill and high mortality. Coral diversity in this lagoon was low and the epifaunal invertebrate assemblages normally present in coral reef lagoons were virtually non-existent. The reef platform on the western side was high and conspicuously barren in many places. The reef crest and reef front around the edge of the reef supported moderately rich assemblages of living corals and other invertebrates. The shallow subtidal subzone of the fore-reef was narrow and supported relatively small areas of well-developed coral assemblages.

- *Beach (upper littoral)*

There was a sandy supralittoral subzone, or berm, between the vegetation and the high-water mark, widest on the northern and eastern sides of the island. There was a steep upper littoral beach of coarse coral sand on those sides while on the western and southern sides the upper littoral subzone was mostly beachrock with only a narrow area of beach between the rock and the island vegetation.

The mobile, coarse coral sand of the island's beaches did not appear to provide a suitable habitat for invertebrates, and the suite of bivalves and gastropods that occupied this habitat at other localities was missing.

- *Beachrock subzone (upper littoral)*

Beachrock was only found on the southern and western sides of Browse Island (transects 3 and 4). The upper part of the beachrock subzone was devoid of visible life and the species of littorinid that would normally be expected in this habitat were not found.

The lower part of the beachrock supported a modest invertebrate fauna. However there were few barnacles and no rock oysters or byssally attached filter-feeding bivalves on the rock surfaces. Boring mytilid bivalves (lithophagines) were also absent. Although some algal turf was present on the rock surfaces in this part of the subzone, the grazing and detritus-feeding molluscs characteristic of the habitat were either missing, or present in very low numbers.

Transect 3 was not comprehensively studied because of a tidal influx. In the lower part of the beachrock at Transect 4, small vermetids (with hole diameters of approximately 1 mm) were conspicuous, burrowing in the crustose surface veneer along with clusters of an unidentified prostrate barnacle and abundant muricids (*Morula granulata*, *Drupa morum*, *Thais aculeata* and *Thais kieneri*).

The vasids *Vasum ceramicum* and *Vasum turbinellum* and the small cones *Conus coronatus* and *Conus miliaris* were also present. These gastropods are predators of vermetids and barnacles. The cowries *Cypraea moneta*, *Cypraea annulus*, *Cypraea carneola*, and *Cypraea arabica* were common under stones in the pools, occurring along with a number of other bivalve and gastropod molluscs.

The absence of chitons and cerithiid species was noteworthy, as was the paucity of neritids that are characteristically abundant in the lower part of this subzone at other localities. For example, the study team found only one specimen of *Nerita polita* and one specimen of *Nerita albicilla*.

- *Reef flat (midlittoral)*

The Browse Reef platform consists of a wide intertidal reef flat that surrounds Browse Island.

The midlittoral reef flat was widest (at approximately 1 km) and highest on the western and southern sides (transects 3 and 4) and narrowest (at approximately 450 m) on the north-eastern side (Transect 1). Most of the flat is exposed at low tide.

At the centre of the high reef flat there were two rubble banks, one in the north-west and the other in the south. These had previously been identified by Teichert and Fairbridge (1948) as shingle banks. At the north-western and south-eastern ends of the island, there were drainage gutters, approximately 10 m wide, between the shore and adjacent high sections of the midlittoral reef platform. As the tide floods, the lower eastern flat is covered first, with strong currents flowing westwards around both ends of the island through these gutters into the midlittoral pool on the south-western side. The high western platform then floods from the back, rather than from the seaward side. The last subzones to be covered by the incoming tide were the two rubble banks.

The high western reef platform was dominated by large areas of sand and coral rubble, with some exposed pavement supporting sparse algal turf and many barren shallow pools. Areas of exposed limestone pavement supported sparse algal turf. Few corals or other invertebrates were found in this habitat.

On the western side of the reef flat at Transect 4, a pool which was 0.5–1.0 m deep at low tide separated the shore from a high midlittoral reef flat. It had a sandy floor overlaying hard pavement and extensive coral growth consisting primarily of *Porites* and other massive corals. Further north, at the north-western corner of the island, the pool became shallower and was nearly filled with coalescing microatolls of *Porites lutea.* In places there was evidence of infilling, with dead corals still in place partly covered by sand and rubble.

It was unclear whether this was the result of a recent storm or of progressive geomorphic senility.

Adjacent to the beach on the north-eastern and eastern sides (transects 1 and 2) of the island, there was a similar, but shallower, pool. In the area around Transect 1 there was no midlittoral reef flat and the reef crest passed directly into a coral-rich shallow midlittoral pool.

Sandy-lagoon habitats typical of fringing reefs and atolls usually support an assemblage of burrowing bivalves and gastropods, but these were virtually absent here.

Molluscs seen in the Transect 1 midlittoral lagoon included the giant clams *Tridacna maxima* and *Hippopus hippopus* and the spider conch *Lambis chiragra*. The sea star *Linckia laevigata* was quite common and one specimen of the sea star *Culcita novaeguineae* was observed. The sea cucumber *Holothuria atra* was common but no other sea cucumber species were seen and only a single sea urchin, *Diadema setosum*, was recorded on the transect.

To obtain an estimate of the relative abundance of these species, they were counted along a swath 5 m wide on either side of the transect line within this subzone, that is, over a distance of 240 m to yield an area of 2400 m^2. The density of each species was then calculated by dividing the number of individuals by the area surveyed. The figures obtained show that these animals are not abundant (Table 8-21).

Table 8-21: Estimates of the abundance of selected macroinvertebrates along a section of the midlittoral lagoon on Transect 1 at Browse Island

Species	Number of individuals	Density per square metre
Tridacna maxima (giant clam)	3	0.0013
Hippopus hippopus (giant clam)	1	0.0004
Lambis chiragra (spider conch)	17	0.0071
Linckia laevigata (sea star)	8	0.0033
Culcita novaeguineae (sea star)	1	0.0004
Holothuria atra (sea cucumber)	7	0.0029
Diadema setosum (sea urchin)	1	0.0004

There were few other macromolluscs, although no search was made for cryptic species living under coral slabs. Several individuals of the muricid gastropod *Drupella cornus* were observed feeding on an *Acropora* colony.

The sand habitat between the corals was depauperate: the only molluscs seen were the sand cone *Conus pulicarius* and the terebrid *Terebra crenulata*.

Further towards the south-east, near Transect 2, there was a reef flat behind the reef crest. There was a narrow band of what might have been be a continuation of the inner *Porites* subzone close to the shore.

At Transect 2 a very low diversity of invertebrates was found in the midlittoral lagoon, but no record was made of the species encountered. No invertebrates were observed on the reef platform at Transect 2.

The midlittoral lagoon at Transect 3 was not examined carefully because of an incoming tide. Evidence of invertebrates was found in the midlittoral lagoon, however, with large dead valves of *Hippopus hippopus* conspicuous (though only one live specimen was seen).

The Transect 3 reef platform had very few molluscs other than a few *Tridacna maxima* in pools. On the reef surface *Conus ebraeus* and *Vasum turbinellum* were recorded but uncommon.

The molluscan fauna along Transect 4 was depauperate in the lagoon and on the reef platform. In the lagoon, *Tridacna maxima* and *Hippopus hippopus* were both present but uncommon. *Trochus maculatus* was common but no *Trochus niloticus* were seen. No search for cryptic species under stones was made. Of the echinoderms, only *Linckia laevigata* and *Holothuria atra* were seen, but both were very uncommon.

On the reef platform several *Hippopus hippopus* were seen but there were no *Tridacna maxima*. A single *Trochus niloticus* was seen. The cerithiid *Rhinoclavis sinensis* was present in the sand but was not common. The only echinoderms seen were *Linckia laevigata* and *Holothuria atra*; again, both were very uncommon.

- *Reef crest (midlittoral)*

Although relatively elevated, this subzone is regularly swept by waves, except during the lowest of tides. There were numerous pools, loose stones, slabs of limestone, upstanding boulders and some live domal faviids. A boulder subzone was well developed on the high northern and western side of the reef, but less so on the lower eastern side. The reef crest supported the highest diversity of both surface-dwelling and cryptic invertebrates of all the subzones.

At Transect 1, there was a moderate diversity of other invertebrates on the midlittoral reef crest. However they were not sampled systematically because of time restrictions. The most conspicuous was *Lambis chiragra*. Gerontic *Lambis lambis* were also present and *Tridacna maxima* was present, but not abundant.

The sea star *Linckia laevigata* and the holothurian *Holothuria atra* were common on the reef crest. A single specimen of the holothurian *Bohadschia argus* was also seen.

To obtain an estimate of the relative abundance of four of these key macroinvertebrate species, they were counted along a swath 5 m wide on either side of the transect line within this subzone, that is, over a distance of 40 m to yield an area of 400 m². The density of each species was then calculated by dividing the number of individuals by the area surveyed. The figures obtained are listed in Table 8-22.

Table 8-22: Estimates of the abundance of selected macroinvertebrates along a section of the reef crest on Transect 1 at Browse Island

Species	Number of individuals	Density per square metre
Tridacna maxima (giant clam)	1	0.002
Lambis chiragra (spider conch)	5	0.012
Linckia laevigata (sea star)	16	0.040
Holothuria atra (sea cucumber)	3	0.007

Details of the invertebrate fauna of the reef crest at Transect 2 were not recorded because of a rapidly incoming tide.

At Transect 3 a moderately diverse and abundant molluscan fauna was present on the reef crest. Notable were a few *Trochus niloticus* and *Lambis chiragra*. On the dead parts of the *Goniastrea* colonies there was the suite of molluscs that is typical of this habitat—predatory muricids (*Morula spinosa*, *Morula musiva*, *Morula uva* and *Thais armigera*), burrowing bivalves (*Gastrochaena* and *Lithophaga* species) and suspension-feeding vermetids. One group of *Drupella cornus* was observed feeding on a *Goniastrea* colony. The cryptic molluscan fauna (sheltering under stones) was relatively diverse. No holothurians, echinoids or asteroids were observed in this area.

The reef crest at Transect 4 had a moderate diversity of molluscs. Several species of *Conus* (*Conus coronatus*, *Conus distans*, *Conus ebraeus*, *Conus imperialis*, *Conus lividus* and *Conus rattus*), muricids from the genus *Drupa* (*Drupa morum*, *Drupa ricinus and Drupa rubusidaeus*) and *Morula uva* and a vasid (*Vasum turbinellum*) were common on the reef surface between boulders. The drupes were also present on the dead coral boulders, together with *Thais armigera*. The maculated top shell *Trochus maculatus* was common on and under the boulders but *Trochus niloticus* was not seen.

The cryptic molluscan fauna under stones was not closely investigated. The sea star *Linckia laevigata* was the only asteroid observed. *Holothuria atra* was present but not common.

- *Reef-front ramp (lower littoral)*

The reef edge around the perimeter of the reef was ragged but continuous, except for several narrow drainage gutters that crossed the reef-front ramp on the western side.

There was significant variation in the form of the reef front. On the western side, exposed to heavy swell, it was about 60 m wide with a distinct slope of between two and five degrees, with bare pavement or a crustose algal cover with a low algal turf. On the lower eastern side (transects 1 and 2), the reef front was 30–40 m wide, almost level with a boulder subzone that was poorly developed and which had a moderately rich invertebrate fauna consisting primarily of species that live in crevices or embedded in the algal turf.

At Transect 1, the invertebrates of the lower littoral reef front were relatively diverse. Several species of cones and other predatory gastropods were conspicuous in crevices and nestled in the algal turf on the reef surface along with the cowries *Cypraea caputserpentis* and *Cypraea depressa* and the cerithiid *Rhinoclavis sinensis*. There was a variety of cryptic species living under stones.

There were few echinoderms in this habitat. The sea star *Linckia laevigata*, common in the adjacent reef-crest subzone, was not recorded here. The burrowing urchin *Echinometra mathaei* was observed, but was not common.

The Transect 2 reef-front ramp had conspicuous colonies of a fine-leaved alga of the genus *Halimeda* and a moderately diverse invertebrate fauna. Although a comprehensive record was not made, some of the most conspicuous molluscs were collected. Predatory cones, including *Conus coronatus*, *Conus distans*, *Conus ebraeus*, *Conus imperialis*, *Conus litteratus*, *Conus lividus and Conus rattus*, were noteworthy, all living in crevices and nestling among the algae on the reef surface. The occurrence of this variety and number of predatory gastropods is an indicator of the presence of a moderately rich invertebrate fauna.

Molluscs were moderately abundant on the reef front at Transect 3. Conspicuous in crevices and sheltering among algae on the reef surface were predatory cones (*Conus coronatus*, *Conus distans*, *Conus ebraeus*, *Conus imperialis*, *Conus lividus* and *Conus rattus*), the muricids *Drupa morum and Drupa ricinus*, and the vasid *Vasum turbinellum*.

The cypraeid *Cypraea caputserpentis* was very common in crevices, and the turbinid *Turbo argyrostomus* was abundant in crevices and under stones. A cluster of *Drupella cornus* was observed feeding on a colony of *Acropora robusta*. A single *Trochus niloticus* was also recorded. Echinoderms were not seen.

The molluscan fauna of the reef-front ramp at Transect 4 included cones (*Conus catus*, *Conus coronatus*, *Conus distans*, *Conus ebraeus*, *Conus lividus* and *Conus rattus*), muricids (*Thais armigera*, *Drupa morum*, *Drupa ricinus* and *Morula uva*) and a vasid (*Vasum turbinellum*). The grazers *Cypraea caputserpentis* and *Turbo argyrostomus* were both abundant. Small vermetids burrowing in the crustose surface were also abundant. There were few bivalves—but only a single *Tridacna maxima* was seen within 10 m of the transect line. No echinoderms were observed in the vicinity of the transect line in this subzone.

Coral assemblages

- *Transect 1*

Coral diversity was low overall, despite the lagoon being abundant in corals (Figure 8-44). Species with branching morphologies were dominant, including species of *Acropora*, *Porites* and *Montipora* along with *Seriatopora hystrix*, *Pocillopora damicornis* and *Pocillopora verrucosa*. Also common, although not dominant, were massive species of *Porites*, *Goniopora* and the alcyonacean *Tubipora* (the latter mostly in the outer part). Present but uncommon were a laminar *Montipora* and the octocoral *Heliopora coerulea*. Faviids were almost restricted to a very uncommon species of *Goniastrea*. One colony of *Favites* was seen. No mussids or fungiids were observed.

Figure 8-44: The shallow coral-rich lagoon in Subzone 3 of Transect 1 at Browse Island

There were large areas of mostly dead but in situ *Acropora palifera* colonies, suggesting a recent heavy mortality event or perhaps senescence. There was an appearance of infilling, with many *Acropora* clumps dead at their centres but with a living fringe.

Corals recorded on the reef crest included the octocorals *Heliopora coerulea* (which was common), *Tubipora musica*, *Sinularia*, *Sarcophyton* and *Lobophytum* and the scleractinians *Acropora palifera*, *Seriatopora hystrix*, *Goniastrea*, *Montipora* and *Porites*.

Live coral cover on the reef-front ramp was approximately 50%, with a moderate coral diversity. A small corymbose *Acropora* was dominant. Less common genera included *Favites*, *Porites*, *Stylophora* and an encrusting species of *Montipora*. At least two species of *Pocillopora* were common in places.

- *Transect 2*

The most common corals in the midlittoral lagoon were flat-topped *Porites lutea* microatolls, up to 2 m in diameter and 0.8 m high. However, other corals were also present, including species of *Goniastrea* and *Pocillopora*, the helioporacean octocoral *Heliopora coerulea* and the alcyonacean octocorals *Tubipora musica* and two species of the genus *Nephthea*.

The rock platform had a sparse algal turf and coral cover of less than 5%. The assemblage included *Goniastrea* and *Favites* as well as small colonies of *Porites* forming microatolls less than 2 m in diameter. Closer to the shore the same corals occurred, with the addition of *Goniopora*, an encrusting *Montipora* and some small colonies of *Acropora hyacinthus.*

The reef crest had very little elevation above the rock platform of Subzone 2 and had numerous loose coral stones and slabs but no upstanding boulders. It had a few live corals, with an approximate cover of less than 5%, but these were not recorded because of a rapidly incoming tide.

The reef-front ramp had a live coral cover of approximately 10%. The common corals included small colonies of *Heliopora*, *Acropora*, *Goniastrea*, *Pocillopora verrucosa*, *Seriatopora*, and encrusting forms of *Porites*, *Montipora* and *Goniopora*. Small colonies of semi-encrusting *Acropora palifera* were also present.

- *Transect 3*

The shallow inner midlittoral lagoon had live coral cover of approximately 20%. These corals were not sampled systematically, but *Porites* and some *Acropora*, *Pocillopora*, and *Seriatopora* were recorded.

The reef platform had areas of lithified branching *Acropora* infilled with sand and rubble, but overall there was less than 10% live coral cover. These corals included *Porites*, *Tubipora* and a few small faviids.

The reef-crest coral fauna was depauperate except for *Goniastrea retiformis*, an unidentified *Goniastrea* species and *Heliopora coerulea*, along with small *Porites*, *Leptastrea*, *Favites*, *Acropora* and various unidentified faviids.

The reef-front ramp corals were small and sparse (approximately 10% coral cover) and included mainly *Heliopora*, *Acropora*, *Pocillopora*, *Tubipora*, *Goniastrea*, *Millepora* and *Porites*.

Photograph courtesy of Zoe Richards (Western Australian Museum)

Figure 8-45: A coral of the genus *Porites*

- *Transect 4*

A few encrusting live corals (approximately 20% cover), mainly of the genus *Goniastrea*, were found on the beachrock ridges.

The shallow midlittoral lagoon contained *Porites lutea* microatolls and some areas had recent sand–rubble fill burying the corals. Coral diversity and live cover were low (less than 10%), except close to shore where live corals were more abundant (live cover less than 25%). The common corals here were *Porites lutea*, *Porites cylindrica*, *Pocillopora damicornis*, *Acropora palifera*, *Seriatopora hystrix*, *Heliopora coerulea*, *Tubipora musica*, *Goniastrea*, *Millepora* and *Cyphastrea.* Microatolls of *Porites* were present throughout and dominated the nearshore part of the lagoon.

The common corals on the midlittoral reef platform were the same as in the lagoon but they were much less abundant, with live coral cover less than 10%.

The reef crest had large numbers of upstanding dead coral boulders (up to 1.5 m high) and dead *Acropora* slabs. The live coral cover was low (at less than 5%) and there was a very low level of diversity. Small colonies of *Porites* and *Goniastrea* were the only corals that were reasonably common. Unlike the reef crest of Transect 3, there were no large live *Goniastrea* colonies.

The reef-front ramp had a variable cover of live corals (10–50%) and a low species diversity. It included mainly encrusting forms and small colonies less than 15 cm in diameter that were possibly young recruits and suggested a recovery phase after a mortality event. Coral taxa included *Pocillopora verrucosa*, small and bushy *Acropora*, an encrusting *Porites* and species of *Millepora*, *Montipora*, *Favites*, *Goniastrea* and *Heliopora*.

Fish assemblages

At Browse Island, 31 species of fishes from 20 families were collected from an intertidal pool, approximately 19 m^2 in area and 0.7 m in depth, on the north-north-east reef crest of the island during a spring low tide in September 2006 (Figure 8-6, Table 8-23). The most abundant fish species were *Abudefduf vaigiensis* (family Pomacentridae), *Ecsenius oculatus* and *Cirripectes filamentosus* (family Blenniidae), and a species of *Gymnothorax* (family Muraenidae); the least abundant were *Acanthurus nigrofuscus* (family Acanthuridae), *Thalassoma hardwicke* and *Thalassoma jansenii* (family Labridae). All of the species found are common in the Indo-Pacific region.

Subtidal habitats

Subtidal habitats and their associated faunal assemblages were investigated in the Bonaparte Archipelago and at Browse Island and Echuca Shoal using four different techniques: tow-camera surveys, benthic sledge-sampling surveys, grab-sampling surveys and ROV surveys (the latter only at Echuca Shoal).

Tow-camera and ROV surveys

Tow-camera surveys were conducted at several islands in the Bonaparte Archipelago—the Maret Islands, the Albert Islands group, the East Montalivet Islands group (East Montalivet, Walker, Don and Patricia islands and their associated islets), West Montalivet Island, the Berthier Islands group, Turbin Island, Corvisart Island, the "Unnamed Islands" (between Berthier Island and South Maret Island), the Robroy Reefs (North Robroy, West Robroy and South Robroy reefs), Lamarck Island, Tournefort Island, Bigge Island, Prudhoe Island, Gaimard Island, Champagny Island and Long Reef.

Tow-camera surveys were not carried out in the Browse Basin either at Browse Island or Echuca Shoal, and ROV surveys were conducted only at Echuca Shoal.

Table 8-23: Numbers of individuals of each fish species collected from an intertidal pool on the north-north-east reef crest of Browse Island

Family*	Species	Number of individuals
Muraenidae (moray eels)	*Gymnothorax* sp. (unidentified moray eel)	12
Bythitidae (live-bearing cusks)	*Ogilbia* sp. (unidentified brotula)	1
Ophidiidae (cusk eels)	*Ophidion muraenolepis* (blackedge cusk)	2
Scorpaenidae (scorpionfishes)	*Scorpaenopsis diabolus* (false stonefish)	3
Platycephalidae (flatheads)	*Inegocia japonica* (rusty flathead)	2
Serranidae (rockcods)	*Cephalopholis argus* (peacock rockcod)	2
Grammistidae (soapfishes)	*Grammistes sexlineatus* (lined soapfish)	1
Pseudochromidae (dottybacks)	*Assiculus punctatus* (bluespotted dottyback)	2
	Pseudochromis tapeinosoma (blackmargin dottyback)	4
	Pseudochromis sp. (dottyback)	4
Lutjanidae (tropical snappers)	*Lutjanus decussatus* (chequered snapper)	8
Nemipteridae (threadfin breams)	*Nemipterus* sp. A (threadfin bream)	1
Mullidae (goatfishes)	*Parupeneus trifasciatus* (doublebar goatfish)	2
Chaetodontidae (butterflyfishes)	*Chaetodon lunula* (raccoon butterflyfish)	2
Pomacentridae (damselfishes)	*Abudefduf vaigiensis* (Indo-Pacific sergeant)	19
	Plectroglyphidodon leucozonus (whiteband damsel)	3
Labridae (wrasses)	*Halichoeres margaritaceus* (pearly wrasse)	3
	Halichoeres marginatus (dusky wrasse)	3
	Halichoeres nebulosus (cloud wrasse)	4
	Thalassoma hardwicke (sixbar wrasse)	3
	Thalassoma jansenii (Jansen's wrasse)	1
Blenniidae (blennies)	*Blenniella periophthalmus* (bluestreaked rockskipper)	8
	Cirripectes filamentosus (filamentous blenny)	12
	Cirripectes variolosus (redspeckled blenny)	7
	Ecsenius oculatus (ocular combtooth blenny)	19
Acanthuridae (surgeonfishes)	*Acanthurus nigrofuscus* (dusky surgeonfish)	1
	Acanthurus sp. (surgeonfish)	1
Balistidae (triggerfishes)	*Balistoides viridescens* (titan triggerfish)	1
Monacanthidae (leatherjackets)	Unidentified leatherjacket	1
Tetraodontidae (pufferfishes)	Unidentified pufferfish	1
Diodontidae (porcupinefishes)	*Diodon liturosus* (blackblotched porcupinefish)	1
Total no. of families = 20	**Total no. of species = 31**	**134**

* The taxonomic order of the families in this table follows Yearsley, Last and Hoese (2006).

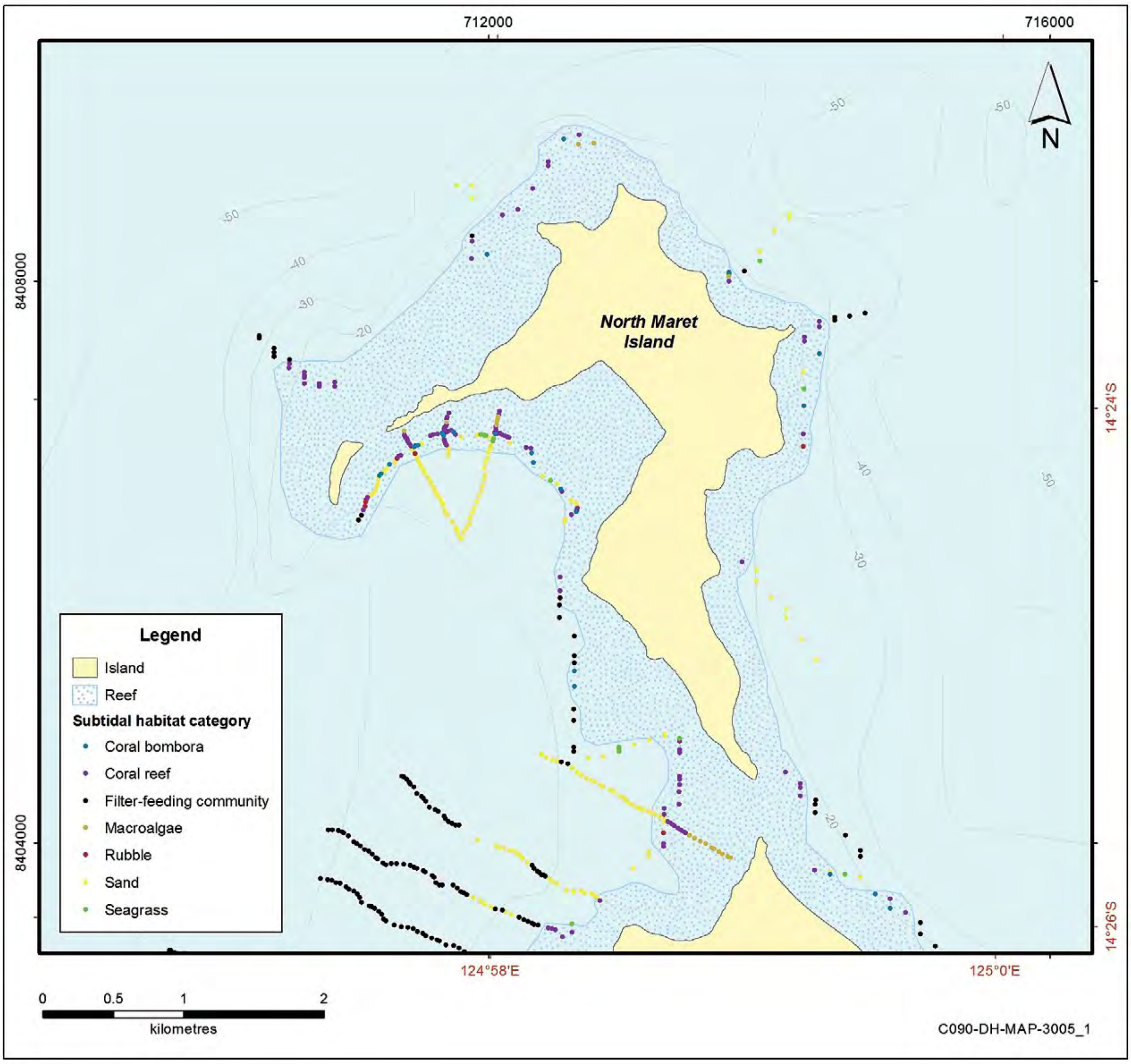


Figure 8-46: Subtidal habitats at sampling locations near North Maret Island

The Maret Islands

The subtidal benthic assemblages surrounding the Maret Islands were highly varied, and included soft substrates mostly bare of epibenthos, soft substrates with seagrass, hard pavements supporting filter-feeding communities, and coral-dominated assemblages (figures 8-46 and 8-47).

- *Soft substrates*

Unconsolidated sediment substrates occurred on all sides of the Maret Islands. Very soft substrates with obvious bioturbation from infaunal activity but with a sparse epibenthos were recorded in Brunei Bay on the north-west coast of North Maret Island and in the bay west of the isthmus between North Maret Island and South Maret Island. A brief examination of the sediments collected from Brunei Bay indicated that they contained large numbers of foraminiferans. In comparison, the soft sediments on the western side of the isthmus contained no foraminiferans and very little organic material.

Medium-to-coarse sand accumulations (sandbanks) were found on the southern sides of the islands and near a large emergent rock offshore the western side of South Maret Island. The sandbanks were bare of epibenthos and there was no evidence of burrowing organisms. Large areas of sand were observed offshore from both the western and eastern coasts of the islands. The dominant benthic taxa encountered on these substrates were stalked hydroids and small bryozoans. These occurred as low-density and low-diversity communities over very large areas, typically in depths of between 20 m and 30 m.

Small communities of seagrass of the genus *Halophila* were encountered on subtidal soft substrates on the western, southern and eastern sides of the islands. Their distribution was very patchy, however, with only low densities of rhizomes.

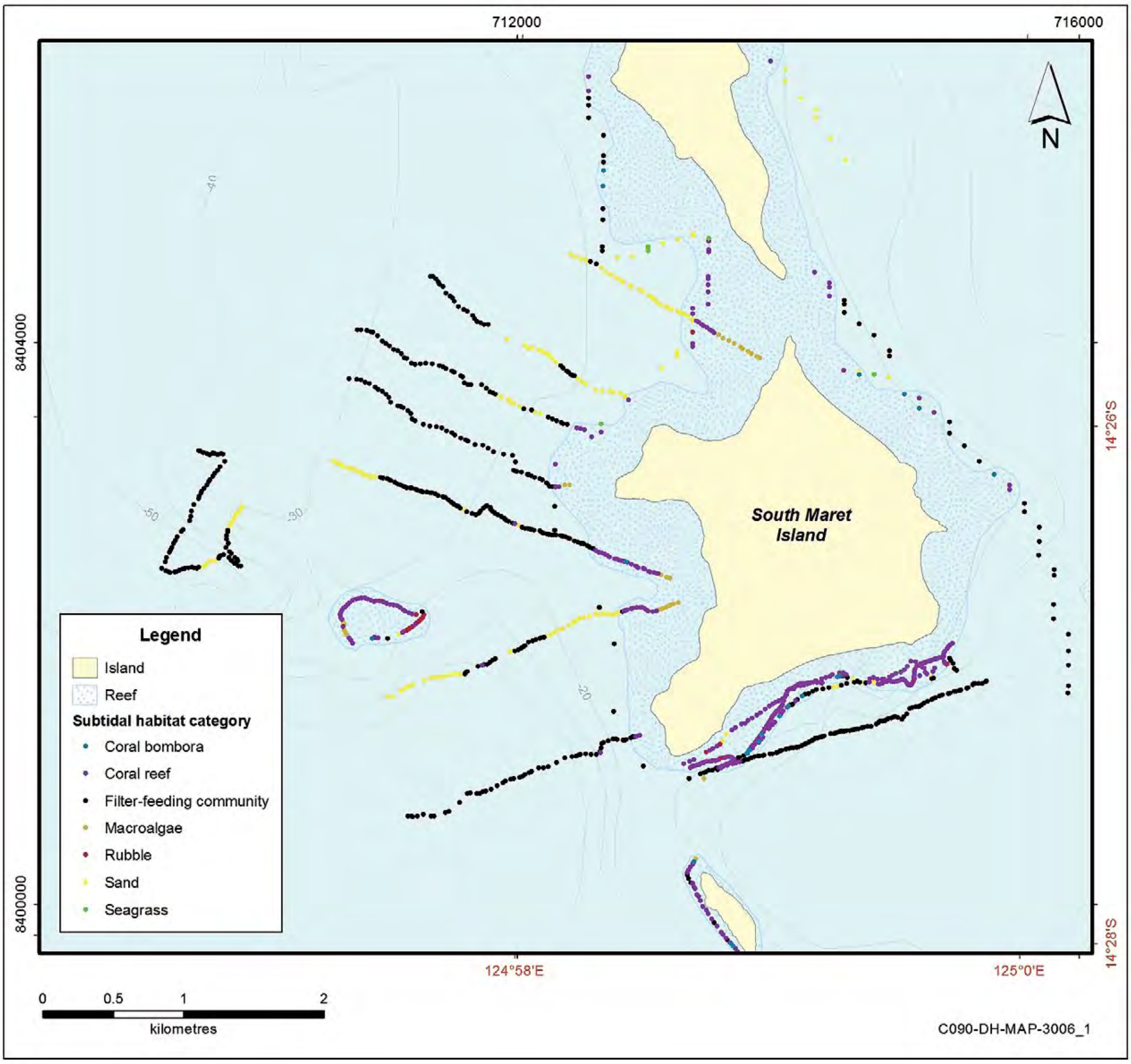


Figure 8-47: Subtidal habitats at sampling locations near South Maret Island

- *Hard substrates*

Hard-substrate communities at depths to 20 m included coral-dominated assemblages on exposed reef slopes and in protected areas on the southern and eastern sides of the islands. Reef slopes supported a high diversity and level of cover of coral communities dominated by species of massive morphology in the shallows, with an increase in species of laminar morphology in deeper waters. Investigations of the subtidal assemblages on the slopes were not possible, but investigations of the lower littoral zone during tow-camera surveys indicated that the reef slopes supported very high coral diversity.

The coral assemblages in very shallow protected areas were dominated by branching *Acropora*, with an increasing richness of genera with depth.

Large *Porites* colonies were often a dominant feature of the mid-depth (4–8 m) coral communities, together with laminar (e.g. *Pachyseris*, *Mycedium* and *Montipora*), branching (e.g. *Acropora*, *Hydnophora* and *Seriatopora*), massive (e.g. *Goniopora* and *Pavona*), subarborescent (e.g. *Pectinia*) and tabular (*Acropora*) species occurring in a mixed coral matrix.

Hard pavement supporting sponge gardens and other filter-feeding communities was found in waters deeper than 15 m on the western, northern and southern sides of the islands but less frequently off the east coast. The pavement communities were dominated by sponges, gorgonians, hydroids and bryozoans. Sponges included taxa of various morphologies, including branching, laminar and barrel forms. Gorgonians included simple sea whips (*Junceella*), branching sea whips (*Ctenocella*) and sea fans (*Gorgonia*).

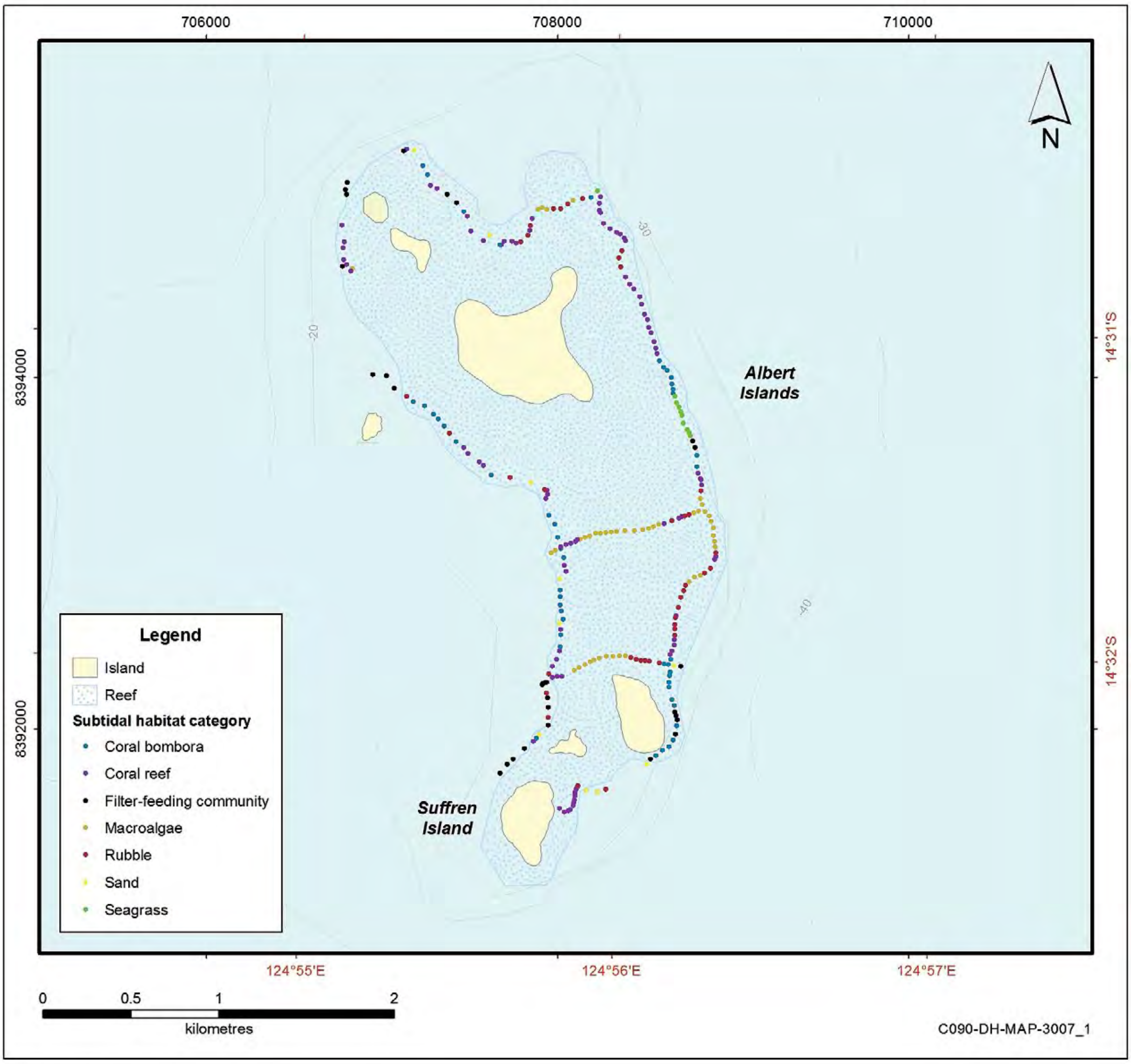


Figure 8-48: Subtidal habitats at sampling locations in the Albert Islands group

The Albert Islands group

The subtidal habitats around the Albert Islands group included coral communities, limestone pavements and sandy substrates (Figure 8-48). Coral communities were represented by diverse assemblages on the steeply plunging western-facing reef slope, and by narrow fringing reefs and shallow permanent lagoons on the north-eastern and eastern sides of Albert Island, the largest island.

The fore-reef slope appeared to support a coral assemblage similar to that observed on comparable slopes at the Maret Islands, with the acroporids and corals of massive and encrusting morphology abundant in the shallows and more laminar morphologies occurring at depth. One variation was the profusion of corals of the family Pocilloporidae (*Pocillopora*, *Seriatopora* and *Stylophora*) along the upper reef slope west of Albert Island. Branching *Acropora* was the dominant coral form in the lagoons.

Rocky pavements, suspected to be limestone, were restricted to areas deeper than 20 m and supported a moderately dense filter-feeding community dominated by sponges. Extensive sand substrates occurred along the eastern side of Albert Island, extending to the south parallel to the intertidal reef flat linking the northern Albert Islands with the group's southernmost member, Suffren Island. The sands supported sparse macroalgae of the genus *Sargassum* in the shallows adjacent to the reef flat, and seagrass (*Halophila ovalis*) in waters between 8 and 12 m deep. In places, the density of *Halophila* was sufficient to cover the substrate. This area supported the most extensive and abundant seagrass community encountered at any location during the study.

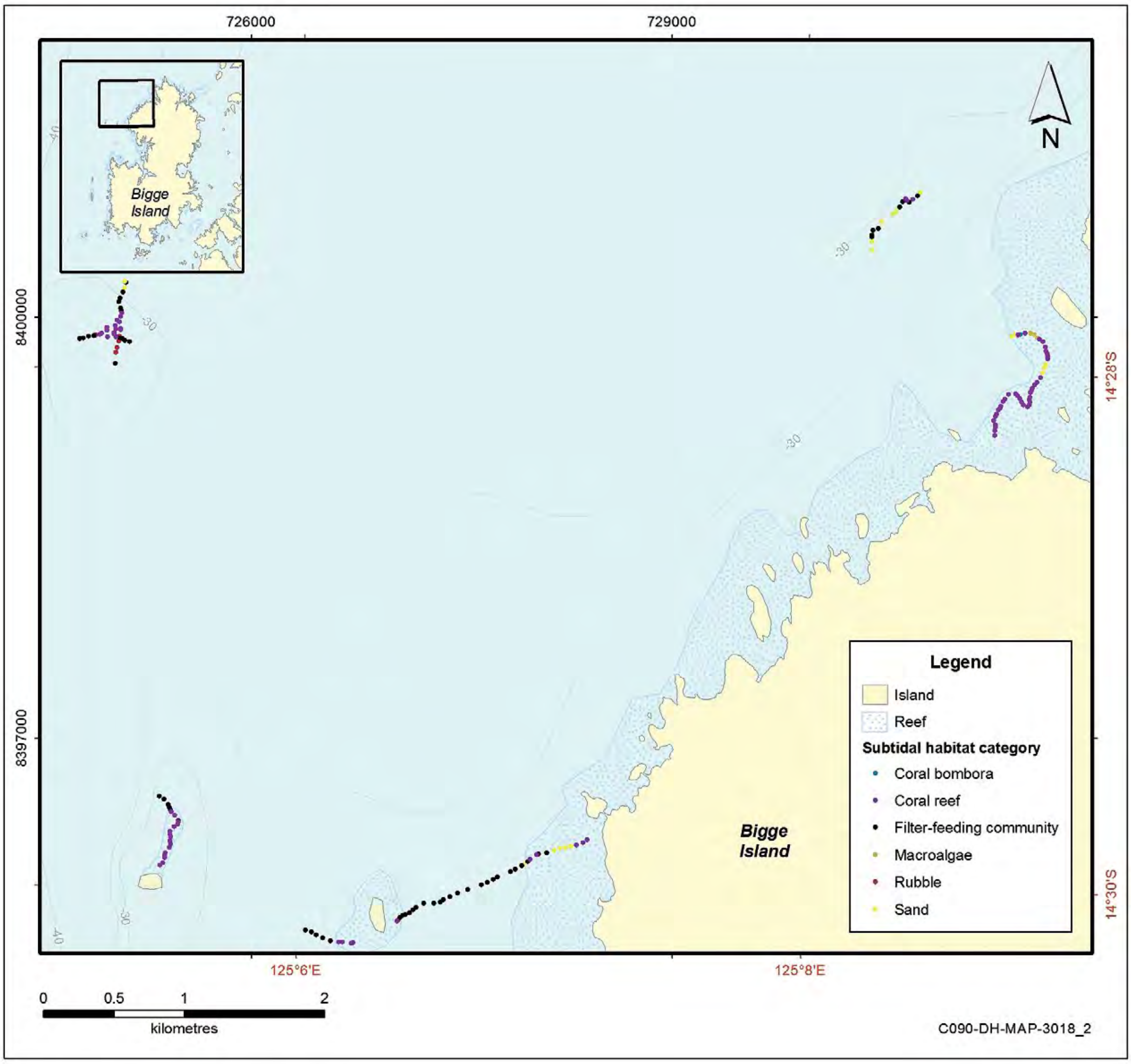


Figure 8-49: Subtidal habitats at sampling locations off the north-western coast of Bigge Island

Bigge Island

The tow-camera surveys conducted near the north-west coast of Bigge Island (Figure 8-49) encountered highly diverse and abundant coral reefs inshore, including the genera *Acropora*, *Heliopora*, *Montipora* and *Porites* and a variety of faviids. Both branching and tabular *Acropora* were dominant in the intertidal zones, including many *Acropora* plates greater than 1 m in diameter. Further offshore, around the 20 m contour, seabed substrates were predominantly of fine sand with a sparse filter-feeding community composed mainly of sponges, sea whips and gorgonians.

The tow-camera investigations off the west coast of Bigge Island (Figure 8-50) encountered a rocky-reef community of mainly soft corals, including *Xenia* and *Lobophytum*. In the deeper water further offshore, the benthic community on hard substrates consisted of sponges, hydroids and gorgonians.

The transects on the south-west side of Bigge Island (Figure 8-51) found occasional rock outcrops in shallow water that were covered in encrusting corals and macroalgae of the genera *Sargassum* and *Halimeda*. In the deeper areas (around the 30 m isobath), sponges and soft corals were the dominant benthic community on pavement with sand veneers. Similar observations were made from the shallow-water transects: rocky substrates supported a benthic community mainly comprising corals of the genera *Porites*, *Montipora* and occasionally *Acropora*, while in deeper waters, hard substrates supported sponges, hydroids, sea whips and gorgonians.

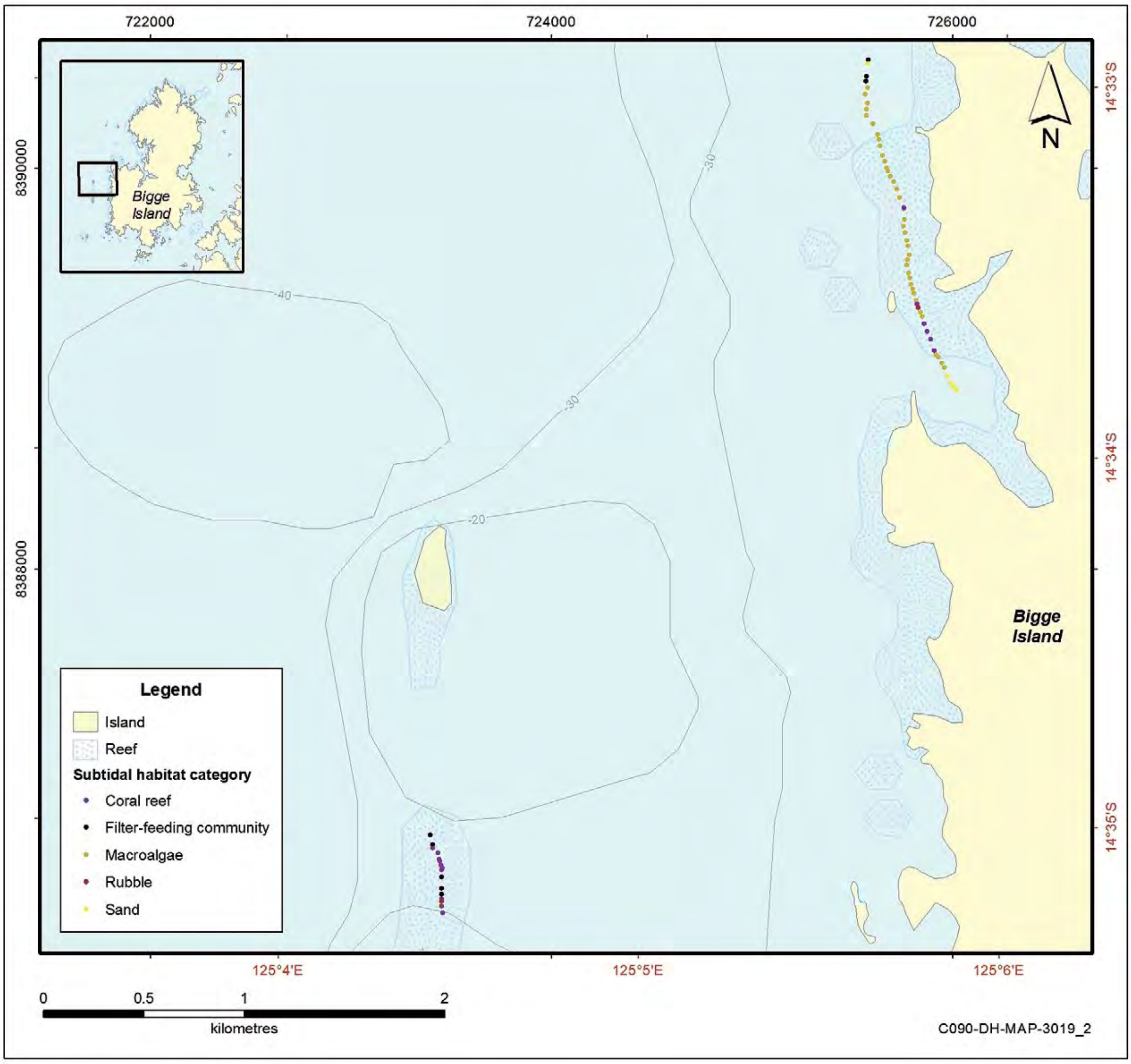


Figure 8-50: Subtidal habitats at sampling locations off the western coast of Bigge Island

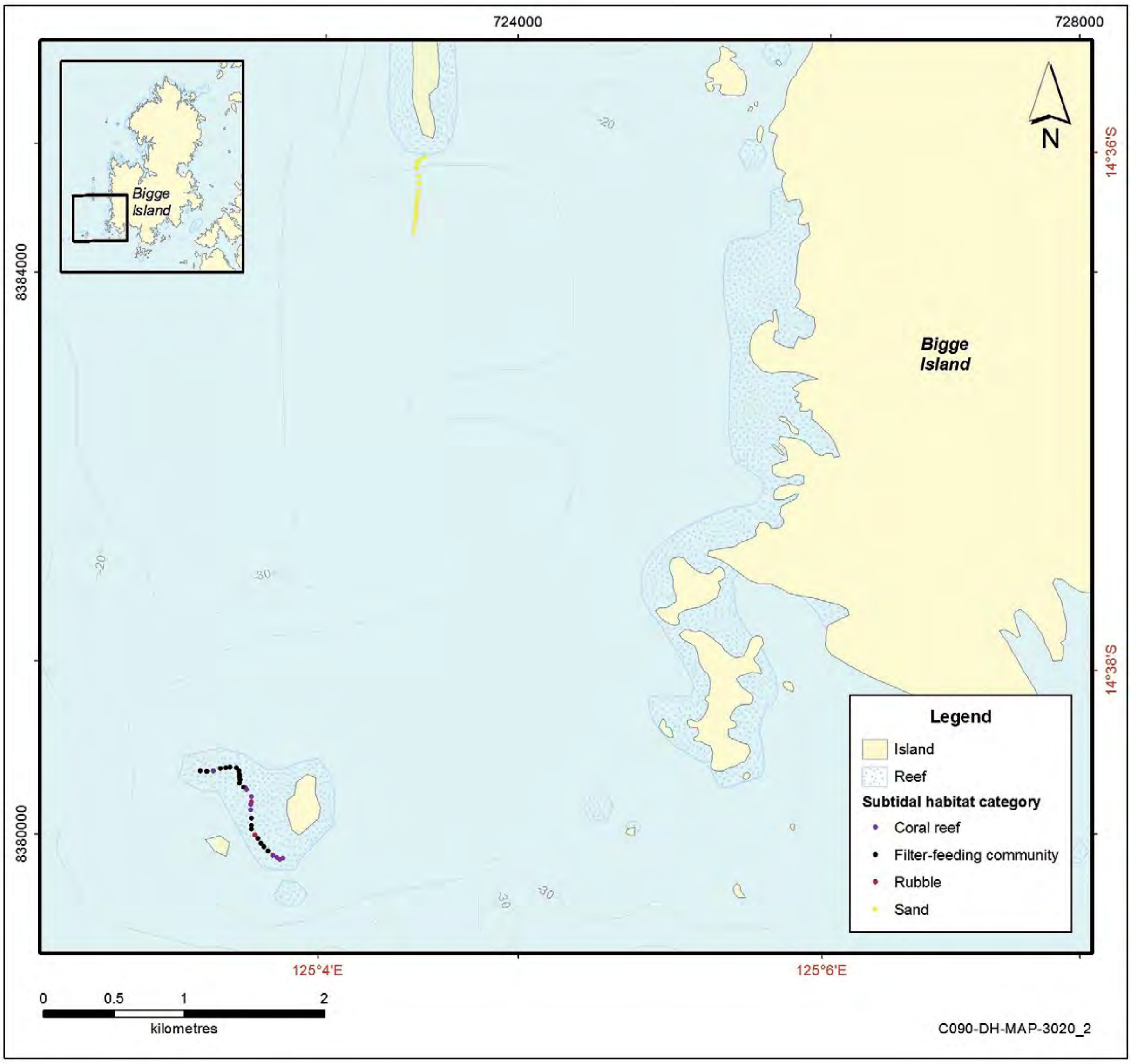


Figure 8-51: Subtidal habitats at sampling locations off the south-western corner of Bigge Island

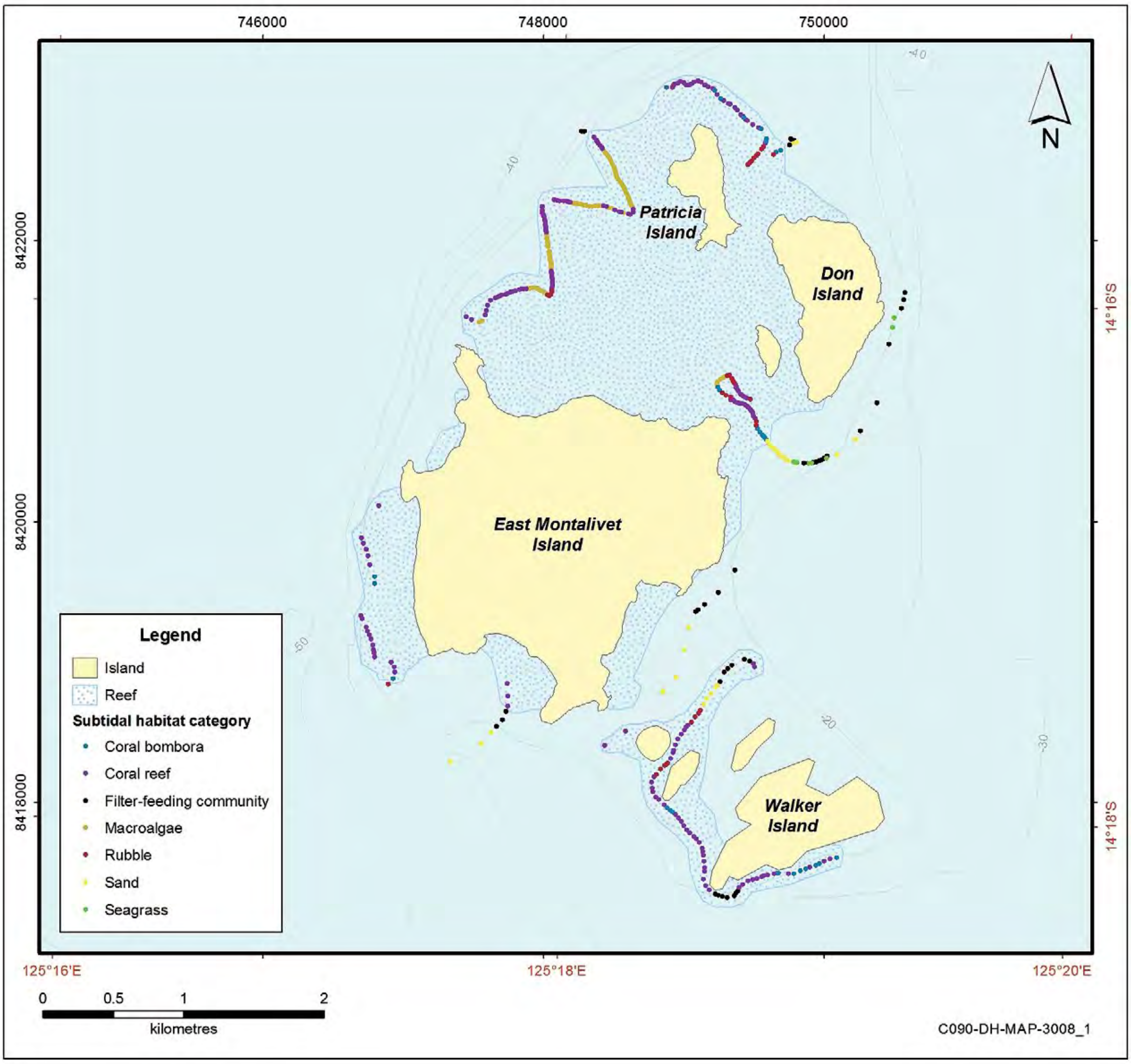


Figure 8-52: Subtidal habitats at sampling locations within the East Montalivet Islands group

The East Montalivet Islands group

The subtidal surveys at East Montalivet Island also included investigations of the other islands in the group, Walker Island, Don Island, Patricia Island and their surrounding islets. Tow-camera investigations around Walker Island (Figure 8-52) encountered an extensive and diverse subtidal coral reef which appeared to surround most of the island and its associated islets. The reef had a high profile, with large colonies of *Porites* and complex assemblies of diverse corals on reefal substrates. Noticeable at Walker Island were areas where large colonies of tabular *Acropora* formed a dominant upper storey, with smaller species occupying mostly lower levels of the reef. This community type was not encountered at any other location around the outer islands of the study area. Only a shallow reef at Bigge Island was found to support a similar large tabular *Acropora* assemblage, but that community did not appear to have either the species diversity or community structure observed at Walker Island.

Walker Island is separated from East Montalivet Island by a shallow channel with a patch of outcropping basalt boulders. The channel supported a macroalgal community of very dense *Sargassum*, the only observed break in the coral reef fringing the island.

At Don and Patricia islands, coral communities were most developed along the eastern margins, where an irregular raised terrace of mixed massive and branching corals was present. These protected a shallow lagoon adjacent to the islands which had a sandy floor with extensive patch reefs, some of which were *Acropora* thickets with few species. Others were raised rock substrates supporting a high diversity of mixed corals, including *Acropora*, *Montipora*, *Pocillopora* and a diverse range of faviids and mussids. The lagoon also contained some large *Porites* colonies (more than 4 m in diameter) which were constrained in height by the depth of low water.

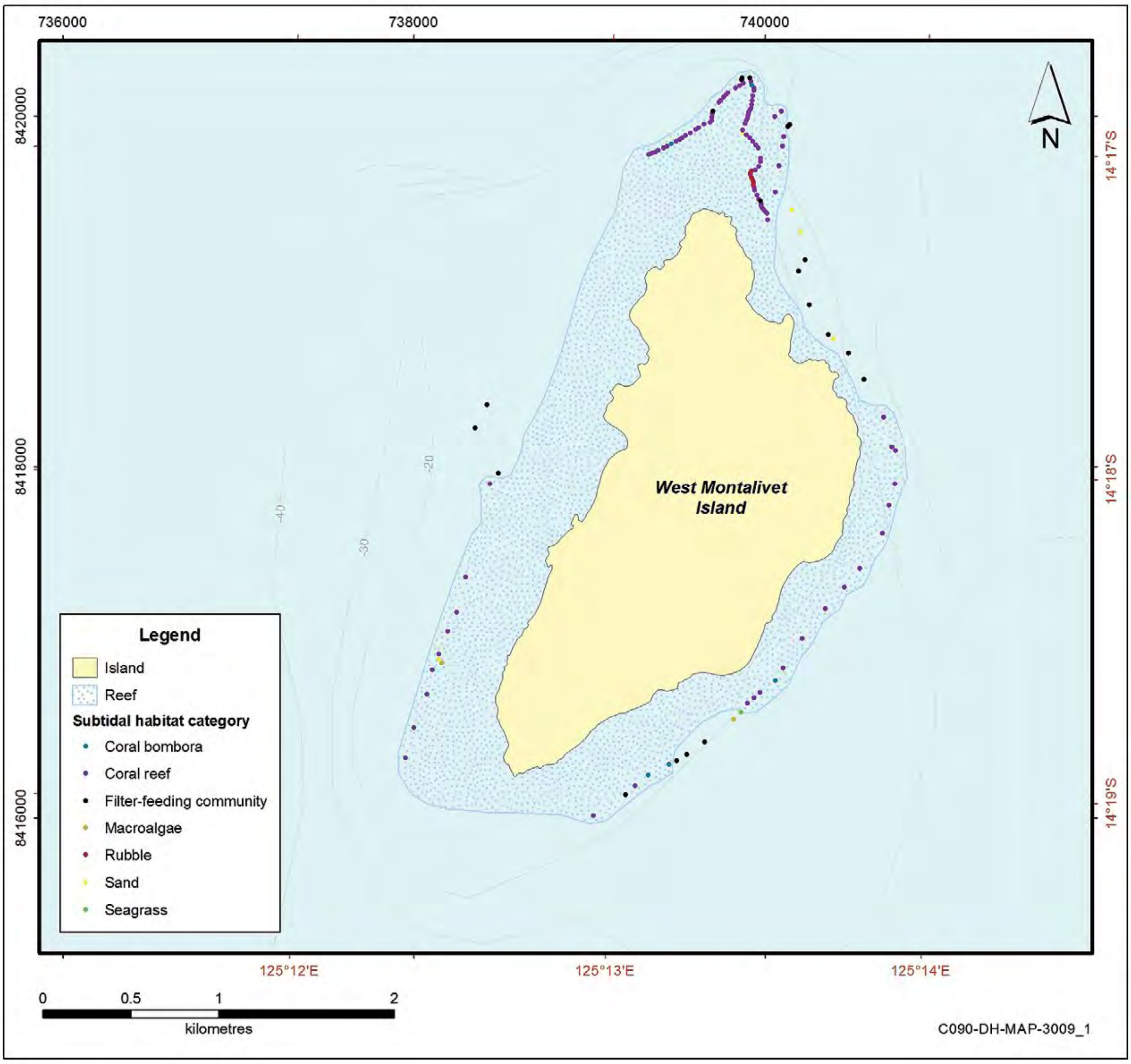


Figure 8-53: Subtidal habitats at sampling locations near West Montalivet Island

The deeper coral zone on the seaward side of the lagoons supported a large diversity of corals, including small tabular and branching *Acropora*, large colonies of *Porites* and faviids and numerous lesser species in a mixed coral matrix.

The subtidal coral assemblages on the northern and western sides of the island were similar in form to those on West Montalivet Island and the Maret Islands. The reef edge comprised a narrow zone of impact- and exposure-resistant corals, with increased diversity in the shallow subtidal zone. The reef front was highly irregular, with deep chasms and near-vertical faces. Coral species on the shallow faces were restricted to those with robust or encrusting morphologies. Coral form tended to become more varied with increased depth, with laminar and foliose species becoming dominant near the depth limit of the coral community.

Rocky pavements around the island supported a community dominated by sponges and gorgonians, similar in diversity to that observed around the Maret Islands, West Montalivet Island and Berthier Island.

West Montalivet Island

The tow-camera surveys conducted around the greater part of the reef edge at West Montalivet Island (Figure 8-53) showed that the shallow subtidal habitat around the island was predominantly composed of coral reef. The intertidal platform on the western side ended in a steep wall, which gave way to a gently sloping pavement and sandy seabed. The reef edge was ragged, with a heavy cover of small faviids and a variety of encrusting and digitate secondary species. The wall supported a high density of corals.

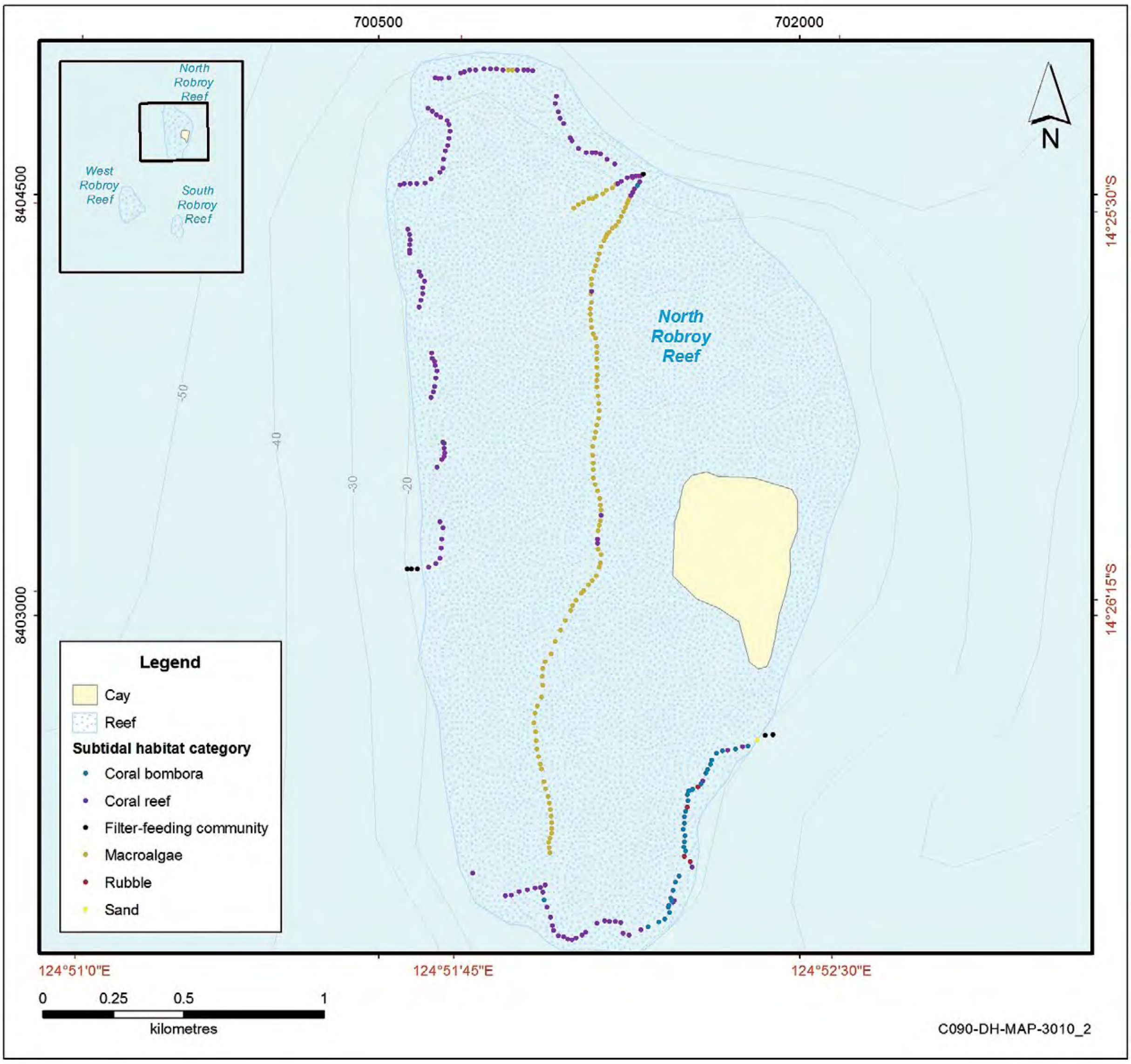


Figure 8-54: Subtidal habitats at sampling locations near North Robroy Reef

Massive species, mainly members of the families Poritidae and Faviidae, occupied the shallower zone, and foliose species (e.g. *Pachyseris speciosa*) became increasingly common with depth. The seabed at the base of the wall included rocky substrates that had probably fallen from the reef wall. The epibenthos at the base of the wall included sponges and gorgonians attached to the rocky substrates. The seabed sloped rapidly away from the island to a depth of 40 m, where small sponges, hydroids and gorgonians were observed on a mostly sandy seabed.

On the southern side of the island, a sandy beach sloped into the subtidal habitat, without the formation of an intertidal platform. Some large *Porites* bomboras formed a patch reef surrounded by branching *Acropora*. This was a narrow zone, and the seabed sloped rapidly away beyond 15 m, which is where the coral community also ended.

The subtidal zone adjacent to the western side of the island had a gentler slope into deep water, and there was a more extensive coral community in depths shallower than 15 m. *Acropora* was the dominant genus here, and included large areas of branching staghorn and tabular species. *Acropora* was particularly dominant in the shallow subtidal zone, with the diversity of other corals increasing with depth. This community appeared to have a zonation and coral composition similar to that observed on the eastern side of the Maret Islands.

The northern side of the island is exposed to increased wave action and this is reflected in the bathymetry of the subtidal zones. The reef platform had a ragged edge, with a plunging, coral-dominated wall. The reef-edge communities appeared to be very similar to those on the northern reef edge of North Maret Island, with diverse corals and other macrobenthic invertebrates.

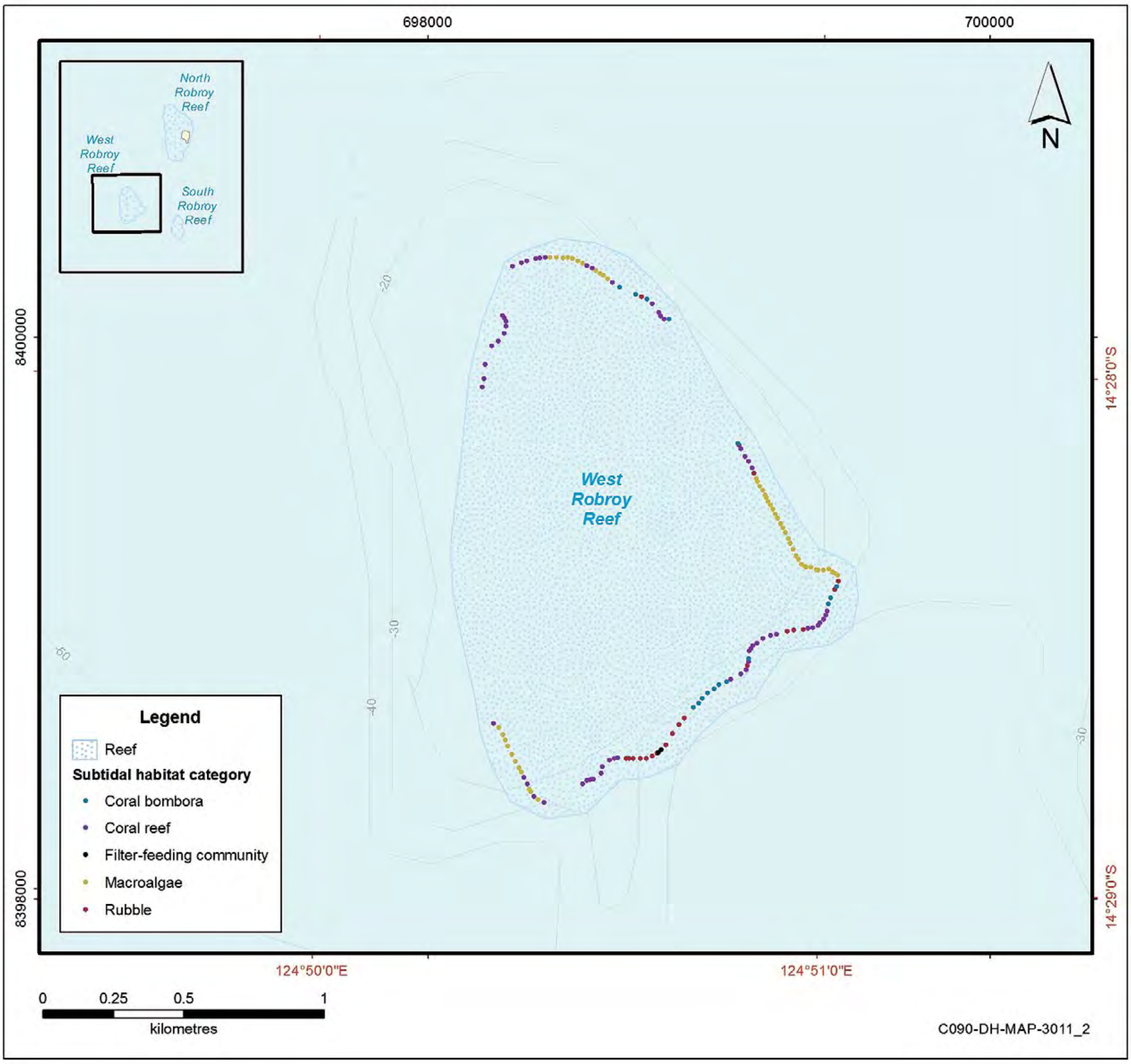


Figure 8-55: Subtidal habitats at sampling locations near West Robroy Reef

Similarly, hard substrates around the break of slope also supported abundant invertebrate communities, but this abundance decreased with depth.

Robroy Reefs

Tow-camera surveys were conducted over the three large reefal structures collectively named the Robroy Reefs (figures 8-54, 8-55 and 8-56). The reefs are steep-sided with a shallow intertidal zone on top of the reef platform and near-vertical fore-reef slopes on the western and northern sides, descending to the sea floor at approximately 30 m. North Robroy Reef and West Robroy Reef were found to be similar in topography and community composition. At these reefs, the shallow intertidal reef platform was dominated by a heavy covering of the macroalgal genus *Sargassum*. At the edge of the reefs the *Sargassum* gave way to a coral community, which extended down the steep fore-reef slope.

On the northern and western sides of the reefs, the substrate was rocky and high profile with a high level of coral abundance. The dominant coral families were the Acroporidae and Pocilloporidae, occurring along with a range of small faviids and various encrusting species. The coral dominance changed with increasing depth from small acroporids and faviids to larger corals of more diverse morphology, including *Porites*, *Montipora*, *Platygyra* and *Pachyseris*. At the base of the reef wall, small bomboras, largely covered in encrusting corals, were scattered on a sand-covered pavement, before giving way to filter-feeding communities of sponges, sea whips and soft corals at greater depths.

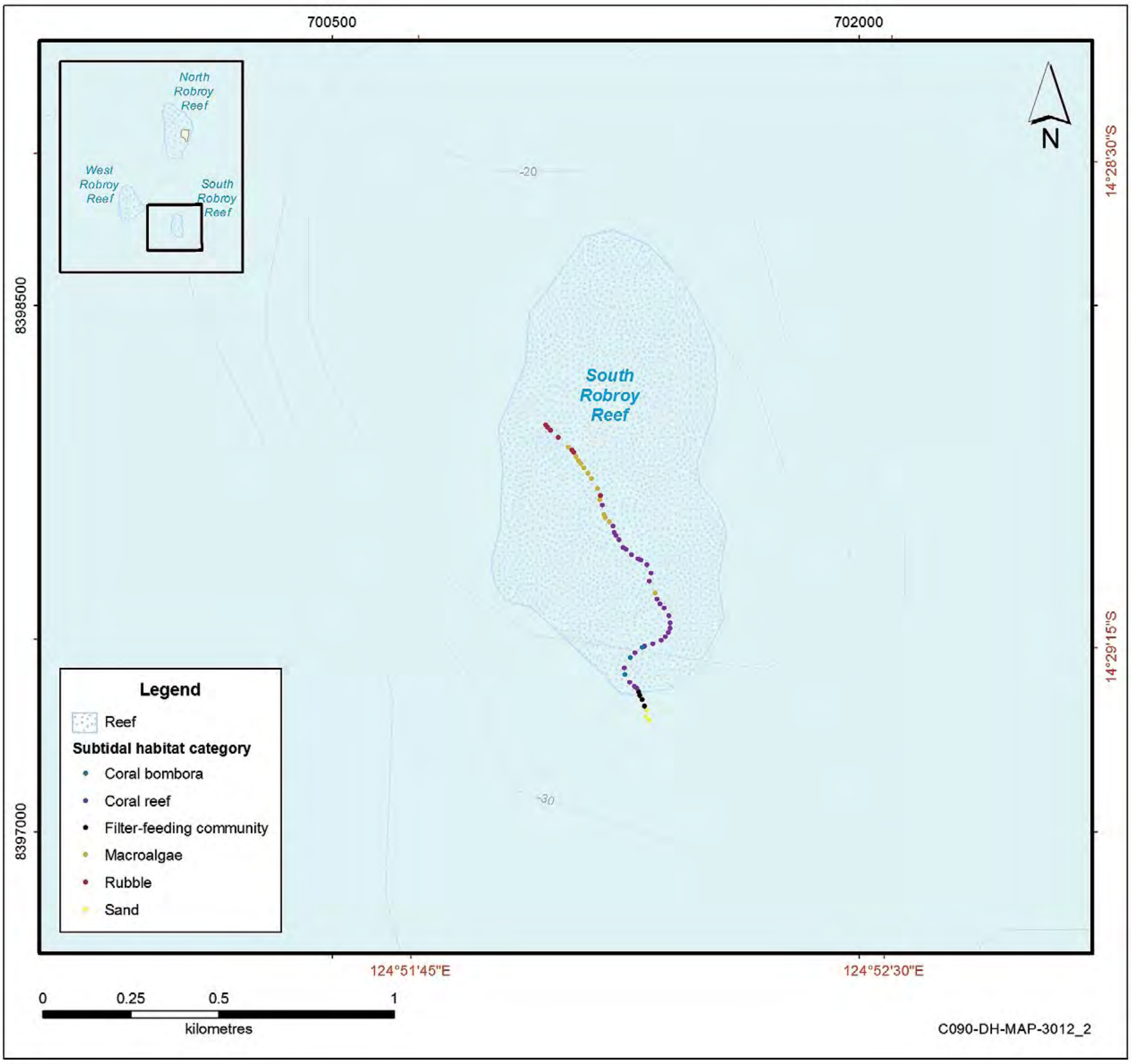


Figure 8-56: Subtidal habitats at sampling locations near South Robroy Reef

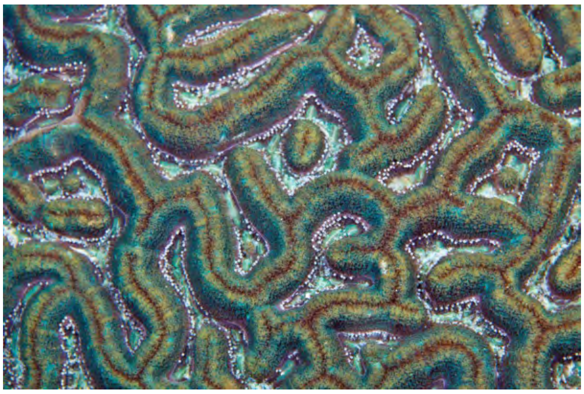
On the eastern and southern sides of the reefs, the intertidal zone was characterised by small faviids and encrusting corals. The reef edge on the southern and eastern sides is less exposed and slopes down to a depth of approximately 30 m. The upper slope supported some very large *Porites* colonies and patches of mixed coral and rubble. The deeper slope comprised mainly unconsolidated sediments with occasional sea whips and sponges.

South Robroy Reef was found to have an intertidal zone on top of the platform similar to those found at the northern and western reefs of the group, but the walls were not as steep. This reef did not have a *Sargassum* community in the intertidal zone, but instead was covered with coral rubble, sparse macroalgae and turfing algae. The outer edge of the reef was a boulder zone with scattered encrusting corals, including *Porites* and *Montipora* and encrusting coralline algae.

This community continued down a gently sloping wall on the southern side to about 20 m, where the benthic community was dominated by sponges, sea whips and soft corals.

Turbin, Berthier and Corvisart islands

Tow-camera surveys were carried out on the reefs around Turbin Island (Figure 8-58), Berthier Island (figures 8-59 and 8-60) and Corvisart Island (Figure 8-61). The 20 m contour was often quite close to shore at these islands. In these places, the narrow reef platforms extended horizontally from the islands before plunging to depth as near-vertical walls. The walls were generally dominated by encrusting, small massive, and foliose corals, and included *Porites*, *Montipora*, *Symphyllia* and *Pachyseris* as well as various faviids and mussids. In general, encrusting and small massive corals typically dominated the shallow high-energy zone, with the foliose species becoming increasingly abundant with depth.



Photograph courtesy of David Abdo

Figure 8-57: A stony coral of the mussid genus *Symphyllia*

A large *Acropora* thicket, similar to that found on South Maret Island, was encountered on the north-east side of Turbin Island. Further south along the eastern side of the island there was a greater diversity of hard corals to a depth of 15 m, beyond which the bottom community was dominated by sponges, sea whips and soft corals, including the black coral *Cirrhipathes*.

An extensive intertidal shallow coral community dominated by mixed *Acropora* species was encountered on the southern side of Turbin Island.

Berthier Island also had a very steep reef wall close to shore on all sides. The wall was covered with mixed encrusting and foliose hard corals. Below 20 m, the community was dominated by sponges, hydroids, bryozoans and soft corals.

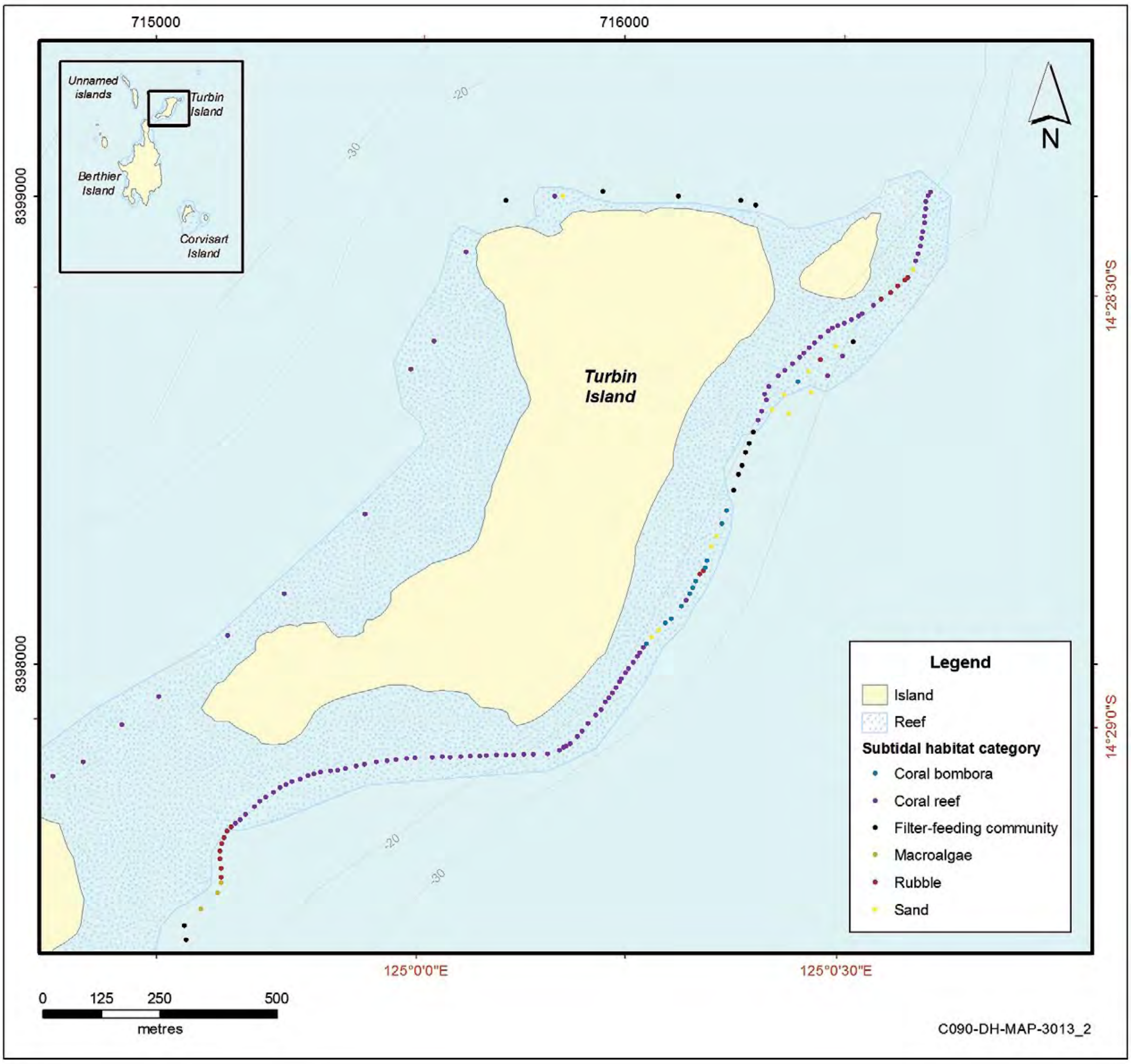


Figure 8-58: Subtidal habitats at sampling locations near Turbin Island

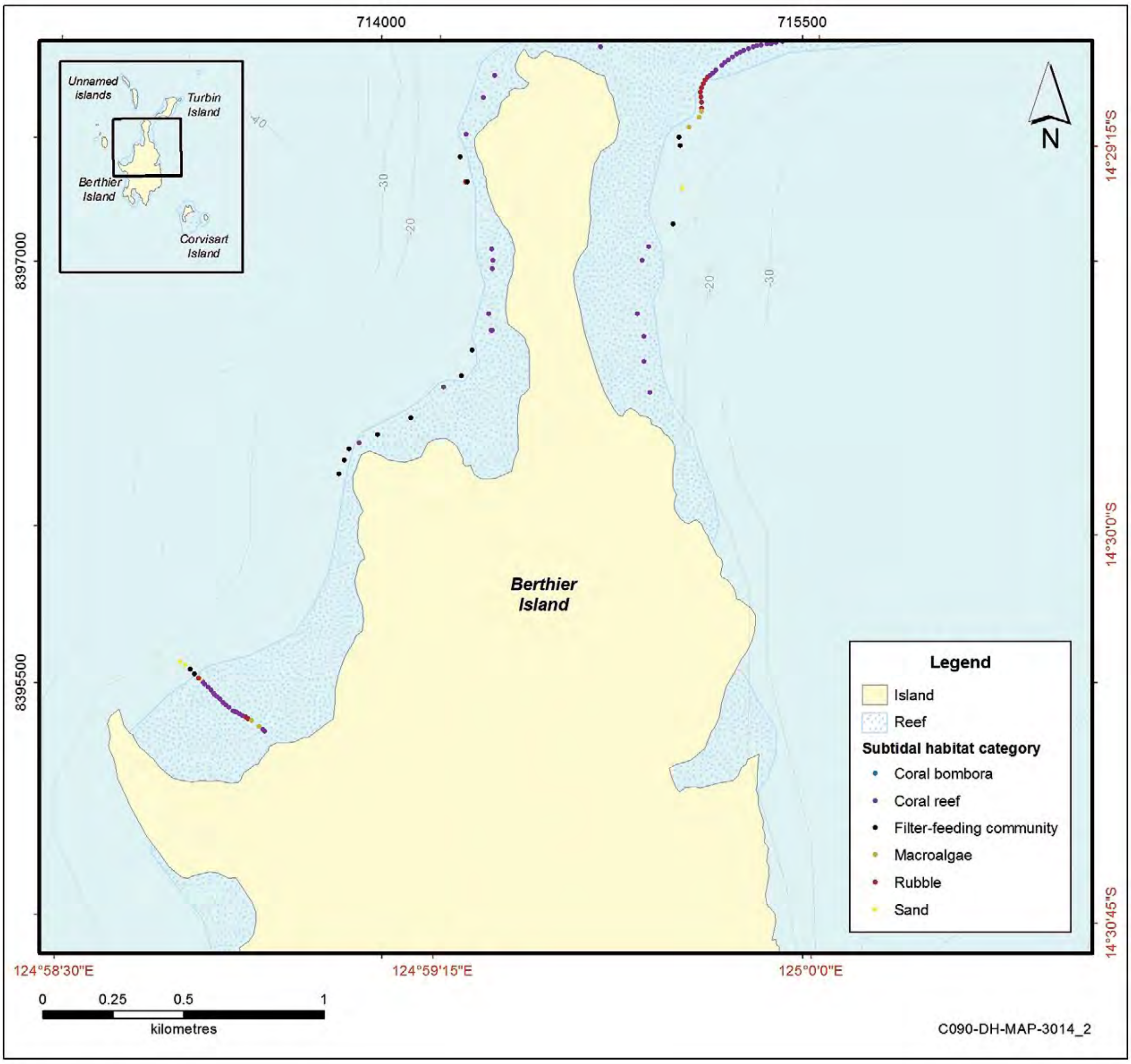


Figure 8-59: Subtidal habitats at sampling locations around the northern end of Berthier Island

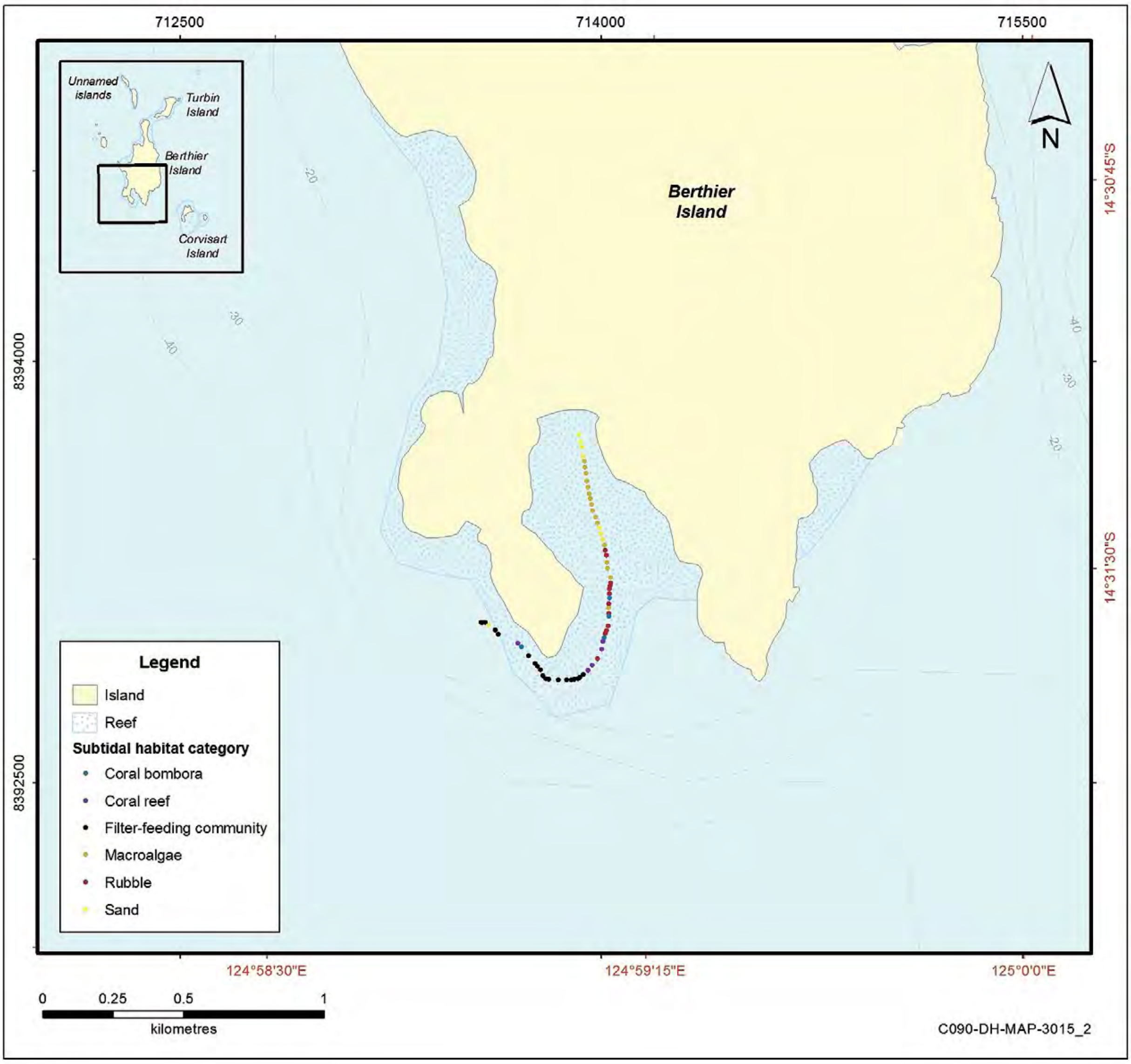


Figure 8-60: Subtidal habitats at sampling locations around the southern end of Berthier Island

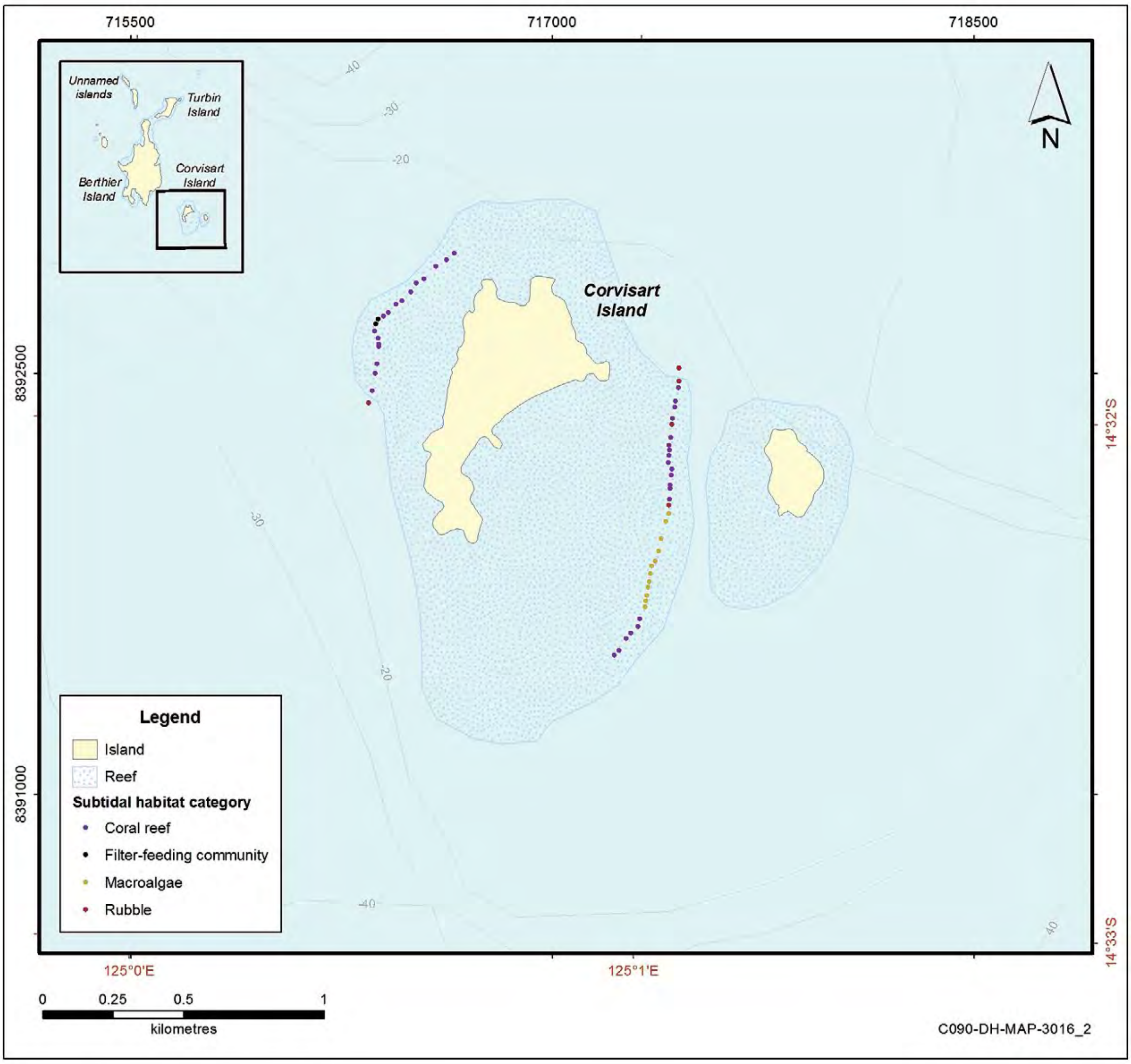


Figure 8-61: Subtidal habitats at sampling locations near Corvisart Island

The large sandy bay at the southern end of Berthier Island sloped gently from the shore before plunging steeply to depth. This was consistent with the general bathymetry of the island. The gently sloping substrates comprised sand, rubble and pavement, with sparse macroalgae and mixed coral communities dominated by *Acropora*, *Millepora* and *Porites*.

The subtidal habitats on both the east and west coasts of Corvisart Island were dominated by coral communities. The west coast was predominantly composed of pavement with sand veneers, with a medium coral cover of tabular *Acropora* in the shallow intertidal zone and of *Porites* in the subtidal zone. On the east coast, there were abundant foliose corals (e.g. *Montipora*) in the north, grading to an *Acropora*-dominated reef in the middle, and becoming *Acropora* rubble at the southern end of the island.

The "Unnamed Islands"

There was almost no platform reef on the west coast of the two "Unnamed Islands" north of Berthier Island and to the west and north-west of Turbin Island. The coast had sheer walls where live coral cover was estimated at 40% (Figure 8-62). The dominant coral communities consisted of species of foliose and encrusting morphologies, with *Montipora* probably the dominant genus. At the bottom of the wall, large coral-covered boulders and bomboras dominated, along with sponges and soft corals in the deeper water.

The subtidal substrate along the east coast of the island was predominantly composed of coral rubble, with foliose corals growing on top of the consolidated rubble at the northern end of the island, and branching and tabular *Acropora* at the southern end. A narrow intertidal reef platform was also present at the southern end of the island.

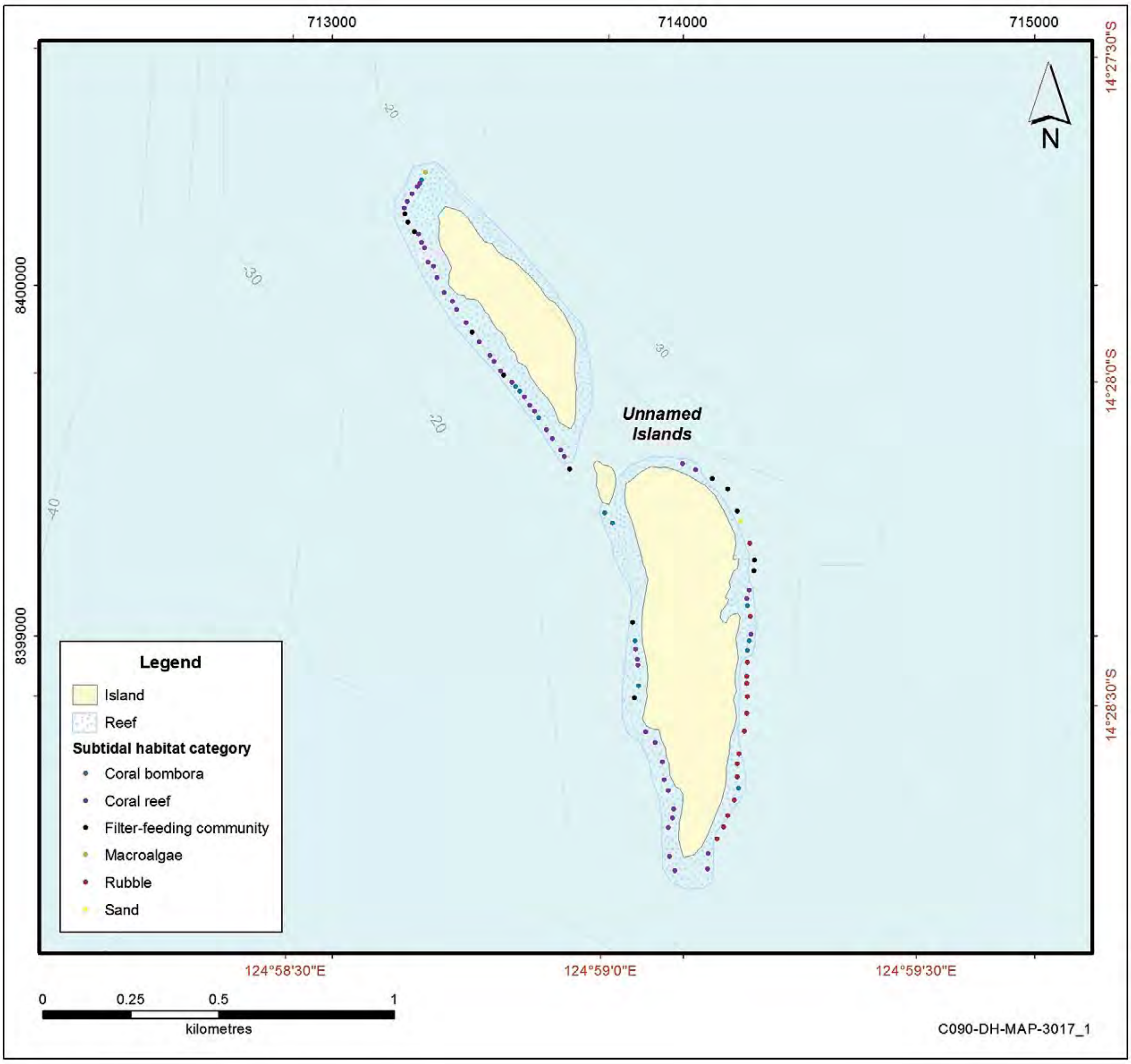


Figure 8-62: Subtidal habitats at sampling locations near the "Unnamed Islands" north of Berthier Island and west of Turbin Island

Prudhoe Island and Gaimard Island

The subtidal habitats around Prudhoe Island and Gaimard Island were found to have a moderately diverse range of habitat types and communities (Figure 8-65).

Figure 8-63: A beach and rocky headland on Prudhoe Island

An emergent rocky islet surrounded by a shallow platform lies to the north of Prudhoe Island. The platform supported a well-developed coral reef dominated by branching and small tabular *Acropora*, massive *Lobophyllia*, and *Millepora* hydrocorals. As depth increased towards Prudhoe Island the coral community became thinner, with an increasing dominance of the dendrophylliid *Turbinaria* (Figure 8-64), before grading into a sponge-garden community below 15 m. The hard substrate with its sponge garden was replaced by sandy substrates in the deeper channel between the islet and Prudhoe Island.

Photograph courtesy of David Abdo

Figure 8-64: A stony coral of the dendrophylliid genus *Turbinaria*

The shallow substrates on the northern side of the island included mud, sand, coral rubble and areas of reef. The muds showed evidence of heavy bioturbation, indicating the presence of an abundant infauna, while the sandy substrates appeared more depauperate. Areas of rubble and pavement mostly supported macroalgae, particularly *Sargassum*. Areas of diverse coral reef occurred on the hard substrates that generally fringed the deeper channels between the island and various emergent rocks close to the island. Small *Acropora* and *Pocillopora*, faviids, and encrusting corals were recorded, often with soft corals such as *Sarcophyton*. The turbidity-tolerant (or low-light-tolerant) genera *Pachyseris*, *Turbinaria* and *Astreopora* were common, reflecting the often turbid nature of the environment.

The benthic habitat in the deeper water of the western side of the island consisted of abundant filter-feeding communities, dominated by sponges, sea whips, gorgonians and hydroids.

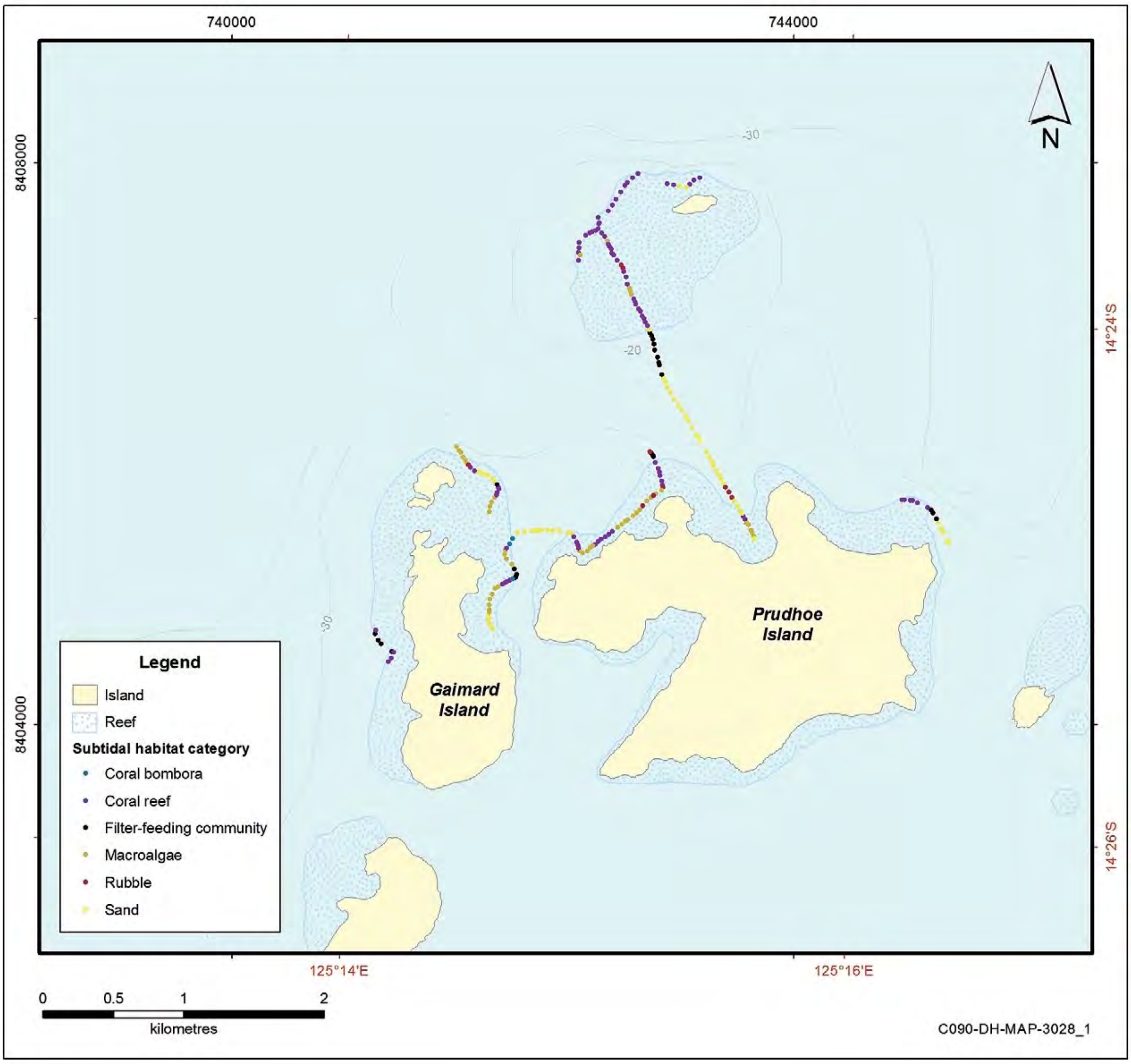


Figure 8-65: Subtidal habitats at sampling locations near Prudhoe Island and Gaimard Island

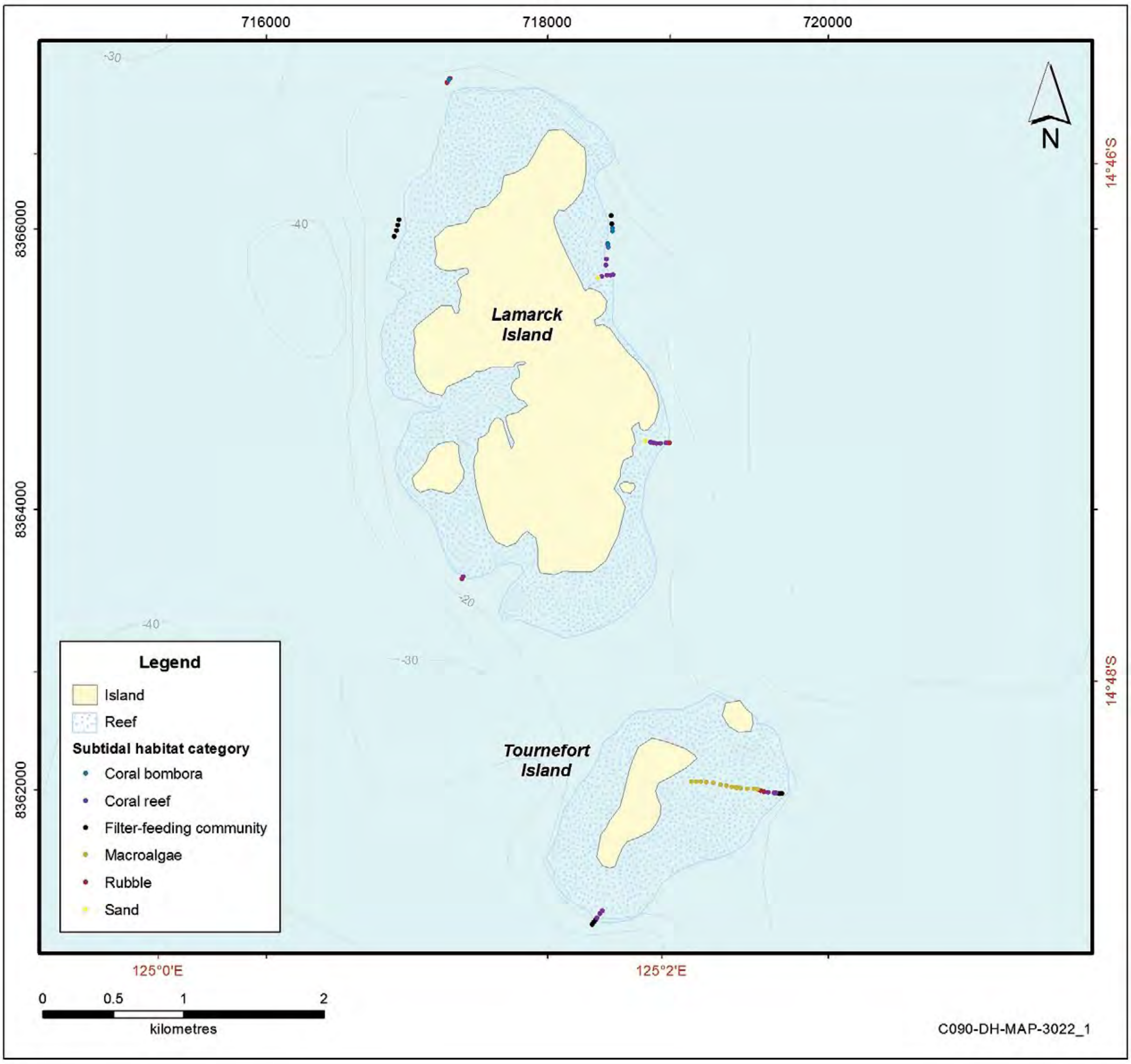


Figure 8-66: Subtidal habitats at sampling locations near Lamarck Island and Tournefort Island

Lamarck Island and Tournefort Island

The tow-camera surveys around Lamarck Island (Figure 8-66) recorded predominantly hard substrates off the north-west coast, with patches of encrusting sponges, sea whips and gorgonians. The survey off the south-west coast found a high-profile coral reef dominated by mixed scleractinian corals.

The small bay on the north-east side of the island contained a small *Acropora* thicket. This graded into coral rubble with a high diversity of hard corals and soft corals in the deeper water further offshore. Off the south-east coast of Lamarck Island there was an extensive *Acropora* thicket in the intertidal zone, interspersed with *Pocillopora*. Further offshore, the *Acropora* thicket gave way to coral rubble and sponges.

Two tow-camera transects were conducted off the southern and eastern sides of Tournefort Island. At the southern end of the island the intertidal benthic community was found to consist of a high-profile coral reef dominated by *Acropora*, *Montipora*, *Porites* and various faviids. In waters deeper than the coral-dominated zone, an abundant filter-feeding community was dominated by gorgonians, sea whips and sponges. There were no well-formed coral reefs on the eastern side of the island; the substrate was coral rubble, dominated by *Sargassum*, with occasional patches of encrusting corals.

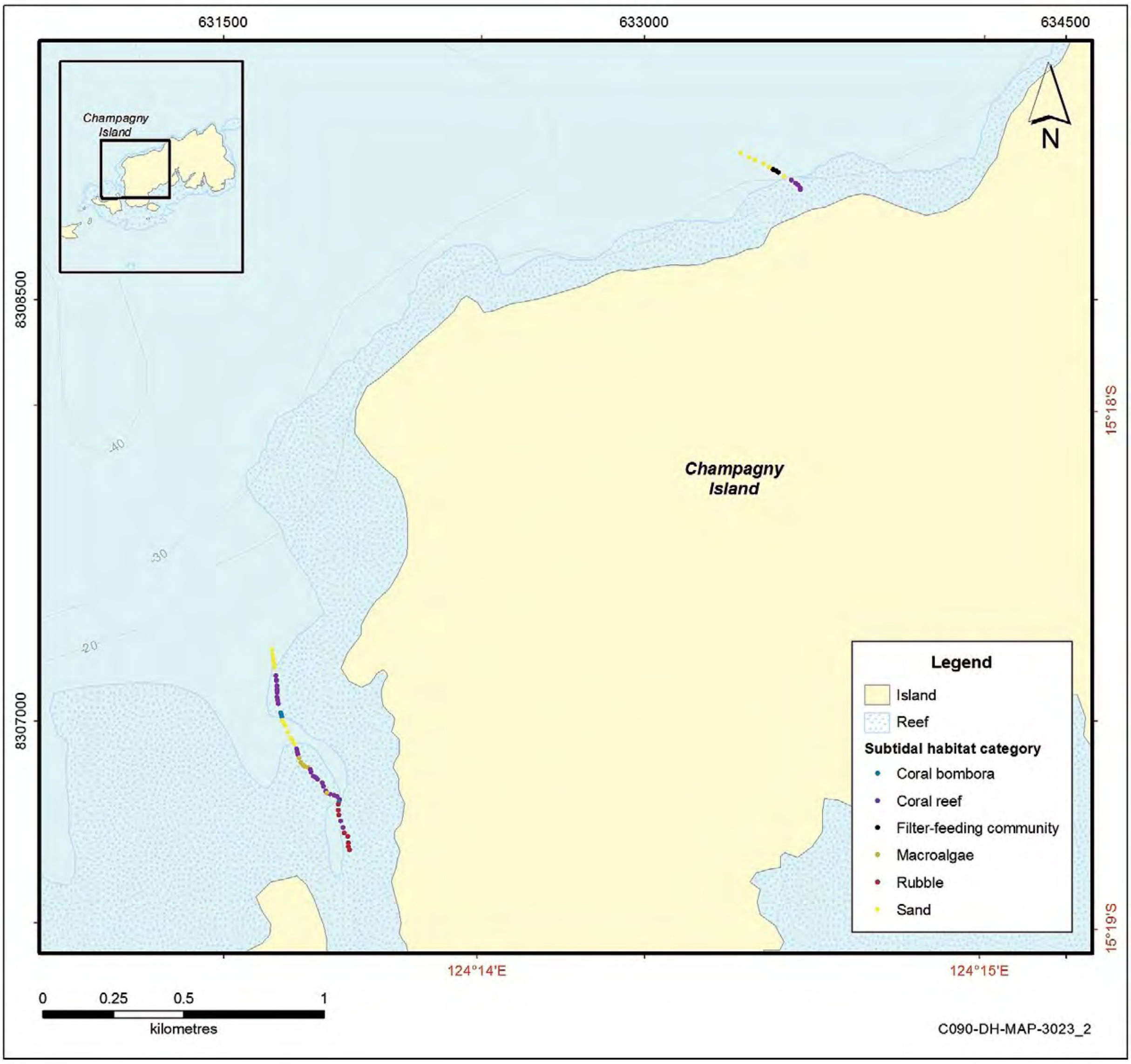


Figure 8-67: Subtidal habitats at sampling locations near the western coast of Champagny Island

Champagny Island

Habitat categories from the subtidal surveys around Champagny Island are presented in figures 8-67 and 8-68.

Reefs and pavements at Champagny Island were dominated by hard coral and occasionally by macroalgae. On the western side of the island, the intertidal zone was pavement with a scattered covering of small corymbose *Acropora*, small faviids, and macroalgae. The intertidal zone sloped gently seawards to a subtidal wall dominated by branching *Acropora*. Substrates at the base of the wall consisted mainly of sand with scattered coral bomboras of *Montipora* and *Porites*, including some forming small isolated patch reefs.

The intertidal zone on the northern side of Champagny Island consisted of low-profile limestone pavement reef with scattered faviids, *Porites*, small *Acropora* and encrusting corals. The reef edge was ragged, with deep chasms and vertical faces. Corals were abundant and diverse along the reef edge and on the reef faces. There was a sandy substrate at the base of the reef face, devoid of epibenthos other than small bryozoans.

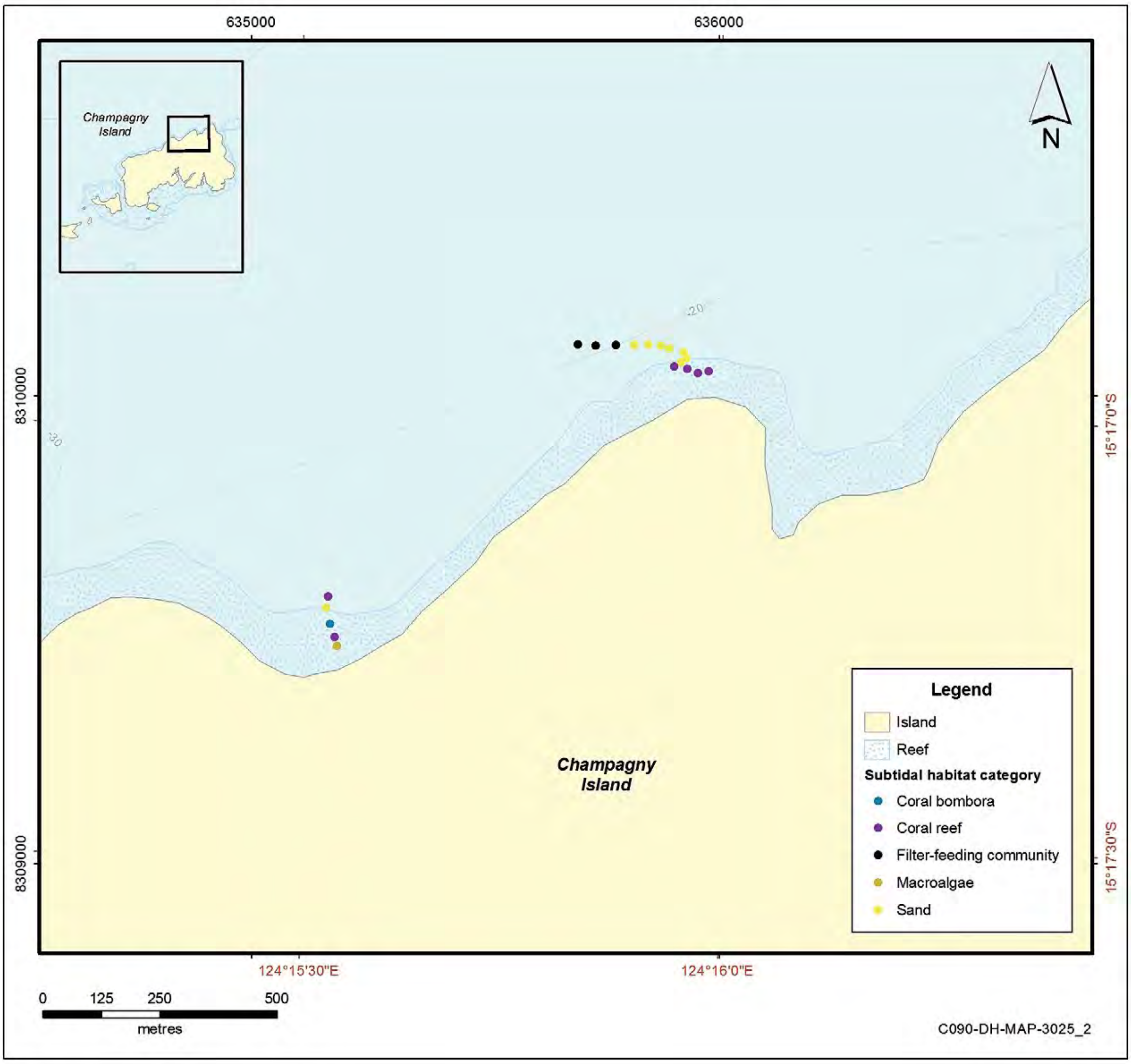


Figure 8-68: Subtidal habitats at sampling locations off the northern coast of Champagny Island

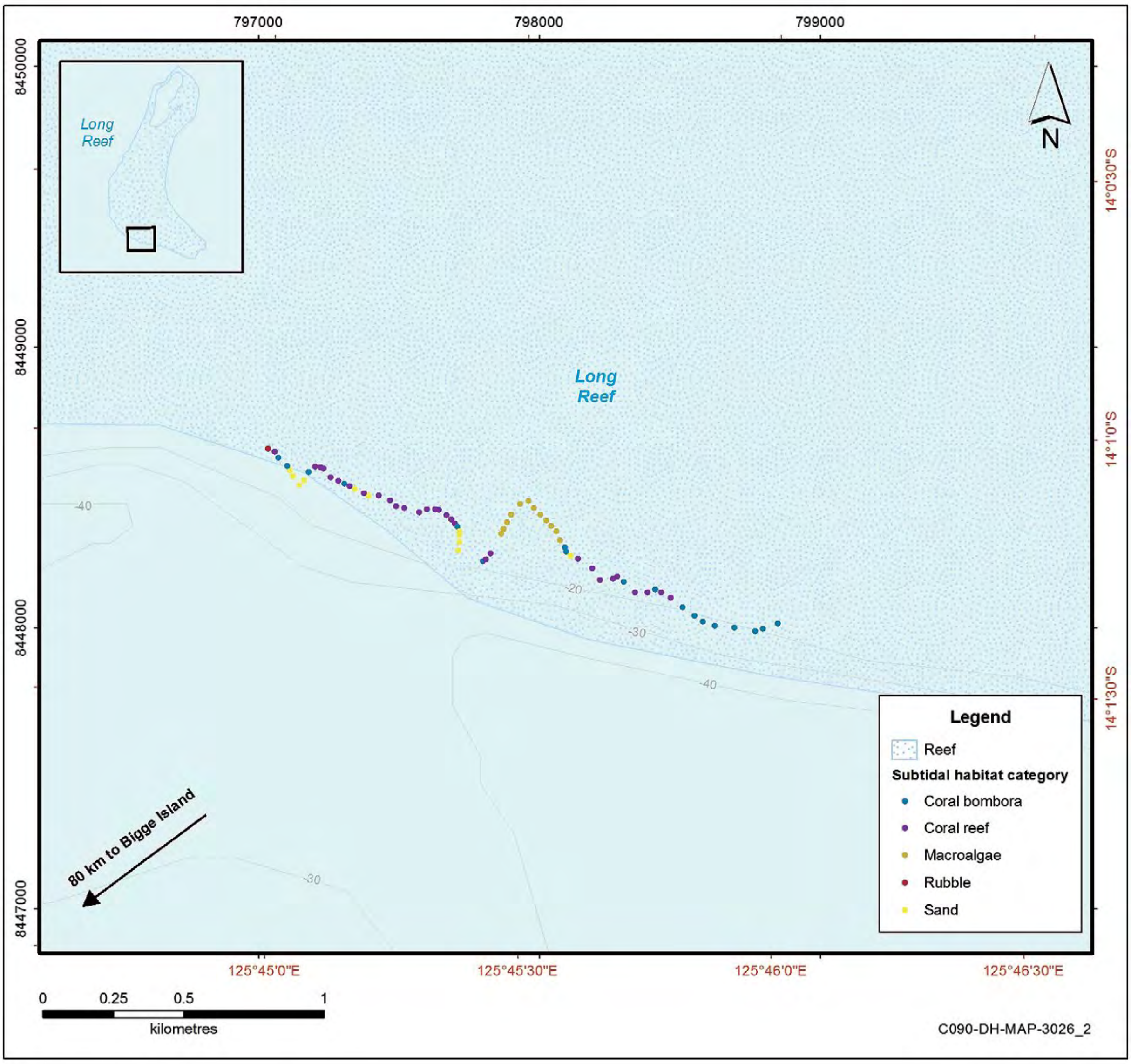


Figure 8-69: Subtidal habitats at sampling locations around the south-western end of Long Reef

Long Reef

Two tow-camera surveys were conducted at Long Reef (figures 8-69 and 8-70). The subtidal form of Long Reef is similar to that of the Robroy Reefs, with a near-vertical reef face on the seaward side, a low-profile reef top, and a reef slope on the more protected side. The coral communities were highly diverse and abundant with extensive areas dominated by the seagrass genus *Sargassum*.

The south-western reef margin was mainly high profile with steep drop-offs, and included large, coral-covered bomboras with high species richness. *Porites* colonies were a dominant component of the coral community, but many other species of various growth forms were also observed, located principally around the edge of the reef complex. Substrates on the top of the reef consisted mainly of low-profile sand and rubble and were dominated by *Sargassum*.

Habitats on the eastern side of the reef were sandy *Sargassum*-dominated areas with broken coral rubble zones and patches of coral reef.

Browse Island

The shallow fore-reef zone (less than 20 m deep) generally ranged from 50 to 200 m in width and was widest at the south-eastern end of the reef in the areas covered by the Transect 2 intertidal habitat surveys. The morphology of the seabed of the fore-reef slope reflected the energy regime of the different locations. The greater part of the oceanic swell appeared to impact the reef from a north to south-west direction where the shallow seabed was mainly bare limestone with minor corals of mostly encrusting or low massive morphologies.

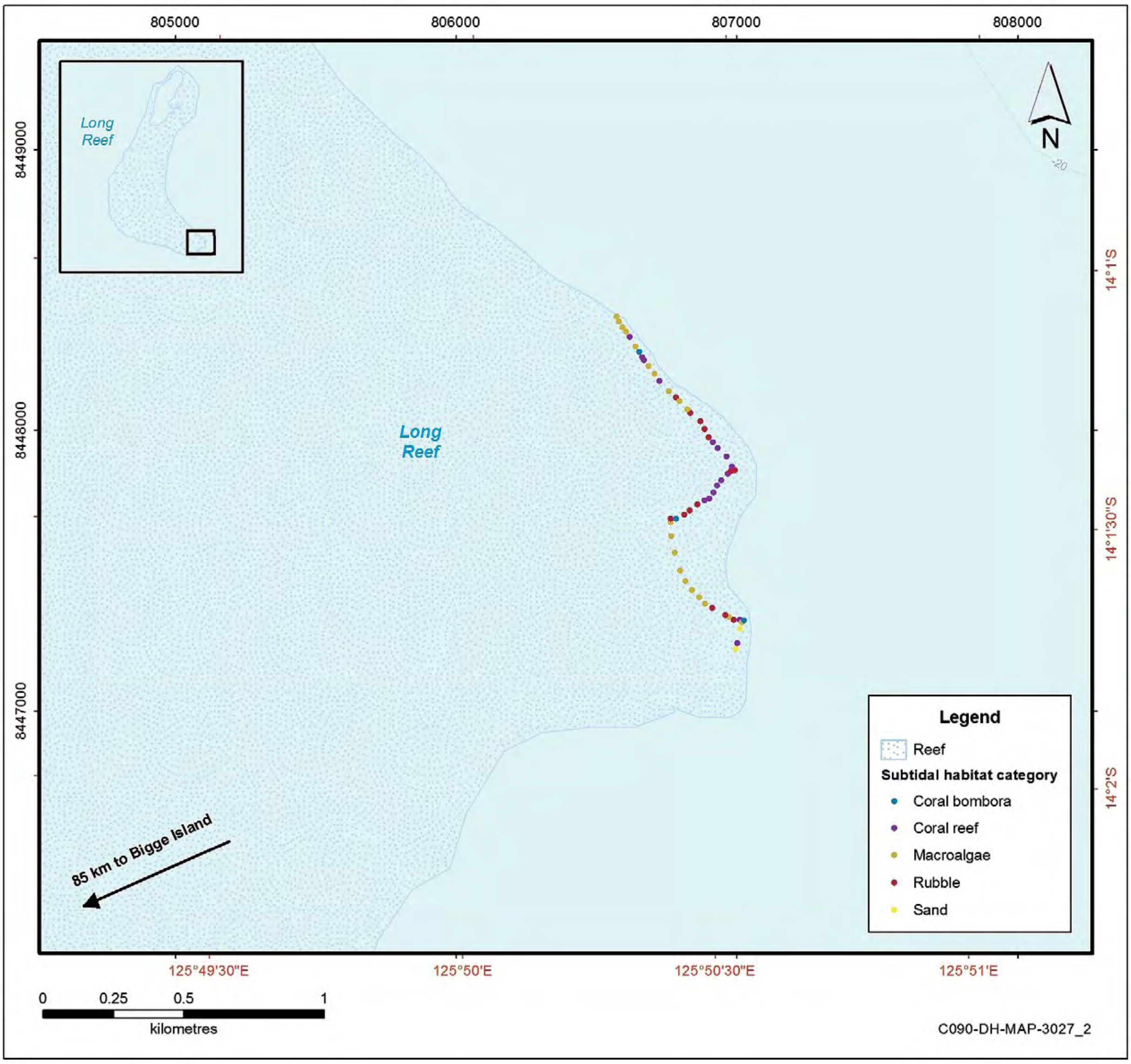


Figure 8-70: Subtidal habitats at sampling locations around the eastern edge of Long Reef

Elsewhere there was a more diverse range of substrates and community types, including broad areas of coarse sand, low-profile pavements, rubble zones and small patch reefs. Coral communities included some large monospecific thickets of branching *Hydnophora rigida*, tabular *Acropora*, and occasional large *Porites* colonies. Some parts of the fore-reef consisted of near-vertical drop-offs to 10–12 m, supporting more diverse and abundant coral communities, including *Acropora*, *Goniopora*, *Platygyra*, *Goniastrea*, *Seriatopora*, *Pocillopora*, *Montipora* and *Coeloseris*. There were large areas of *Acropora* rubble close to the reef edge on the southern side of the island that appeared to be the remains of extensive coral growth fragmented by a past storm event.

Echuca Shoal

The ROV surveys at Echuca Shoal (Figure 8-13) were limited to transects where the vehicle could maintain direction and where the research vessel could maintain safe position in the prevailing currents. The transects traversed the top of the shoal, which was 20–30 m below the sea surface, dropping down the slope to a depth of 120 m. While these transects provided some indication of habitat types, the coverage of the shoal plateau area was limited.

The ROV surveys generally encountered an environment characterised by high currents, and seabed substrates dominated by coral rubble. Relatively small colonies of *Porites* were common, but the communities had both a low species richness and a low coral abundance. The presence of occasional large rocky outcrops, generally supporting sponges, suggested that larger coral structures have occurred previously, and may still occur elsewhere on the shoal.

The dominant substrate in the shallower areas (between 20 and 30 m) was coarse sand and coral rubble, with small patches of exposed pavement. The benthic community was made up of a sparse assemblage, dominated by occasional hard and soft corals, sponges, crinoids, hydroids and turfing algae. Small *Porites* colonies were the most common of the hard corals, with faviids and acroporids present but less common. In the shallows were the remains of large coral colonies, heavily eroded and covered in encrusting and boring sponges. Soft corals included *Junceella*, *Sarcophyton*, *Dendronephthya*, *Sinularia*, *Tubipora* and the black coral *Antipathes*.

Isolated areas of exposed rock and sheer drop-offs on the slope supported a diverse and abundant filter-feeding community, consisting mainly of sponges, soft corals, hydroids and crinoids. These isolated areas of hard substrates and their associated fauna were encountered on two of the three slope surveys in depths between 55 m and 65 m.

Benthic sledge-sampling

Benthic sledge-sampling using a sledge of Ockelmann design was undertaken at 23 locations around North Maret Island and South Maret Island, between Berthier Island and the Albert Islands, at Turbin Island and at Bigge Island, at depths between 18 m and 47 m where fringing coral reefs were not expected (figures 8-11 and 8-71). Each sledge transect was approximately 500 m long and included substrates such as pavement with thin sand veneers, fine or coarse sand and coral rubble. Diverse and abundant benthic filter-feeding communities of sponges and soft corals occurred on many pavements, while in other areas only sparse sponge communities were encountered. Areas that were mainly composed of sand and shell rubble supported low to moderately diverse, but sparse, faunal assemblages.

Figure 8-71: Benthic sledge sample dominated by yellow laminar sponges and orange gorgonian fans

The benthic sledge-sampling locations in the Bonaparte Archipelago and the benthic habitat types encountered are listed in Table 8-24.

Abundant sponge gardens were found to the south, south-west and west of South Maret Island, with all four study areas crossing diverse sponge gardens. To the east of South Maret Island, the seabed was composed of fine sand and shell rubble, inhabited by diverse biota. One transect to the north (NMW-1) and one transect to the east (NME-1b) of North Maret Island were dominated by a sandy seabed with limited biota, but at another transect to the east of North Maret Island (NME 1) the seabed was composed of sand and supported a more diverse biota (Figure 8-11).

The Maret Islands

Two of the sledge-sampling transects, designated PR-1 and PR-1R, were surveyed west of the isthmus between North Maret Island and South Maret Island. Transect PR-1 produced only small numbers of specimens, including sponges, bryozoans, echinoderms, and soft corals such as *Junceella* and *Dendronephthya*. Transect PR-1R was conducted following some equipment modifications and yielded a larger sample which provided a more accurate indication of community composition. It was dominated by sponges, many of which were not encountered at other sites. At least 20 species of sponge were noted, including the specimens of the genus *Xestospongia* shown in Figure 8-72. Soft corals (octocorals), branching and fan gorgonians, echinoderms, ascidians (sea squirts) and bryozoans were also abundant.

Transect PR-2R was conducted a short distance to the south-west of transects PR-1 and PR-1R. This transect yielded a very large sample, dominated by numerous large sponges and a large number of smaller sponge species. Numerous small gorgonians, hydroids, polychaete tubeworms, echinoderms and bryozoans were also present, but only a few crustaceans and molluscs were found.

Transect PR-3 yielded a moderate to large sample, dominated by large sponges such as *Xestospongia* and approximately 11 other sponge species. Large tubeworm cases encrusted in hydroids and bryozoans were common. Approximately eight species of hydroids, at least eight species of soft corals (gorgonian fans and *Dendronephthya*), as well as a few crustaceans, fishes and solitary hard corals were collected. Numerous species of echinoderms were recorded, including crinoids, ophiuroids and holothurians.

Table 8-24: Benthic sledge-sampling locations in the Bonaparte Archipelago and the benthic habitat types encountered

Location	Transect label	Depth (m)	Sample size*	Benthic habitat type
North Maret Island				
North Maret Island	NMW-1	44–47	S	Fine sand with sparse epifaunal assemblage.
	NME-1	36–46	S	Sand and rubble with diverse epifaunal assemblage.
	NME-1b	25	S	Fine sand with sparse epifaunal assemblage.
Study Area 1 (west of North Maret Island)	PR-1	26	S†	Sponge garden.
	PR-1R	22–25	VL	Sponge garden.
Study Area 2 (west of North Maret Island)	PR-2R	29	VL	Sponge garden.
Study Area 3 (west of South Maret Island)	PR-3	18–21	M–L	Sponge gardens and coral rubble.
	PR-3R	23–26	M–L	Sponge garden.
Study Area 4 (off the southern tip of South Maret Island)	PR-4	38–40	S	Sponge garden and fine sand.
	PR-4b	41–43	M	Sponge garden.
South Maret Island				
South Maret Island (along southern perimeter)	SB-1	23–30	M	Sponge garden.
	SB-2	26–29	VL	Sponge garden.
South Maret Island (east)	SME-1	42	M–L	Sand and shell grit with diverse biota.
	SME-1b	29	L	Sand and shell grit with diverse biota.
Other islands of the Bonaparte Archipelago				
The Berthier Islands	BI-1	46	M	Hydroid, bryozoans and sparse or occasional sponges.
	BI-1b	40–46	VL	Sponge garden.
	BI-2	28–30	VL	Sponge garden.
	BI-3	45	M–S	Shell rubble with sparse or occasional sponges.
	BI-4	40	M	Sand and shell grit with sparse biota.
Bigge Island	BIG-1	25	VL	Sponge garden.
	BIG-2	28	L	Sand and shell grit with sparse biota.
	BIG-3	28	M	Sand and shell grit with diverse biota.
	BIG-4	32	M	Sand and shell grit with diverse biota.

* Sample size: S = small, M = moderate, L = large, VL = very large.

† The yield may reflect a smaller sampling effort; PR-1R is more likely to be representative.

Adjacent to Transect PR-3, Transect PR-3R produced a medium to large sample, with numerous species of sponges, large branching gorgonians such as *Junceella* species and hydroids, but only limited numbers of molluscs, crustaceans and crinoids.

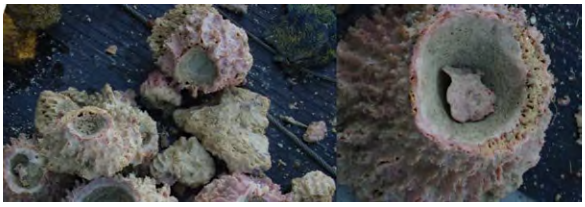


Figure 8-72: Samples of a sponge of the genus *Xestospongia* from Transect PR-1R west of North Maret Island

The sample from Transect PR-4 off the south-west coast of South Maret Island contained live material mixed with mud and sand. A small sample of biota was retrieved after flushing and contained approximately seven species of sponge (only a few of which were large), octocorals such as *Dendronephthya*, hydroids, and tubeworms encrusted in hydroids and bryozoans.

Transect PR-4b (adjacent to Transect PR-4) produced a sample that was devoid of sand and mud, and was dominated by sponges (at least 10 species) with many large individuals. Octocorals, hydroids and bryozoans were also present. A large number of echinoderm species were found, including crinoids and ophiuroids, many of which were living in large *Xestospongia* individuals. Small numbers of ascidians and crustaceans were also present.

North Maret Island

The sledge samples along transects NMW-1 (off the north-west coast of North Maret Island) and NME-1 and NME-1b (off the east coast of North Maret Island) were small, consisting mainly of fine sand and shell grit. The sample from Transect NMW-1 contained limited biota, but included small sponges, small colonial and solitary ascidians, and echinoderms such as sea urchins, brittlestars and sea stars. Crustaceans and molluscs were also present, but the absence of hydroids, octocorals and bryozoans—common at other locations—was noteworthy.

Once the fine mud had been removed, Transect NME-1 yielded a small sample of shell grit containing a diversity of live biota. There were colonial gelatinous ascidians (at least three species), octocorals of the genus *Dendronephthya*, molluscs and crustaceans; however, sponges, hydroids and echinoderms were absent.

Transect NME-1b returned a small sample of fine, light-coloured soft mud with very limited epi- or macrofauna. There were a few very small sponges, one species of hydroid, and very few crustaceans, molluscs and echinoderms (sand dollars and brittlestars). No ascidians were recorded at this site.

South Maret Island

Two transects, SB-1 and SB-2, were located parallel to South Beach at the south end of South Maret Island. A limestone pavement seabed with abundant sponge gardens was the commonest assemblage. A sample from the western transect (SB-1) was dominated by sponges, hydroids and octocorals. The sample at the eastern transect (SB-2) reflected an abundant and more diverse sponge community. At least 18 species of sponges were recorded, some of which were very large. The sample also contained at least 10 species of octocorals (including *Dendronephthya*, gorgonians, a *Junceella* species and sea whips) and a number of hydroids and echinoderms (including crinoids, asteroids, holothurians and a gelatinous spiculed sand dollar).

The two samples from transects SME-1 and SME-1b, collected off the north-east coast of South Maret Island, were composed mainly of sand and shell grit associated with a diverse biota. Transect SME-1 yielded a large sediment sample with abundant biota, including a diversity of echinoderms—crinoids, two species of pencil urchins and at least five species of holothurians. Live molluscs included a *Murex* species and a gold-lip pearl oyster (*Pinctada maxima*). At least 18 species of sponge were noted, including a number of smaller but less abundant sponges. Gorgonian fans and other soft corals were present, as well as solitary hard corals. Transect SME-1b (inshore from SME-1) produced a very large sediment sample with sparse macro- and epifauna, but included a diversity of solitary and colonial ascidians. Some hydroids, echinoderms (sand dollars, sea urchins and sea stars), small sponges and sparse crustaceans and molluscs were also present.

Other islands of the Bonaparte Archipelago

Transect BI-2 located off the north-west coast of Turbin Island represented the southern end of the basin between South Maret Island and Turbin Island. A very large sample reflected a diverse and abundant sponge garden community. At least 25 species of sponges, including large long-lived species, were recorded. Soft corals, bryozoans, ascidians, crinoids and various annelids were found, many living within the sponges. Echinoderms were diverse and included numerous species of crinoids, five species of asteroids, and at least two species of holothurians.

Four transects, BI-1, BI-1b, BI-3 and BI-4, were sampled to the west of the Berthier Islands. Transect BI-1b yielded a very large sample, dominated by a diversity of sponges and soft corals, including up to 28 species of sponges. Bryozoans, hydroids, small colonial and solitary ascidians, tubeworms and echinoderms (including basket stars) were abundant. Crustaceans, fish and molluscs were also captured. In contrast, a smaller, more moderate sample was taken at Transect BI-1, containing hydroids, an abundance of bryozoans, and some sponges.

Transect BI-3 yielded a moderate to small sample consisting largely of rubble with approximately 10 species of sponge, including *Xestospongia*. The sample from BI-4 was also composed mainly of shell rubble with sparse epibiota. Few hydroids, occasional sponges, and some gorgonians were present. The sample also included few crustaceans, no live molluscs, and a low echinoderm abundance and diversity.

Four sites were sampled off the west coast of Bigge Island, transects BIG-1, BIG-2, BIG-3 and BIG-4. Transect BIG-1 revealed an abundant and diverse benthic community dominated by sponges (up to 23 species), including various taxa with large morphologies. Also collected were gorgonian fans, *Dendronephthya*, echinoderms, bryozoans, and solitary hard corals. In contrast, Transect BIG-2 yielded a large amount of gravelly material, possibly of terrigenous origin, with little epibiota. Transect BIG-3 produced a moderate sample, including a large number of rock oyster shells, many hydroids, and some octocorals (gorgonians, *Junceella* and *Dendronephthya*). Sparse sponges and other biota were also present. Transect BIG-4 yielded a sandy, medium-sized sample, composed of small sponges, branching and fan octocorals, and small colonial and solitary ascidians.

Infauna surveys

Sediment samples were collected from eight offshore sites in September 2005 and from ten inshore sites in May 2007 to gather baseline data on the infaunal assemblages of these areas. The offshore sites were in the Browse Basin north-west of Browse Island and between Browse Island and the Maret Islands; the inshore sites were around the Maret Islands and at Berthier Island, Albert Island and West Montalivet Island (Figure 8-12). The collections were made using a Van Veen grab.

At the inshore sites, numbered 1 to 10, at least 216 taxa comprising 3492 individuals from 12 phyla were identified, representing approximately 75% of the total number of species and 88% of the total number of individuals collected from all sites, inshore and offshore (Table 8-25). Site 2 had the greatest abundance, with 1596 individuals recorded. This was primarily driven by one replicate where 1419 individuals were recorded, which was almost six times more than the next most abundant replicate at Site 9 where 247 individuals were recorded. The most diverse phylum was the Arthropoda (especially the crustacean component), represented by 77 nominal species and accounting for 35.6% of the species recorded at the inshore sites. However, the phylum Annelida (especially the polychaete worm component) was the most abundant high-level taxon, accounting for over 70% of all individuals sampled. This was largely attributable to the very high number (1378) caught in one replicate at Site 2. The Arthropoda was the second most abundant phylum, accounting for approximately 21% of the individuals sampled.

Table 8-25: Breakdown of the infaunal assemblages collected by grab-sampling from sediment at 10 inshore and 8 offshore locations in September 2005 and May 2007

Phylum	Inshore sites (1–10)				Offshore sites (11–18)				All sites			
	Species		Individuals		Species		Individuals		Species		Individuals	
	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Annelida	>45	20.8	2452	70.2	>22	23.4	183	38.5	84	29.3	2635	66.4
Arthropoda	77	35.6	746	21.4	44	46.8	148	31.2	101	35.2	894	22.5
Bryozoa	9	4.2	9	0.3	1	1.1	1	0.2	7	2.4	10	0.2
Chaetognatha	1	0.5	1	0.03	0	0	0	0	1	0.3	1	0.02
Chordata	4	1.8	21	0.6	1	1.1	1	0.2	6	2.1	22	0.5
Cnidaria	19	8.8	30	0.9	3	3.2	3	0.6	20	7.0	33	0.8
Echinodermata	19	8.8	98	2.8	7	7.4	58	12.2	19	6.6	156	3.9
Echiura	1	0.5	1	0.03	0	0	0	0	1	0.3	1	0.02
Mollusca	22	10.2	54	1.5	10	10.6	70	14.7	27	9.4	124	3.1
Nematoda	3	1.4	37	1.1	1	1.1	2	0.4	3	1.0	39	1.0
Platyhelminthes	1	0.5	4	0.1	0	0	0	0	1	0.3	4	0.1
Sipuncula	15	6.9	39	1.1	5	5.3	9	1.9	17	5.9	48	1.2
Total	**>216**	–	**3492**	–	**>94**	–	**475**	–	**287**	–	**3967**	–

At the offshore sites, numbered 11 to 18, a total of 475 individuals from nine phyla and at least 94 nominal species were collected. The phyla Arthropoda and Annelida were the most species-rich and numerically dominant, together contributing more than 70% (46.8% and 23.4% respectively) of the species identified and 70% (31.2% and 38.5% respectively) of the individuals counted. Polychaetes were represented by 51 species from 17 families, and accounted for approximately 45% of the total individuals collected. The samples collected included tube-dwelling deposit-feeders from the families Ampharetidae, Terebellidae, Magelonidae and Spionidae and members of the family Capitellidae which feed on surface deposits. Crustaceans were represented by 31 species from 13 families. Gammarid amphipods and tanaids were the most abundant taxa, accounting for 25 of the 54 individuals collected.

Photomicrographs showing examples of four of the infauna species sampled are presented in Figure 8-73.

Comparison

Both the total number of species (species richness) and total number of individuals (abundance) were greater at the inshore locations than at the offshore locations (Figure 8-74). In addition, the species richness for the inshore locations was far more variable than that found at the offshore locations.

DISCUSSION

Tropical marine intertidal environments are subject to relatively high water temperatures and periodic disturbance from cyclone activity. The high water temperatures may promote high growth rates of benthic organisms but, when extreme, can cause stress, coral bleaching and mortality. Although cyclones can also inflict periodic catastrophic impacts on benthic communities, Cyclone George traversed the area in March 2007 without causing obvious damage.

Figure 8-73: (Left to right) a bristle-cage worm of the family Flabelligeridae; a sea spider of the family Pycnogonidae; a peanut worm of the family Sipunculidae; a brittlestar of the class Ophiuroidea

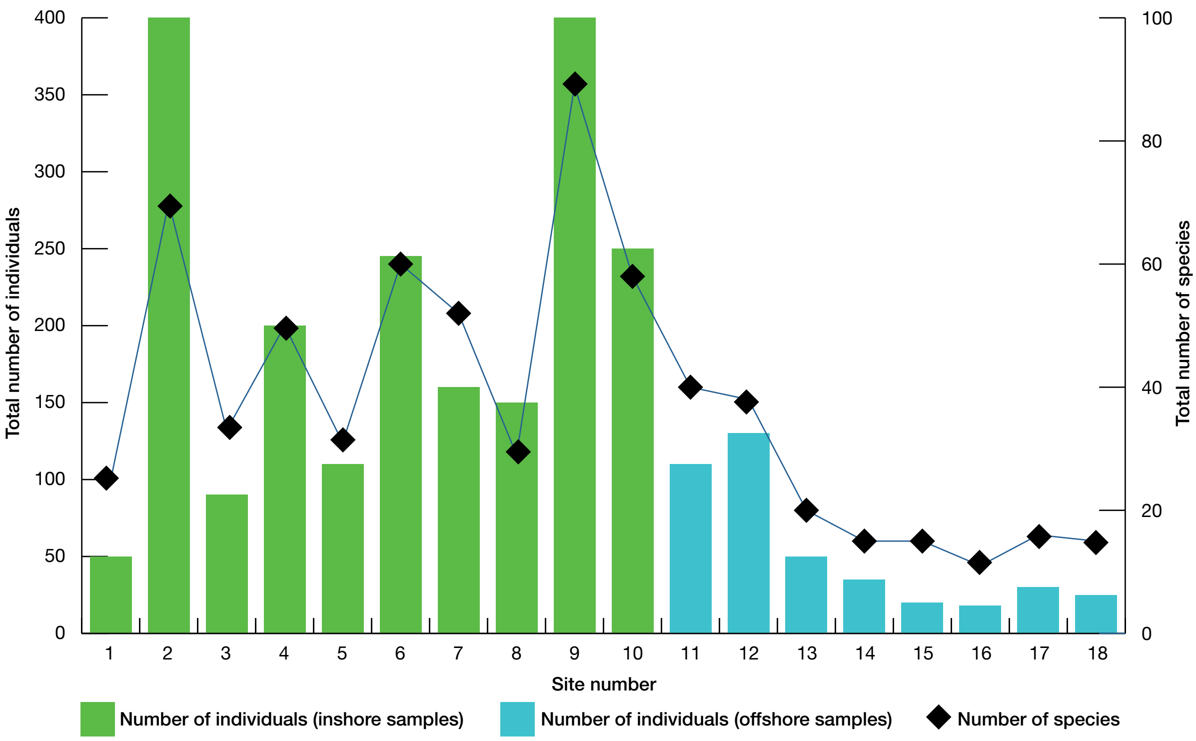


Figure 8-74: Total number of species and individuals caught in three replicate sediment samples at each sampling location in May 2007 (inshore sites) and September 2005 (offshore sites)

This study provides a detailed short-term record of the condition of the regional marine and intertidal environments, but does not include temporal information that captures dynamic processes that act over larger time-scales.

Intertidal assemblages of the Bonaparte Archipelago

Macroalgal assemblages

Of the 162 species of macroalgae recorded during this survey, the majority found at the Maret Islands are widespread in the tropical Indo-Pacific region.

Six significant macroalgal records were obtained from the Bonaparte Archipelago and Browse Island. The coralline alga *Mastophora rosea* (Figure 8-75, Table 8-3) represents a new record for Western Australia and was recorded from North Maret Island, South Maret Island and the Albert Islands. It is, however, widespread in other regions to the north, including the Philippines, Guam and Papua New Guinea, and it is expected to be widely, if sparsely, distributed in the Kimberley Bioregion.

Five hitherto undescribed species of algae were collected during the survey: a brown alga of the genus *Sargassum* was collected at South Maret Island, and four red alga species of the genera *Ceramium*, *Crouania*, *Hypoglossum* and *Martensia* were collected at the Maret Islands and Browse Island (Huisman in press, Huisman in prep.).

Figure 8-75: The coralline alga *Mastophora rosea*, a new record for Australia

Seagrass assemblages

Only two species of seagrass were observed during this study, *Thalassia hemprichii* and *Halophila ovalis*, and, with the exception of the *Halophila ovalis* meadow recorded on the eastern side of Albert Island, neither species was found in dense meadows by the survey teams. This is consistent with previous studies from the region, which recorded only four species of seagrass from the northern islands in the Kimberley and noted the absence of well-developed seagrass meadows (Walker 1996, 1997). The best-developed seagrass meadows in the Kimberley Bioregion occur further to the south-west in the Buccaneer Archipelago.

The two species of seagrass found around the Maret Islands are also among the most common species in the Buccaneer Archipelago. *Thalassia hemprichii* is widely distributed there and covers up to 50% of parts of the intertidal flats (Walker 1995).

Intertidal mollusc assemblages

The upper littoral zone of the rocky shores around the Maret Islands and the Montalivet Islands is usually made up of basalt or laterite rocks (or, in some places, both) and with beachrock present at some sites. The basalt and laterite habitats support a well-developed mollusc assemblage; however, the beachrock is virtually barren. The depauperate nature of the beachrock mollusc assemblage probably reflects periodic covering of the rock with sand.

The suite of rocky-shore mollusc species was typical of upper littoral rocky shores throughout northern Australia, except for the presence of two Kimberley endemics, the littorinid *Tectarius rusticus* and the neritid *Nerita reticulata*. The absence of any species of the cerithiid genus *Clypeomorus* from the molluscan fauna was also notable. The mytilid *Brachidontes ustulatus* is a very common crevice-dweller on rocky shores of the Pilbara region of Western Australian, but only a few individuals were found in the Bonaparte Archipelago, at the Maret Islands. Generally it was replaced in equivalent habitats by *Isognomon nucleus*.

The molluscan fauna on the reef flats of the islands of the Bonaparte Archipelago was dominated by a limited suite of taxa. Although a moderate diversity of cowries of the genus *Cypraea* (some 23 species) is present in the Bonaparte Archipelago, none of these were common, and many are represented in the collections and observation records by only single specimens. Other herbivorous gastropods were similarly uncommon. Cones were represented by a limited suite of species. The larger cones that prey on fish (and which, incidentally, are also dangerous to humans) were common. *Conus textile* was particularly common and *Conus geographus* and *Conus striatus* were also collected.

The molluscan fauna of the Bonaparte Archipelago includes more species than that of Browse Reef, but many fewer than the presently known molluscan fauna recorded in the Pilbara region (Table 8-26). The number of bivalve and gastropod species obtained during this study is less than half that recorded from the Montebello Islands and the Dampier Archipelago in the Pilbara region (Slack-Smith & Bryce 2004; Wells 1992; Wells, Slack-Smith & Bryce 1993).

Table 8-26: The number of species of bivalves and gastropods recorded at six localities in north-western Western Australia

	Maret and Montalivet islands	Browse Island	Montebello Islands*	Dampier Archipelago†	Rowley Shoals‡	Scott Reef§
Bivalves	67	22	223	300	84	50
Gastropods	161	118	320	287	166	212
Total	**228**	**140**	**543**	**587**	**250**	**262**

* Wells, Slack-Smith and Bryce (1993) and Wells, Slack-Smith and Bryce (2000).

† Slack-Smith and Bryce (2004).

‡ Wells and Slack-Smith (1981).

§ Bryce and Whisson (2009).

This is probably due in part to the far greater diversity of habitats that has been surveyed in the Montebello and Dampier archipelagos in the Pilbara region than has been the case in the Bonaparte Archipelago, and in part to the less intensive survey effort so far applied to the Bonaparte Archipelago and the Kimberley region. In addition, the Dampier Archipelago and Montebello Islands datasets include collections from subtidal habitats as well as from sand- and mudflat and mangal habitats. The study reported on in this chapter was designed to sample intertidal habitats only[11] and mangals are poorly developed in the Bonaparte Archipelago.

Previous research has identified a significant Pacific element among the reef molluscs at the outer atolls of the Oceanic Shoals Bioregion (including Browse Island) that is not evident on the fringing reefs of the Kimberley coast (Wells 1989; Willan 2005; Wilson 1985; Wilson & Allen 1987). The species referred to are oceanic Indo-West Pacific species and their failure to colonise the Kimberley reefs is possibly attributable to a lack of habitats suitable to sustain successful populations. Evidence that oceanic taxa occasionally reach the nearshore reefs, but do not establish sustainable populations, comes from two species of predatory gastropods, *Drupina grossularia* (a muricid) and *Vasum ceramicum* (a vasid); these are common in reef-front and reef-crest habitats of oceanic coral reefs, including the reef at Browse Island, but were only represented by single specimens in collections made by this study from the islands of the Bonaparte Archipelago. Other normally common reef species that were recorded rarely at the Bonaparte Archipelago were *Conus miles* (a single very old live specimen collected at South Maret Island) and *Conus vexillum* (recorded as a single dead shell at West Montalivet Island).

[11] Incidental samples of molluscs were collected during sledge-sampling surveys and grab-sampling surveys (Table 8-25) but are not included in the analyses in this chapter.

Fish assemblages

Sampling of fish assemblages in intertidal pools in the platform reefs around Browse Island, the Montalivet Islands group and the Maret Islands indicated similar levels of species richness among these reefs. However, the data collected at these reefs by this study are qualitative, not quantitative, because the location of the sampled pools within the intertidal range, the habitat structure within the pools, and the size of the pools all influence the composition of the fish assemblages found at each locality.

Intertidal fish assemblages on the surveyed islands featured a similar suite of species, with the families Pomacentridae, Labridae, Apogonidae, Serranidae and Blenniidae generally being the most abundant. These families are well represented throughout the Bonaparte Archipelago and northern Western Australia (Allen & Swainston 1988). While some taxa were recorded from only a few of the sites, this is likely to reflect sampling intensity and such taxa are highly unlikely to be restricted to these sites. Further, the intertidal rock pool fauna generally represents a only subset of the local fish assemblage and the species composition in the pools is expected to change daily.

Coral assemblages

The fringing reefs of the Maret Islands and other islands of the Bonaparte Archipelago support well-developed coral assemblages, generally with a high level of cover of live coral, especially towards the lower littoral zone. Exposed reefs on the northern and western sides of the Maret Islands supported coral assemblages which were different from those of the more sheltered reefs on the eastern and southern sides of the islands. All of the surveyed islands in the Bonaparte Archipelago displayed similar patterns of community composition in relation to their degree of exposure to oceanic swell. While reef morphology and coral-community composition were broadly consistent among fringing reefs of the bioregion, there was a degree of variability in species richness, abundance and the species composition of the communities.

The high-energy areas of all of the islands surveyed supported a suite of massive and encrusting corals, generally dominated by robust domal faviids on the reef front. The reef edges were typically steep with a high coral cover of diverse branching and foliose morphologies. The base of the fore-reef slope, in waters approximately 8–15 m deep, appeared to support a high diversity of corals. These robust, reef-building assemblages have formed wide-ranging platform reefs extending seaward from the island shores.

Low-energy shores, generally on the eastern and southern sides of islands in the archipelago, or sheltered by peninsulas, did not support well-developed fringing reefs with wide rock platforms. Instead there was usually a reef consisting of banks of *Acropora*, with or without a fringe of faviids and other massive corals along an indistinct seaward edge sloping into a subtidal *Porites* zone at depths of 10–15 m. The reefs along the eastern and southern shores of the Maret Islands, and of Don Island and Patricia Island in the East Montalivet Islands group, are examples of fringing *Acropora* banks of this kind.

The intertidal coral assemblages on the low-energy leeward reefs were very different from those of the high-energy seaward reefs. Differences in coral-community composition and coral morphology were reflected in the associated invertebrate fauna. For example, the giant clam *Tridacna maxima* was common on the rock platforms of seaward reefs, whereas *Tridacna squamosa* was dominant in the *Acropora* banks and shallow lagoons of the leeward reefs.

Two coral assemblage types at the Montalivet Islands did not appear to be represented at the Maret Islands or at any of the other surveyed islands. These were a diverse and abundant *Acropora*-dominated intertidal community of small digitate and tabular colonies, and a community dominated by large tabular *Acropora* colonies with a diverse assemblage of subdominant species.

The corals at the Maret Islands and the other islands surveyed appeared to be very healthy and there was little evidence of excessive predation, coral mortality or bleaching. In comparison, coral reef communities on emergent offshore reefs in the Oceanic Shoals Bioregion such as Ashmore Reef and Scott Reef have been severely affected by overfishing and by coral-bleaching events (Kospartov et al. 2006; Smith, Gilmour & Heyward 2008).

Intertidal coral species richness

A total of 275 scleractinian coral species were recorded from the intertidal reefs around the Maret Islands, the Berthier Islands and the Montalivet Islands during this study (Table 8-27). The high number of new records from the surveys (54 new records for the Kimberley Bioregion, two of which are new records for Australia) reflects the relative lack of research effort in the region prior to 2006 (Table 8-27).

The high coral species richness encountered throughout the study area is a consequence of the extensive development of fringing-reef communities throughout the Bonaparte Archipelago. A total of 221 coral species were recorded in the intertidal zone at the Maret Islands alone; this exceeds the total number recorded at the other islands in the archipelago. However, this is likely to be an artefact of the greater sampling effort expended at the Maret Islands. Direct comparisons of species tallies among islands are not valid because of differences in sampling effort between reefs. While each reef site was surveyed for a full low tide, the effective survey effort achieved for each reef was dependent on the stage of the tidal cycle at which the site was surveyed, the timing of the low tide and the relative levels of experience of the coral taxonomists and scientists.

The Kimberley Bioregion is characterised by large tidal ranges, with amplitudes of up to 11 m in some places, particularly in the south. Sessile invertebrates of intertidal reefs may therefore experience long periods of exposure to air and sun during periods of low tide. Some species of faviids are relatively tolerant of these conditions and are the most common corals on the midlittoral reef flats of seaward fringing reefs.

Table 8-27: Genus and species richness of scleractinian coral reef communities in northern Western Australia

	This study*	Ningaloo Reef†	Dampier Archipelago†	Rowley Shoals†	Scott and Seringapatam reefs†	Ashmore Reef†	Kimberley Coast‡
Species	275	217	223	188	219	255	181
Genera	59	54	57	52	56	56	62

* Records from the intertidal zone only (all other studies include intertidal and subtidal records).

† Veron and Marsh (1988).

‡ Marsh (1992)

Coral diversity increased through the lower littoral zone and into the sublittoral zone, probably reflecting the more benign conditions in deeper waters where regular exposure and drying are not major influences.

It is not possible at present to compare the coral species richness of the Bonaparte Archipelago reefs with other parts of the Kimberley Bioregion, such as the Buccaneer Archipelago. There is very little published information on coral assemblages of the broader Kimberley coast and there have been marked differences in the intensity of survey effort among sites. Marsh (1992) reported a total of 181 species from 62 genera, following an intertidal and opportunistic snorkel study of the Kimberley coast and nearshore Kimberley islands. This expanded greatly on the previous work of Veron and Marsh (1988), who reported 102 species from 45 genera. The present study has expanded further on all previous studies in the region.

Although the large tidal range allowed some subtidal corals to be sampled, only the intertidal zone of each island was investigated during the coral diversity surveys. It follows that the coral fauna may be substantially richer than indicated by this study. The total number of species has been estimated as being closer to 400, which would rank this bioregion among the most species-rich coral bioregions in the world (Professor Charlie Veron, Centre for Marine Studies, University of Queensland, pers. comm. 2007).

Intertidal assemblages of the Browse Island reef complex

The coral reefs, habitats and biota of the Browse Island reef complex are similar to those of the outer shelf atolls, banks and platform reefs that characterise the Oceanic Shoals Bioregion and differ markedly from those around the islands of the Bonaparte Archipelago, which are representative of the more turbid, macrotidal, fringing nearshore reefs and rocky shores that characterise the Kimberley Bioregion. The molluscan intertidal assemblage was limited and strongly dominated by widespread Indo-West Pacific oceanic species that do not occur on the inshore reefs of the archipelago.

The habitats and biotic assemblages at the Browse Island reef complex are believed to be broadly characteristic of oceanic coral platform reefs throughout the Indo-West Pacific region. Geomorphically and biologically, this reef closely resembles Cartier Reef approximately 200 km further north and described by Berry (1993), Kospartov et al. (2006) and Skewes et al. (1999). However, the small area and limited variety of the intertidal habitats at Browse Island, the elevation of the reef flat and the limited shallow subtidal area appear to have limited the development of benthic communities on the reef.

The elevation of the reef platform appears to restrict the development of coral communities on the reef flat. Coral diversity was greatest on the fore-reef face, reef front and in the midlittoral platform pools. The pools appeared to be in a late stage of infill (coral growth and sedimentation) suggesting that Browse Reef is approaching biogeomorphic senility.

Long-term harvesting of reef animals may also have depleted the stocks of target species such as clams (*Tridacna* spp.), trochus and holothurians (Clay Bryce, Department of Aquatic Zoology, Western Australian Museum, Perth, pers. comm. 2007).

Macrophytes such as seagrasses and macroalgae of the genus *Sargassum*, which are abundant in inshore areas, do not appear to occur in the intertidal or shallow subtidal zones at Browse Reef.

Biogeographical affinities of the reef invertebrates of the Bonaparte Archipelago and Browse Reef

The coastal fringing reefs of the Bonaparte Archipelago and the oceanic platform reef of Browse Island are ecologically different in many respects and the intertidal molluscs of the two differ accordingly. Species of the coastal Kimberley reefs were generally found in the relatively turbid conditions of nearshore continental localities, while the species of the Browse Island reef complex, like those of other shelf margin reefs of the Oceanic Shoals Bioregion, are found in the clear oligotrophic oceanic waters of open oceans. In other words, while both the shelf margin reefs and the coastal reefs have Indo-West Pacific affinities, their species tend to have separate oceanic and continental ecological distributions within the wider biogeographical region.

These biogeographical generalities are illustrated here using the example of shelled macromolluscs. As expected, the restricted habitats of the Browse Island reef complex support a much smaller invertebrate fauna than do the much more diverse habitats of the Kimberley coastal reefs. For example, this study recorded 140 species of shelled macromolluscs at Browse Reef, little more than half the number (235) recorded in the Bonaparte Archipelago. Furthermore, of the total, only 55 Browse macromollusc species were also recorded on the fringing reefs of the Bonaparte Archipelago. Stated differently, this means that only one-quarter of the 235 shelled macromollusc species found in the Bonaparte Archipelago occur also at Browse Reef.

Table 8-28 is based on what is known of the regional geographic distributions of the molluscs identified during the present study. Four categories of biogeographical distribution pattern are applied.

Category 1 includes species found in the respective study areas that are also widespread throughout most of the Indo-West Pacific region. Species in Category 2 are found in the respective study areas and in the adjacent Central Indo-West Pacific region. Species in categories 3 and 4 are endemic to northern Australia or to the North West Shelf.

Table 8-29 shows the biogeographical affinities of the gastropod and bivalve molluscs from the Bonaparte Archipelago (as represented by the Maret Islands, the Albert Islands group and the Montalivet Islands group) and from Browse Island in terms of the categories listed in Table 8-28.

The molluscan fauna of the fringing intertidal reefs of the Bonaparte Archipelago is typical of the nearshore faunas of the North West Shelf. Most of the species found on the reefs of the Maret Islands and the Montalivet Islands have extralimital distributions either throughout the Indo-West Pacific or within the more restricted Central Indo-West Pacific regions. A significant component is endemic to the North West Shelf or more widely in the continental shelf habitats across northern Australia. However, even this suite of regionally endemic species belongs to Indo-West Pacific genera.

In contrast, the Browse Reef molluscan assemblage is dominated by species with wide distributions in oceanic habitats throughout the Indo-West Pacific, with very little regional endemism.

Subtidal assemblages

Subtidal assemblages around the Maret Islands included coral and other filter-feeding communities and soft-substrate communities. Coral communities were widespread, dominating almost all areas of rocky seabed in water depths between 0 m and 8 m below LAT (Lowest Astronomical Tide), and extending to a depth of at least 15 m in places where there was suitable hard substrate. Although diversity studies of these subtidal communities have not been undertaken, it is evident from tow-camera surveys and surveys at extreme low tide that they are both highly diverse and varied in form and in species composition.

Filter-feeding communities with only a small representation of scleractinian corals were widespread and particularly well developed in deeper areas (more than 15 m) of hard substrate and high tidal flows. These communities were dominated by invertebrates such as sponges and soft corals.

The areas on the energy-rich west coast of South Maret Island all include rocky benthic habitats supporting diverse filter-feeding communities. Similar communities were encountered in benthic habitats bordering Turbin Island, Bigge Island and the Berthier Islands.

The composition of the filter-feeding communities differed between sites and ongoing sampling continued to add additional species, particularly of sponges, indicating that this element of the benthic fauna of the region is rich in species and that much is yet to be learned about its composition.

Table 8-28: Biogeographical distribution categories for molluscs identified during this study

Category	Region	Distribution pattern
1	Indo-West Pacific	The wide tropical area of the Indian and western Pacific oceans, including the northern Australian region
2	Central Indo-West Pacific	The waters of the Indo-Malay Archipelago, that is, Indonesia, Malaysia, the Philippines, New Guinea and the mainland coast of South-East Asia (roughly equating with the “coral triangle”, probably the world’s richest centre of marine biodiversity)
3	Northern Australia	The tropical coast of northern Australia from Shark Bay in the west to southern Queensland, including the northern parts of the western and eastern overlap zones (Wilson & Gillett 1971)
4	North West Shelf	The geomorphic region known as the North West Shelf, from the North West Cape to Melville Island (Purcell & Purcell 1988).

Table 8-29: Affinities of the gastropods and bivalves from the Bonaparte Archipelago and Browse Island with four biogeographical distribution categories

Location	Number of species	Percentage of species represented within each biogeographical category			
		Indo-West Pacific	Central Indo-West Pacific	Northern Australia	North West Shelf
Bonaparte Archipelago	232	80	5.6	5	9.3
Browse Island	140	95	2.5	0	2.5

Seabed habitats

Areas of mud and fine sand are widespread on the outer shelf and slope in the Browse Basin, indicating that it is a depositional area where fine sediments and detritus accumulate. However, there were also large sand waves in parts of the basin, showing that in these locations there were strong seabed currents. The sand waves are likely to move in response to seasonal changes in the currents and therefore substrate instability is expected to limit the development of infaunal communities in this habitat.

Along the transect across the middle shelf between Browse Island and the Maret Islands the seabed also generally consisted of uniform soft sediment substrates dominated by infauna. However there were areas of exposed pavement and some features of high relief with moderately rich epifaunal assemblages.

Substrate was much more varied on the inner shelf, such as around the Maret Islands. Exposed rock pavement and rock outcrops were common on this inundated terrestrial topography and there were extensive areas with diverse epifaunal invertebrates and associated demersal fishes. Moderate-density filter-feeding communities (sponge gardens) growing on exposed areas of hard substrate at depths below 20 m were widely distributed along the western side of North Maret Island and Berthier Island, on the south side of South Maret Island and on the northern side of Turbin Island. They were also found in limited surveys around Bigge Island. All areas of exposed reef in deeper areas within the archipelago are likely to support similar filter-feeding communities.

Infauna

Annelids (particularly polychaetes) and arthropods (particularly crustaceans) were the most numerous organisms encountered in the sediments at both inshore and offshore locations. This is consistent with other studies in the Timor Sea region, which also encountered high numbers of polychaetes and crustaceans (Heyward, Pinceratto & Smith 1997).

The diversity and composition of the infaunal assemblage appears to be related to water depth, but is likely to be influenced by a number of other factors, including oceanographic conditions, productivity rates, availability and range of food sources and habitats, and sediment grain-size composition.

Inshore areas are likely to be exposed to greater variability and a wider range of environmental influences than offshore areas, and this may lead to increased species diversity and abundance, as suggested by Alongi (1989). Similarly, inshore areas are likely to display greater local variability in sediment grain-size distribution than offshore locations, increasing the range of habitats available to infaunal species and therefore increasing species diversity.

In addition, the greater variation in habitat at inshore locations leads to increased productivity, with a consequently wider range of potential food sources. Benthic primary producers in shallow areas may also support greater infaunal productivity than detritus does in deeper areas.

Endemism

The surveys of the intertidal zones at Browse Island found that approximately 95% of the molluscan taxa are widely distributed in the Indo-West Pacific region. They represent a suite of species characteristic of clear-water, oceanic, coral reef habitats. A further 2.5% are found in the central part of the Indo-West Pacific region. Only 2.5% are endemic to northern Australia, all of them confined to the North West Shelf; none of these endemic species have been recorded from Scott Reef or the other more remote atolls of the Oceanic Shoals Bioregion and their occurrence at Browse Island may be explained by the relative proximity of this reef to the mainland coast.

North West Shelf endemic molluscs were well represented at the Maret, Albert and Montalivet island groups, constituting approximately nearly 15% of the bivalve and shelled gastropod fauna recorded in this survey. Examples are *Acrosterigma fultoni*, *Haliotis squamata*, *Astralium rotularium*, *Cronia crassulnata* and *Oliva australis*. Two species that are endemic to the Kimberley coast, but are not found in the Canning and Pilbara bioregions, *Tectarius rusticus* and *Nerita reticulata*, were also found in the Bonaparte Archipelago.

A group of direct-developing volutids of the genera *Amoria* and *Cymbiola* were apparently not present in intertidal habitats at the Maret, Albert and Montalivet island groups, probably because of the absence of sand habitat. Nor was the endemic gastropod *Syrinx aruanus* found, although it is very common in similar habitats further south. However, the volutid *Melo amphora* was found to be moderately common.

Very few of the endemic North West Shelf mollusc species were recorded at the Browse Island reef complex. This provides further evidence for the very low degree of larval connectivity between the inshore and offshore bioregions.

None of the macroalgal or fish species collected from the Bonaparte Archipelago and Browse Reef are recognised as being endemic to the area.

Scleractinian corals were generally regionally widespread; however one genus, *Montigyra*, is only known from the single holotype specimen of *Montigyra kenti* from the Lacepede Islands in the southern Kimberley and is presumably a Kimberley endemic.

Although this species was not found during the present study, it may occur elsewhere in the Kimberley Bioregion. A small number of unusual coral specimens found during the current surveys were collected for further taxonomic study. Considering the richness of the scleractinian coral assemblage and the paucity of previous studies in the region, one or more of these could be found to be presently undescribed endemic species.

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Cetaceans

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ABSTRACT

This chapter summarises the findings of aerial and vessel-based cetacean surveys conducted in the Bonaparte Archipelago and Browse Basin in the Timor Sea off the coast of the Kimberley region of Western Australia from August 2006 to August 2007 and June 2008 to November 2008. The purpose of the surveys was to assess the level of cetacean biodiversity, to determine the critical areas of use by cetaceans, and to establish their relative abundance in the offshore and nearshore waters of the Kimberley.

In 2006 and 2007, aerial surveys were conducted north from Broome while vessel-based surveys were conducted in an area from north of Pender Bay to the Maret Islands and west to Browse Island. Cetaceans recorded during these surveys included four species of baleen whales (pygmy blue, humpback, Antarctic minke and dwarf minke whales) together with a number of dolphins and other small toothed whales.

In 2008, vessel-based surveys covering an area of 24 000 square kilometres near Scott Reef and Browse Island were conducted over 40 days in June and July and over 40 days in October and November. These surveys were timed to coincide with the expected northern and southern migrations of pygmy blue whales through the area. Cetacean species diversity was again relatively high with at least 15 species recorded. From 711 hours of survey effort, 194 cetacean sightings (totalling 3750 individuals) were registered.

In total, 23 species of cetaceans were observed through aerial and vessel-based surveys in the period 2006–2008. The Browse Basin was the most comparatively diverse site studied, with 20 species recorded, including five species of baleen whales.

Of the large cetaceans, the humpback whale was found to be the most abundant during the more wide-ranging 2006 and 2007 surveys that covered the whole region, while pygmy blue whales were the most abundant in 2008 when the survey plan was altered to selectively target blue whales. The 2008 study differed significantly from the earlier surveys in two ways: only vessel-based surveys were conducted and only the Browse Basin area was studied, with a particular focus on Scott Reef. Consequently, the 2008 results are not directly comparable with the earlier surveys.

During the surveys, systematic oceanographic sampling was also conducted using a logged dual-frequency echo sounder and a conductivity–temperature–depth profiler with the capacity to measure the distribution of chlorophyll-*a* (used as a measure of the concentration of suspended phytoplankton, i.e. primary productivity). Of particular interest at Scott Reef were collected samples of live krill, which were coincident with high-density echo-sounder targets that were assumed to be krill swarms, and the concurrent passage of pygmy blue whales through the same area.

INTRODUCTION

This chapter summarises the findings of aerial and vessel-based cetacean surveys conducted in the Browse Basin and the Bonaparte Archipelago off the coast of the Kimberley region of Western Australia from August 2006 to August 2007 and from June to November 2008.

The surveys of 2006 and 2007 in the Browse Basin and the Bonaparte Archipelago, including the Maret Islands, were commissioned by INPEX and carried out through RPS Environment Pty Ltd (RPS 2007). The Browse Basin studies of 2008 were commissioned as part of a joint industry initiative by INPEX, Shell Development (Australia) Proprietary Limited, and Woodside Energy Ltd. (Jenner, Jenner & Pirzl 2009).

The purpose of the surveys was to assess the level of cetacean biodiversity in the Kimberley region, to investigate the temporal and spatial patterns of cetacean occurrence, to determine the critical areas of use by cetaceans (for example those used for feeding, resting and calving), and to establish their relative abundance in the offshore and nearshore waters of the region. Specifically, the surveys focused on areas around the Maret Islands and on certain areas within the Browse Basin, which extends to the Australian–Indonesian seabed border with water depths reaching 5000 m (Geoscience Australia 2013). The study site included areas near Pender Bay and Camden Sound where large numbers of calving humpback whales were observed between 1995 and 1997 during surveys by the Centre for Whale Research, Western Australia (Jenner, Jenner & McCabe 2001).

Cetacean activity along the Western Australian coast

Cetaceans are important high-level predators in marine environments. They contribute to the cycling of nutrients and can be a key indicator of ecosystem health (DSEWPaC 2010). They are generally highly mobile, with the great whales in particular migrating over thousands of kilometres between their breeding and feeding grounds.

The Kimberley region is rich in cetacean species. The surveys there by Jenner, Jenner and McCabe (2001), Jenner, Jenner and Pirzl (2009) and RPS (2007) found a wide range of toothed cetaceans of the suborder Odontoceti (including dolphins, beaked whales, pilot whales and sperm whales) and baleen whales of the suborder Mysticeti (including the humpback whale *Megaptera novaeangliae*, pygmy blue whale *Balaenoptera musculus brevicauda*, Bryde's whale *Balaenoptera edeni*, Antarctic minke whale *Balaenoptera bonaerensis* and dwarf minke whale *Balaenoptera acutorostrata*).

Humpback whales

Humpback whales are large baleen whales that can grow to 17 m in length and weigh up to 36 t (Clapham & Mead 1999; NOAA 2013). They have a worldwide distribution comprising two broad population groups, one in the northern hemisphere and one in the southern hemisphere (Australian Museum 2009; Chittleborough 1965; Clapham & Mead 1999).

In the southern hemisphere the International Whaling Commission (IWC) currently recognises six feeding areas (I to VI) around Antarctica associated with seven high-latitude breeding stocks (A to G) (IWC 1998). These breeding stocks were originally thought to remain segregated year-round, maintaining direct movements between their feeding and calving areas (Chittleborough 1965; Mackintosh 1942). Recent genetic evidence, however, shows that there is in fact exchange between populations, which has been suggested to be occurring in overlapping Antarctic feeding grounds (Schmitt et al. 2013). The humpback whale stock that winters off the Western Australian coast is known as Breeding Stock D, and is thought to feed predominantly in summer in Antarctic Area IV, between longitudes 70°E and 130°E (Bannister & Hedley 2001; Chittleborough 1965; IWC 1998; Salgado Kent et al. 2012).

During the last survey conducted by the IWC in 2008, the number of humpback whales migrating to the Western Australian coast was thought to have been between 24 000 and 40 000 (with a “best” estimate of 29 000), with an annual rate of increase of approximately 10% between 1999 and 2008 (IWC 2013). Salgado Kent et al. (2012) noted that, based on a preliminary assessment of perception bias for the 2008 surveys, the Western Australian humpback population size in that year could be crudely estimated at 33 333.

The humpback whales that travel to Western Australia are known to feed in Antarctic waters over summer, before migrating to calving grounds in the north-west of Australia (DSEWPaC 2012a). These calving grounds are in relatively shallow water (generally not deeper than the 100 m isobath) between the Lacepede Islands and Camden Sound (Jenner, Jenner & McCabe 2001).

During the southerly migration from late August to early September, most whales travel close to the shore, between the 20 m and 30 m isobaths, while during the northerly migration between late July and early August they travel further offshore (Jenner, Jenner & McCabe 2001). The timing of these migrations can vary by as much as three weeks between years, which is likely to be due to annual variations in the availability of food in the Antarctic (Chittleborough 1965; Jenner, Jenner & McCabe 2001).

Photograph courtesy of Micheline Jenner, Centre for Whale Research

Figure 9-1: Adult humpback whale resting in the waters of the Kimberley

During the northerly migration, there is a marked segregation of the population by sex and age. Sexually immature whales (both male and female) and older females at the end of lactation migrate northwards first, the majority of the adult males travel next, and pregnant females migrate last. During the southerly migration, the cow–calf pods are the last to leave the calving grounds (Chittleborough 1965; Dawbin 1997).

A large proportion of Breeding Stock D (the Western Australian humpback whale population) is likely to winter off the Kimberley coast (Dawbin & Gill 1991), although Jenner, Jenner and McCabe (2001) also recorded scattered pods both north and south of this area during this period. Within the Kimberley calving grounds, Jenner, Jenner and McCabe (2001) identified three key areas where humpback whales appear to cluster: Pender Bay, the Tasmanian Shoal area near the Buccaneer Archipelago, and (particularly) Camden Sound. In recognition of its importance to humpback whales, Camden Sound was proposed for listing as a marine park by the Western Australian Government in 2009 and was duly gazetted as such in 2012 (Government of Western Australia 2012).

Humpback whale behaviours can be categorised into two broad types: "surface-passive", which includes behaviours such as travelling, resting and milling, and "surface-active", which includes behaviours such as breaching, pectoral-fin slapping and lobtailing (K.C.S. Jenner, Centre for Whale Research (Western Australia), Inc., Fremantle, Western Australia, pers. comm. July 2013). The frequency of occurrence of either behaviour pattern in a particular management area lends insight into area usage. Areas where the majority of whales are surface-passive may be further described as resting and/or nursing areas if pods contain calves, while areas that contain surface-active pods may be mating areas.

Blue whales

The blue whale (*Balaenoptera musculus*) is the largest of the whale species, growing to a length of 33 m and weighing up to 180 t (DSEWPaC 2012b). It can be distinguished from other whale species by its large size, flat U-shaped head and mottled blue-grey coloration (Reeves et al. 2002). They are the most specialised feeders among the groove-throated baleen whales or rorquals (family Balaenopteridae). They feed almost exclusively on krill (Kawamura 1980; Mackintosh & Wheeler 1929; Yochem & Leatherwood 1985) and consume up to 2 t of these crustaceans per day, a greater mass of prey than any other predatory species of mammal (Croll et al. 2005). However, in order to forage successfully, blue whales need to find regions with dense aggregations of krill. Prey density appears to be a critical determining factor in baleen whale feeding, with sufficient threshold densities required before the expense of energy on feeding can be compensated for by the nutritional value of the prey (Piatt & Methven 1992).

Photograph courtesy of Curt Jenner, Centre for Whale Research

Figure 9-2: A humpback whale engaged in surface-active behaviour

It is generally accepted that two subspecies of blue whales inhabit the southern hemisphere, the larger Antarctic blue whale (*Balaenoptera musculus intermedia*) and the smaller pygmy blue whale (*Balaenoptera musculus brevicauda*) (DSEWPaC 2005). The subspecies appear to have geographically distinct ranges, with the Antarctic blue whale usually being found in waters south of 60°S during the southern hemisphere summer and the pygmy blue whale usually in waters north of 55°S (Bannister, Kemper & Warneke 1996; DSEWPaC 2005). However, recent studies have shown that an apparently greater number of pygmy blue whales may now be feeding in Antarctic waters (Attard et al. 2012). Nevertheless it is more than likely that Australian records of blue whales, almost entirely in summer, are of pygmy blue whales (DSEWPaC 2005).

Commercial whaling expeditions caught large numbers of blue whales in Western Australian waters from the 1950s to the 1970s (Branch et al. 2007) and populations have not yet recovered to pre-whaling levels (Jenner et al. 2008). Blue whale numbers in the southern hemisphere prior to commercial whaling have been estimated at between 160 000 and 240 000 individuals, including approximately 10 000 pygmy blue whales (Bannister, Kemper & Warneke 1996). The IWC estimates the current population of Antarctic blue whales to be between 1150 and 4500, with a “best” estimate of 2300, based on the last survey conducted in 1997–1998.

The rate of increase of the population of Antarctic blue whales is estimated at 8.2% per annum between 1978 and 2004 (IWC 2013). There is no current estimate available for the size of the pygmy blue whale population around Australia (DSEWPaC 2005), but in 1996 it was estimated to be 6000 (Bannister, Kemper & Warneke 1996) and Jenner et al. (2008) estimated the Western Australian population that feeds in the Perth Canyon each summer to be no more than 1800 strong.

The environmental factors governing blue whale distribution have not been determined for Western Australian coastal waters. It has been established that the continental slope (200–500 m depth) in other regions is often associated with increased productivity as a result of upwellings, wind shear and other seasonal forcing factors which create favourable feeding grounds for cetaceans (Schoenherr 1991; Woo, Pattiaratchi & Schroeder 2006). Pygmy blue whales are found between January and April each year in the Perth Canyon (32°S) off the coast of Western Australia; the canyon is thought to be a significant feeding area (DSEWPaC 2005; Jenner et al. 2002; McCauley et al. 2000; McCauley et al. 2004). The warm, oligotrophic Leeuwin Current flows southwards over the Perth Canyon, while a cooler, deeper countercurrent flows northwards. The interaction of these currents and the canyon’s bathymetry induces an upwelling of colder, nutrient-rich water that reaches no closer to the surface than 200 m.

Photograph courtesy of Curt Jenner, Centre for Whale Research

Figure 9-3: A pygmy blue whale surfacing to breathe, showing the distinctive U-shaped head of the species

The whales must dive under the Leeuwin Current to depths of 200–500 m to feed on the krill species *Euphausia recurva* (McCauley et al. 2004). The bathymetry of the Browse Basin may also promote localised upwellings of cold water and nutrients, similar to productivity cycles studied in other parts of the world (Croll et al. 2005; Gill 2002; Kämpf et al. 2004), potentially creating a feeding area for pygmy blue whales. Water-quality samples for the area show elevated total nitrogen concentrations that increase with depth.

One study sighted a pygmy blue whale feeding in the Ningaloo Reef region near Exmouth around 1200 km north of Perth in June 2001 (Jenner & Jenner 2002), providing further evidence for the theory that the species may occupy a similar food niche to that of whale sharks and manta rays in tropical areas (Jarman & Wilson 2004; Wilson, Pauly & Meekan 2002). In addition, pygmy blue whales have been sighted swimming through a narrow channel between Scott Reef North and Scott Reef South where whale sharks have been previously sighted, and where krill, the prey of both species, have been recorded (Jenner, Jenner & Pirzl 2009; Wilson et al. 2006).

The migratory habits of Antarctic and pygmy blue whales are poorly understood, although they are thought to move between warm-water breeding areas and cold-water feeding areas (Bannister, Kemper & Warneke 1996) in similar fashion to other baleen whale species. Pygmy blue whales residing in the waters around Australia in the austral summer and autumn (between November and May) are thought to migrate to Indonesia for the austral winter and spring (Branch et al. 2007). Recent satellite-tagging results show that the population of pygmy blue whales that feeds during the summer months in the Perth Canyon (32°S) off the Western Australian coast, migrates to the Banda Sea (10°S) during the winter months (Double et al. 2012). Acoustic logger records from the Western Australian coast at latitude 21°S support this, indicating that pygmy blue whales migrate northwards between June and July, and southwards between November and December (McCauley & Jenner 2010; unpublished data from R.D. McCauley quoted by Branch et al. 2007).

Further evidence for the migration of blue whales along the coast of Western Australia includes the following:

- Russian whaling data from the 1960s and 1970s showing a distribution of blue whales along the Western Australian coast up to Indonesia, which is consistent with migration to a warm-water calving ground (Zemsky & Sazhinov 1982, not seen, cited in McCauley et al. 2000)
- acoustic recordings from an area near Exmouth during November (McCauley et al. 2004)
- numerous sightings during the winter months in locations such as the Savu Sea, west of Timor (Benjamin Kahn, Director, Apex Environmental, pers. comm. 22 February 2006)
- two sightings of blue whales feeding in late winter (11 September 2004) off Cape Talbot (at approximately 13.7°S, 126.65°E and 13.72°S, 126.63°E) near the Western Australian – Northern Territory border (Dr Deborah Thiele, cetacean research scientist, pers. comm. 15 April 2007).

Fin and sei whales

Other baleen whales, including fin whales (*Balaenoptera physalus*) and sei whales (*Balaenoptera borealis*) have been infrequently recorded in Australian waters and may be found in the Kimberley region (DSEWPaC 2012c, 2012d). Fin whales are the second largest of the whale species after the blue whale, growing to a maximum length of 27.1 m and weighing over 75 t, while sei whales grow to 19.5 m and weigh up to 25 t (DSEWPaC 2012c, 2012d; Reeves et al. 2002).

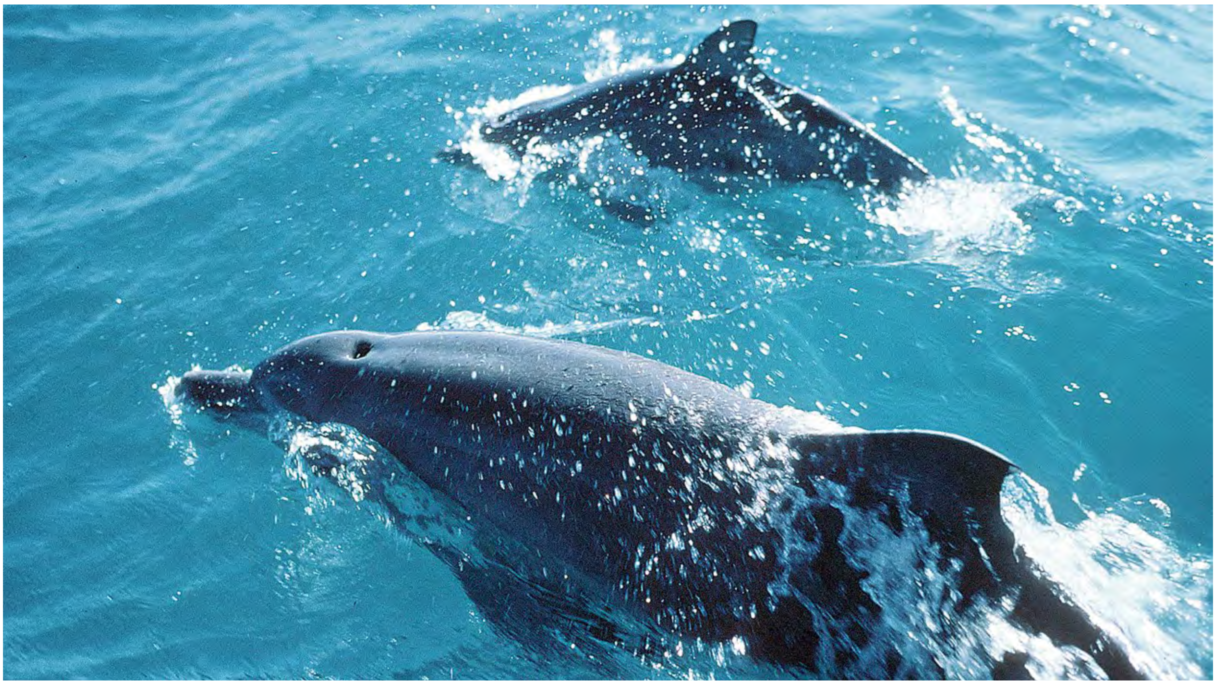
There is limited information available on the biology and life history of fin and sei whales (DSEWPaC 2005). Both species have been observed in offshore waters from polar habitats to the tropics and are thought to migrate north–south with little longitudinal dispersion (DSEWPaC 2012c, 2012d). The critical habitats of these species are not yet known. Both species are known to feed in the Antarctic, although some individuals have also been observed further north in known blue whale feeding areas such as the Bonney Upwelling in Victoria and the Perth Canyon (Butler et al. 2002).

The populations of both fin and sei whales were severely depleted by whaling in the early 1900s. Because sightings are uncommon, the current size of fin and sei whale populations in the southern hemisphere is not known (DSEWPaC 2005, 2012c, 2012d).

Other cetaceans

The seas of the Kimberley region are also known habitat for sperm whales (*Physeter macrocephalus*) (DSEWPaC 2012e) and for a number of smaller species of cetaceans, including false killer whales (*Pseudorca crassidens*) (DSEWPaC 2012f) and various other dolphins (Jenner, Jenner & McCabe 2001). Dolphins can be classified broadly into two groups: those species that favour offshore waters and those that favour inshore areas. The offshore dolphin species in the Browse Basin include the following:

- long-beaked common dolphin (*Delphinus capensis*)
- short-beaked common dolphin (*Delphinus delphis*)
- short-finned pilot whale (*Globicephala macrorhynchus*)
- Risso's dolphin (*Grampus griseus*)



Photograph courtesy of Curt Jenner, Centre for Whale Research

Figure 9-4: Bottlenose dolphin mother and calf

- Fraser's dolphin (*Lagenodelphis hosei*)
- pantropical spotted dolphin (*Stenella attenuata*)
- striped dolphin (*Stenella coeruleoalba*)
- long-snouted spinner dolphin (*Stenella longirostris longirostris*)
- dwarf spinner dolphin (*Stenella longirostris roseiventris*)
- rough-toothed dolphin (*Steno bredanensis*)
- bottlenose dolphin (*Tursiops truncatus*).

Inshore dolphin species are more likely to be present in the areas surrounding the Bonaparte Archipelago and include the following:

- Australian snubfin dolphin (*Orcaella heinsohni*)
- Indo-Pacific humpback dolphin (*Sousa chinensis*)
- spotted bottlenose dolphin (*Tursiops aduncus*).

Linkages between cetaceans and the ecosystem

Water-column characteristics fundamentally influence biomass production and, therefore, the availability of prey to species, such as whales, at high trophic levels. Cetacean prey includes both vertebrates (e.g. fish) and invertebrates (e.g. cephalopods, jellyfish and zooplankton), whose distribution in tropical regions is generally patchy and ephemeral (Jaquemet, Le Corre & Quartly 2007). Trophic relationship studies of similar species assemblages indicate that both resource partitioning (Cherel et al. 2008; Gross et al. 2009; Surman & Wooller 2003) and cooperative or obligate relationships (Clua & Grosvalet 2001; Le Corre & Jaquemet 2005; Vaughn et al. 2008) among predators are likely to play a role in distribution and resource exploitation patterns.

Aims

The aims of the study were as follows:

- to conduct a baseline survey of cetacean biodiversity within the Kimberley region
- to conduct a baseline survey of the abundance of key cetacean species within the Kimberley region
- to determine the critical areas of use by these key cetacean species.

STUDY AREA

In 2006 and 2007, aerial surveys were conducted north from Broome, while vessel-based surveys were conducted in an area extending from north of Pender Bay to the Maret Islands, and west to Browse Island. This was done in order to establish the distribution of humpback whales in the Kimberley region following on from similar surveys conducted in the mid-1990s. In 2008, vessel-based surveys covering a 24 000 km^2 area near Scott Reef and Browse Island were conducted over 40 days in June and July and over 40 days in October and November, timed to determine whether the pygmy blue whale northern and/or southern migration routes passed through the Browse Basin.

The study area covered by the 2006 and 2007 vessel-based transects is presented in Figure 9-5. Also indicated on the map are the humpback whale calving grounds as determined from earlier surveys conducted by the Centre for Whale Research between 1995 and 1997.

METHODS

Aerial and vessel-based line-transect surveys, as described by Burnham, Anderson and Laake (1980), were used to investigate the temporal and spatial patterns of use by cetaceans in the Kimberley region. Aerial surveys were conducted in 2006 and 2007 to gain "snapshots" of cetacean distribution across broad areas. Vessel-based surveys were conducted in 2006, 2007 and 2008 to record whale distribution and behaviour in order to identify areas deemed critical to whales, including those used for feeding, resting and calving.

Vessel-based migration studies of blue whales were conducted in May 2007 (RPS 2007) and between June and November 2008 (Jenner, Jenner & Pirzl 2009). Opportunistic observations made by the project team while travelling to and from the survey area between May 2006 and October 2007 (RPS 2007) and between June and November 2008 (Jenner, Jenner & Pirzl 2009) were also recorded.

Aerial surveys

The aerial surveys designed and conducted by the Centre for Whale Research between early August and late September in 2006 and 2007 are itemised in Table 9-1.

Table 9-1: Aerial survey schedule for 2006 and 2007

2006 survey days	2007 survey days
4 August	2 August
29 August	12 August
5 September	13 August
30 September	26 August
	2 September
	14 September
	30 September

During the peak humpback whale calving period between early August and late September, four survey flights were conducted in 2006 and seven in 2007.

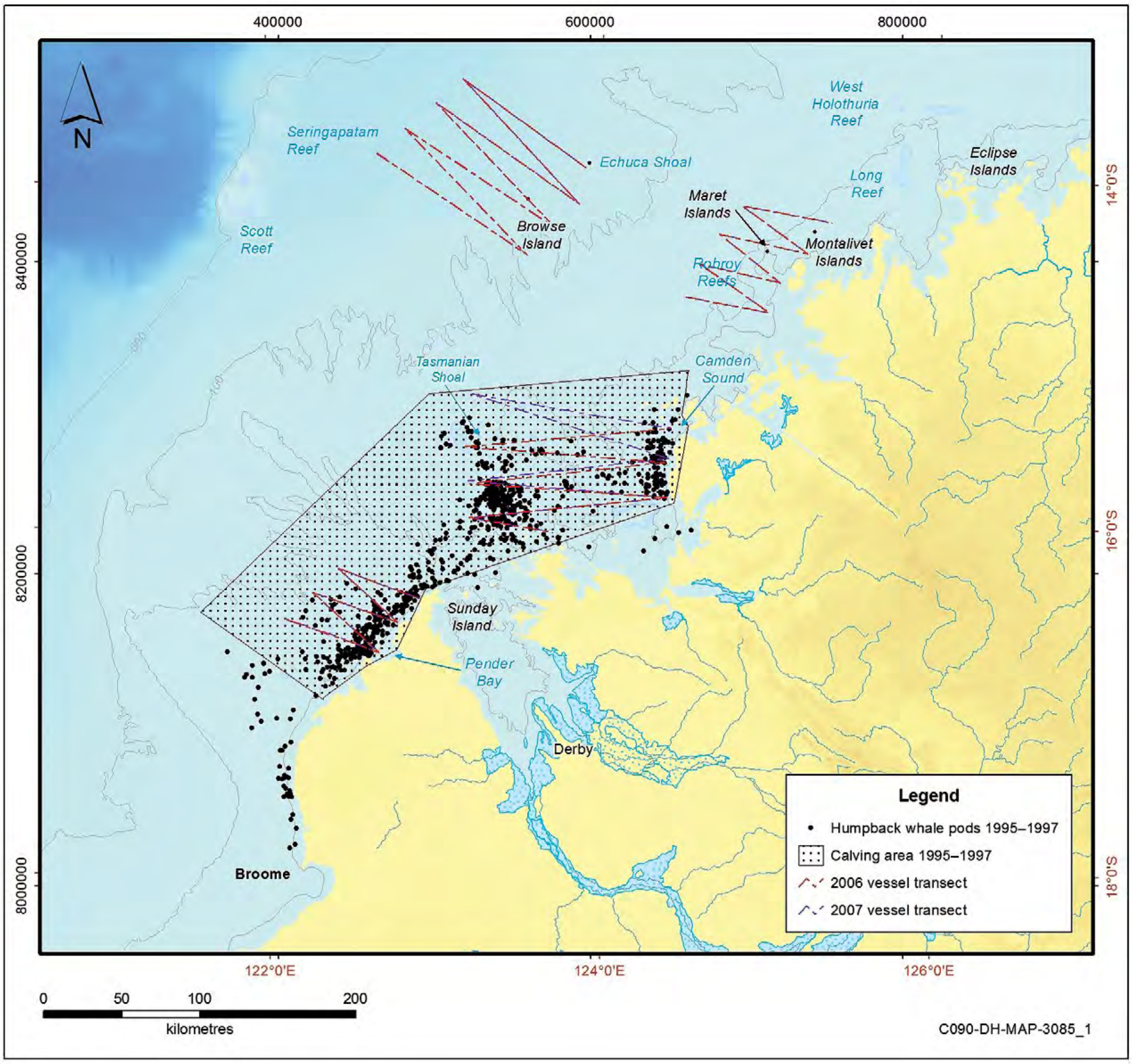


Figure 9-5: The study area covered by the vessel-based cetacean surveys around Pender Bay, Camden Sound, the Maret Islands and the eastern Browse Basin in 2006 and 2007

The transects extended from Broome to the Maret Islands and employed a saw-tooth survey track for passing-mode surveys (i.e. the plane did not deviate from the flight path even after a whale pod was observed). The survey pattern was designed to include areas known to be preferred habitat for humpback whales such as Camden Sound and Pender Bay (Jenner, Jenner & McCabe 2001).

The aerial surveys were conducted at an altitude of 305 m (1000 ft) and at a speed of approximately 222 km·h^{-1} (120 knots) using a Britten-Norman Islander, a twin-engined high-winged aircraft. Surveys were commenced only when wind speeds were less than 33 km·h^{-1} (18 knots).

Observers recorded all cetaceans sighted within a 10-km-wide strip (5 km on each side of the aircraft). The positions of observed whales were estimated by recording the location of the aircraft using a GPS (global positioning system) device and measuring the angles from the aircraft to individuals using Suunto PM-5/360PC clinometers and a compass board. The compass bearing from the aircraft to each observed cetacean was calculated from the measured horizontal angle between the aircraft and the cetacean, and the aircraft heading. Distances were calculated based on formulae in Lerczak and Hobbs (1998) that use the vertical angle to an observed individual and the known altitude of the aircraft at the time of sighting.

The bearing and distance were then used to estimate the latitude and longitude of each cetacean at the time of sighting using the software program Ozi*Explorer* version 3.95. The direction of travel (north, south, milling, or undetermined) of each pod was also recorded. Pods reported as "milling" were generally lying on the surface at the time of observation with no obvious signs of swimming. In 2007, the protocols defined in the computer program Distance (Buckland et al. 2001, 2004; Thomas et al. 2006) were followed. Distance software designs and analyses biological line-transects to estimate density and abundance. The survey method therefore varied slightly, with an "equally spaced zigzag" system of transects being designed over the study area to maximise the probability of coverage during a single day of surveying, assuming eight hours of consistent daylight.

Data analysis

Four aerial surveys were conducted during 2006. The surveys followed the same path although the second survey was shortened as a result of aircraft fuel constraints and bad weather. In order to compare all four flights with slightly different flight paths, cetacean observations were grouped for each flight into latitude bands 0.2 degrees wide to remove the unevenness in the areas sampled.

All seven[1] of the 2007 aerial surveys followed the same flight path. The distribution of observed cetaceans was analysed using the GIS program ArcView 3.2, with its Spatial Analyst and Animal Movement extensions. Kernel density estimation[2] (KDE) was used to assess the tendency for grouping, indicating the preferred range of each species within the sample area. KDE is based on the assumption that the sampling effort is consistent across the study site. The KDE data were partitioned into zones: 50% is the zone where 50% of whales are expected to be found and represents the preferred range; 75% encloses the 50% zone and is the zone where an additional 25% of whales are expected to be found; and 95% encloses both the 50% and 75% zones and is the zone where another 20% of whales may be found and represents the extent of area usage.

A smoothing factor (the "*h*" statistic) was used to ensure that a consistent index of relative abundance was applied, but this has been shown to be inconsistent for different sample sizes (Hooge & Eichenlaub 1997). A second technique, the minimum convex polygon (MCP) method, was therefore used to estimate preferred-area size for both the 2006 and 2007 data. The MCP from the flight that recorded the highest number of observations was used as the area preferred, and the smoothing factor was adjusted until the area of the 95% kernel equalled the area of the MCP, providing an objective method for selecting the smoothing factor (Hooge & Eichenlaub 1997).

Humpback whale numbers, density, encounter rate, and pod size were estimated for each of the seven flights in August and September 2007. In addition, estimates of the population size, the density of individuals and the density of pods were made for the whole of the 2007 sample period. A test for representativeness of whale abundance data from single survey days within the two-week survey periods was carried out during the peak of the season.

1 The voice-data recording tape for 26 August 2007 was damaged irreparably after the flight and handwritten notes made during the survey were used to recall which waypoints referred to different whales or groups of whales.

2 Kernel density estimation is a type of non-parametric multivariate density estimation that, in the case of broad-scale studies, describes the probability that a whale will be found in a particular area.

A detection function $g(x)$, as described by Buckland et al. (2001), was used to estimate the probability of detecting a whale pod based on it being at a distance x from the transect line. This function is one of the underlying concepts which affect the accuracy of the estimation of the size of a population. Recent advances in analytical methods have allowed estimates of populations to include consideration of individuals that are undetectable for part of the survey, such as submerged whales (Marques & Buckland 2003). Distance 5.1 software (Thomas et al. 2006) was used to account for the influence of various factors that might affect the sighting of whales, such as sea state, cloud cover, whale behaviour or variations between observers, and was used to provide a better model for the data.

For the 2007 data set, various functions (half-normal and hazard-rate) were examined, with additional covariates being used to further explain heterogeneity in the probability of detection and to create the model that would best fit the data. A stepwise selection process was carried out as suggested by Marques and Buckland (2003), allowing the most appropriate model to be selected with the lowest Akaike information criterion (AIC) value (Akaike 1973) and consequently the best fit. In addition, to improve the accuracy of estimations of pod density, the data sets were truncated to exclude outliers as described in Bannister, Kemper and Warneke (2006).

After the model had been selected, and the Distance 5.1 program had produced an abundance estimate for each flight, the "availability bias" was calculated, providing a correction factor that estimated the number of animals that were likely to be submerged at the time that the plane passed overhead. The analysis used the correction factor described by Barlow et al. (1988):

$$Pr = \frac{s + t}{s + d}$$

where Pr is the probability of being visible, s is the average length of time a cetacean is at the surface, d is the average amount of time it spends below the surface, and t is the time available to see the cetacean during an aerial survey (taking into account the range of the observer's vision and the speed of the aircraft).

Vessel-based surveys

Vessel-based cetacean surveys were conducted between August and November 2006 and in July and August 2007 (Table 9-2). The 2006 and 2007 vessel-based survey patterns were designed to coincide with areas in which humpback whale pods had been observed by the Centre for Whale Research between 1995 and 1997.

The 2006 and 2007 surveys

A 24-metre motorised fishing vessel, the *Exodus*, was used for the vessel-based surveys. It steamed at between 8 and 9 knots along a series of transects during daylight hours. The GPS location of the vessel was recorded every two seconds and noted on a laptop computer to produce a track of the area covered during the survey.

During the transect surveys, one to three observers scanned the water from the bow of the boat, with no visual aids, using a zigzag technique that covered a 180° sector. When cetaceans were observed, binoculars were used to determine the number of individuals and to identify the species. Where possible, data recorded for each observation included the time, the number of individuals in a pod, the direction of travel and the bearing, range, and observation cue. An electronic hand bearing compass was used to determine the bearing, and the distance from the vessel was estimated. The GPS waypoint of the vessel was also recorded for each observation.

Each observer's distance estimates were calibrated at the beginning of each survey through approximating, and then refining, the observation of a radar reflector buoy at a known distance. Observers who consistently achieved the most accurate range of distances were then used to verify the distances that other observers recorded throughout the survey.

Where possible, observations were recorded to species level. If identification was uncertain, the most suitable "unidentified" category was chosen. For example, "unidentified minke whale" rather than "dwarf minke" was chosen if pectoral fins were not visible, meaning that a definite identification of a dwarf minke whale could not be made.

Observations were recorded in a modified version of the Logger 2010 automatic field-data logging program, developed by the International Fund for Animal Welfare (IFAW), which automatically collects data from GPS and other ships' instruments and stores them in a Microsoft Access database. Cetacean behavioural data were recorded when possible. The presence or absence of calves was also recorded as a "cow–calf pod" if calves were present and as a "non-cow–calf" pod if no calves were present. Ozi*Explorer* software was then used to project the positions of cetaceans on to a chart using the appropriate bearing and distance from the observer's waypoint.

In good weather, photographs of whales were taken for identification purposes from an inflatable dinghy launched from the *Exodus*.

Table 9-2: Schedule for the vessel-based cetacean surveys of 2006 and 2007

Survey no.	Date range	No. of survey days	Locations
2006-1	15-08-2006 to 03-09-2006	20	Broome, Pender Bay, Camden Sound, Maret Islands, Browse Basin
2006-2	09-09-2006 to 28-09-2006	20	Broome, Pender Bay, Camden Sound, Maret Islands, Browse Basin
2006-3	04-10-2006 to 23-10-2006	20	Broome, Pender Bay, Camden Sound, Maret Islands, Browse Basin
2006-4	29-10-2006 to 07-11-2006	10	Maret Islands, Browse Basin
Year total		**70**	
2007-1*	05-07-2007 to 23-07-2007	18	Pender Bay, Camden Sound, Maret Islands
2007-2	29-07-2007 to 17-08-2007	20	Maret Islands, Browse Basin
Year total		**38**	

* The survey vessel left port on 3 July 2007 and arrived on site to commence the transects on 7 July 2007.

Transects were designed to achieve 75% coverage of each area, with an effective survey width of six nautical miles from the upper deck of the vessel (taking the observer's eye height as 5.5 m).

Further details of the vessel-based transects are provided in Table 9-3. All transects were conducted between sunrise and sunset, with any transects unfinished at sunset being resumed at sunrise the following day (or when the weather next permitted).

Physical oceanographic data were recorded at the beginning of each hour during each transect. This included time, position, water depth, the visibility range, sea-surface temperature, the predicted tide height (and the source of that information), wind speed and direction, and the percentage of cloud cover. The direction and speed of the current at the surface and mid-water was recorded using a JLN-620 acoustic Doppler current profiler (ADCP). Photographs were also taken of all cetaceans near the vessel.

The logistic constraints associated with covering a large survey area resulted in some limitations for the vessel-based surveys. Although 10-day blocks are a standard sample period used for comparing separate areas within and between seasons, the large distances covered by this study allowed each site to be sampled only once every 20 days, resulting in fewer sampling opportunities per season and preventing analysis for trends and patterns on a fine scale. Further, some portions of Survey 2007-1 and Survey 2007-2 could not be completed because of adverse windy conditions.

Data analysis

The data collected were broadly segregated into "temporal", "spatial", "behavioural" and "physical" classifications. The information generated included the time of the year (temporal) that a species used a particular area (spatial), how it used the area (behavioural), and the prevailing environmental conditions (physical) that might have affected its distribution or behaviour.

Table 9-3: Details of the vessel-based transects of 2006 and 2007

Location	Start day	No. of transects	Distance covered	No. of survey days (185 km/d)	Distance to next area (km)	No. of transit days (200 n mile/d)	Area covered by transects (km^2)
Broome	1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
Pender Bay	2	5	331	2	185	0.5	3678
Camden Sound	4	6	804	4	111	0.3	8934
Maret Islands	9	7	439	2	96	0.3	4878
Browse Basin	12	7	891	5	187	0.5	9901
Broome	20	n.a.	n.a.	n.a.	556	1.5	n.a.
Total		**25**	**2465**	**13**	**1135**	**3.1**	**27 391**

n.a. = not applicable

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The data collected during the vessel-based surveys were analysed using the same methods used for the data collected during the aerial surveys. ArcView 3.2, with Spatial Analyst and Animal Movement extensions, was used to describe the distribution of cetaceans and other wildlife encountered during the surveys. The vessel-based transects were evenly spaced and achieved a 75% coverage in each of the four sample areas. Once again, KDE was used to estimate the preferred range of each species. Probability contour maps were then generated, depicting 50% (preferred range), 75%, and 95% (extent of area usage) zones. The smoothing factor (*h*) and MCP were also applied to the data to ensure that densities were comparable between surveys.

The 2008 surveys

The 2008 surveys were timed to coincide with anticipated pygmy blue whale northern (June–July) and southern (October–November) migrations through the study area (Table 9-4; figures 9-6 to 9-9). The 24-metre research vessel *WhaleSong II* was used for all of the 2008 surveys.

The methods employed for the 2008 surveys were similar to those described above for 2006 and 2007. Three observers (whose eye heights were taken to be approximately 7.2 m above sea level) scanned from the vessel to the horizon (estimated range 12.8 km) while the vessel steamed at a constant speed of 7–8 knots.

Table 9-4: Survey dates, hours of survey effort and distance surveyed for the northern and southern pygmy blue whale migrations

Survey number	Date range	No. of survey hours		Distance covered (km)		Expected pygmy blue whale migration phase
		Total	In study area	Total	In study area	
2008-1	09-06-2008 to 28-06-2008	171.8	159.7	2158.0	1978.7	Northern
2008-2	04-07-2008 to 23-07-2008	159.8	137.1	1657.5	1321.2	Northern
2008-3	17-10-2008 to 05-11-2008	189.2	169.0	2872.8	2573.5	Southern
2008-4	11-11-2008 to 30-11-2008	191.1	177.0	2470.9	2253.0	Southern
Total	**80 days**	**711.9**	**642.8**	**9159.2**	**8126.4**	

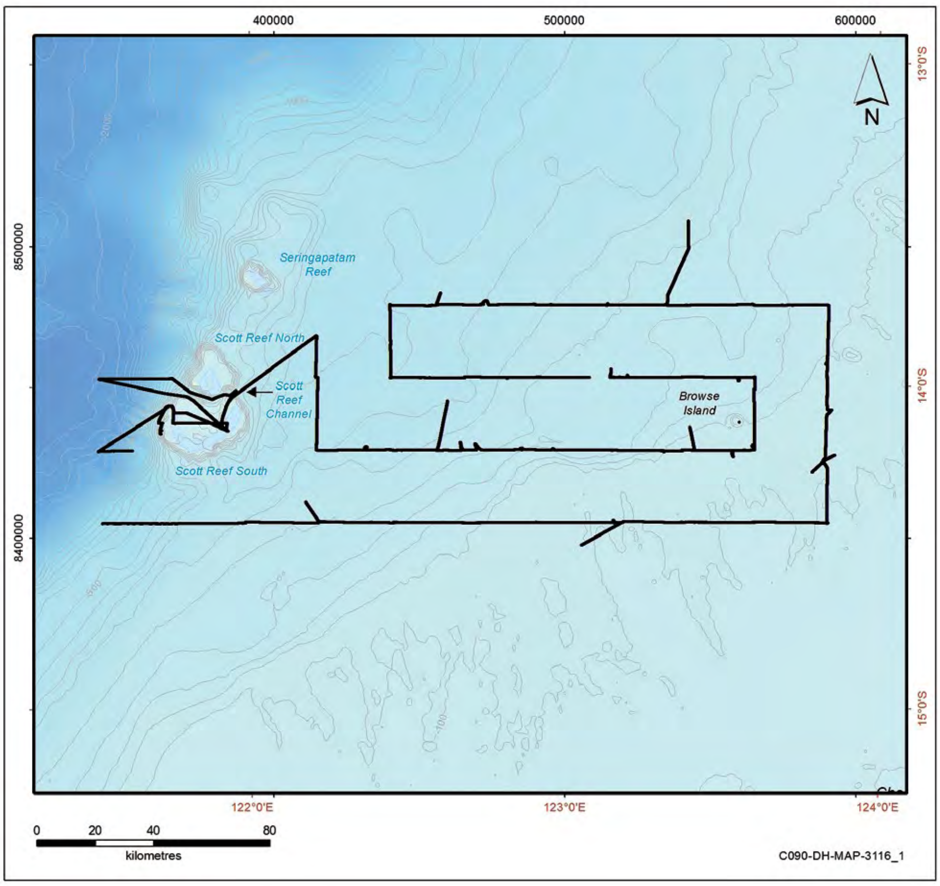

Figure 9-6: Tracks of vessel-based transects conducted during Survey 2008-1 (9–28 June 2008)

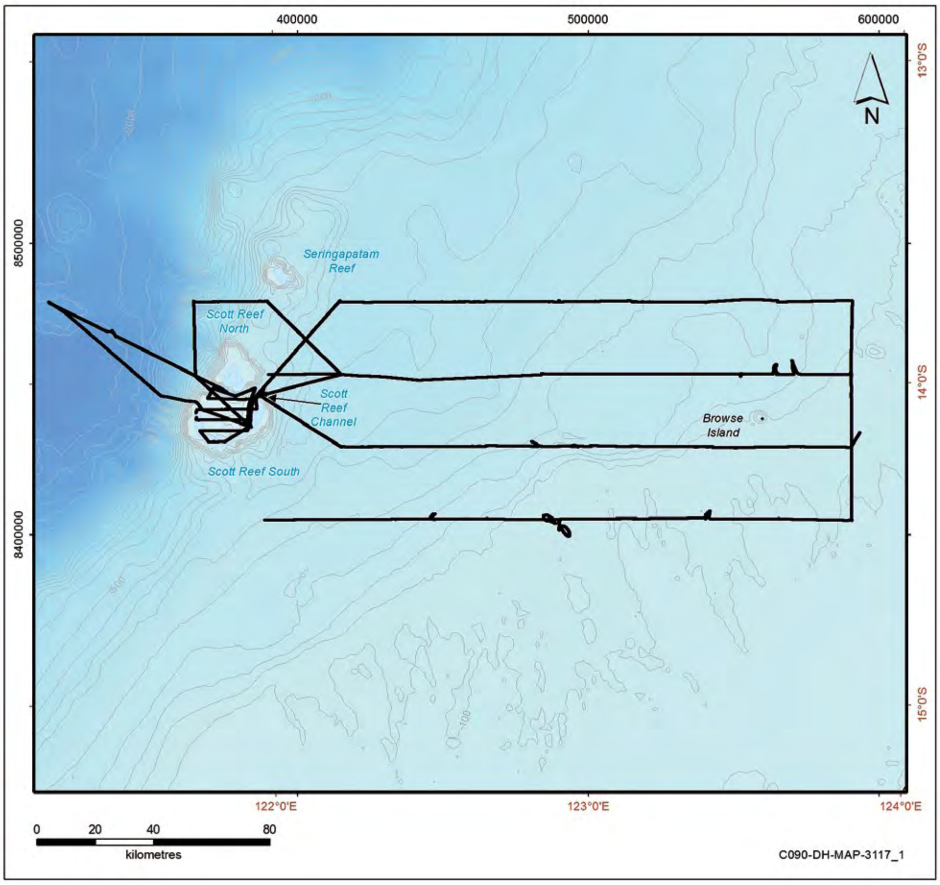

Figure 9-7: Tracks of vessel-based transects conducted during Survey 2008-2 (4–23 July 2008)

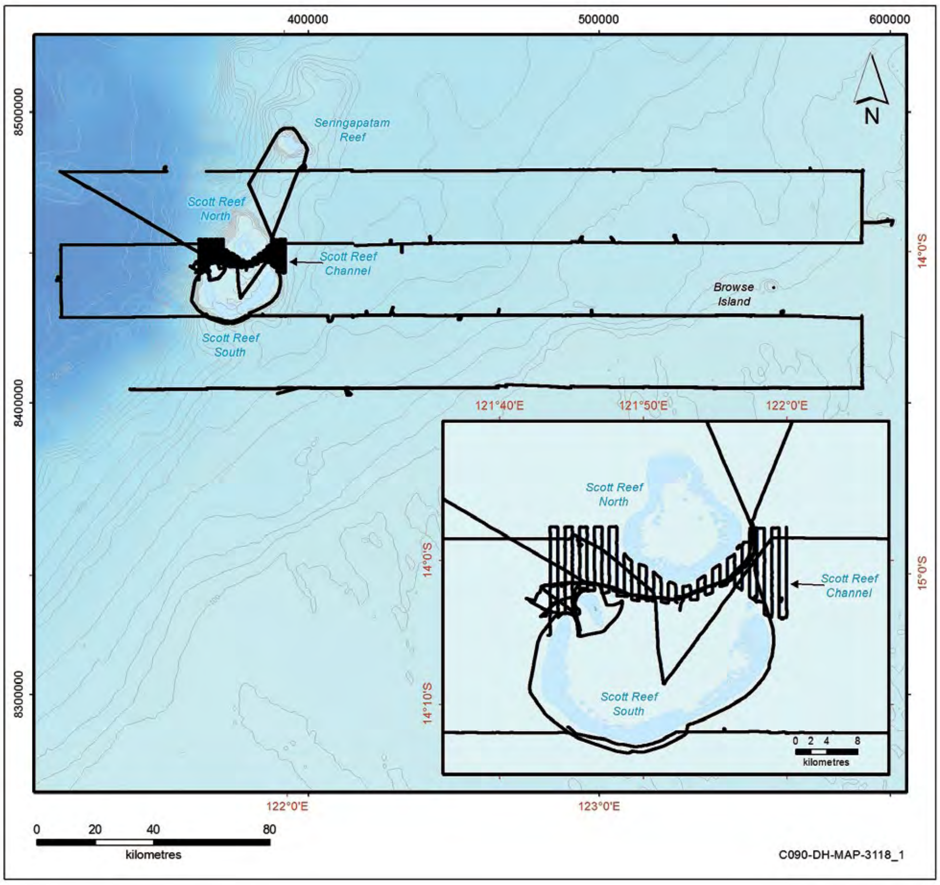

Figure 9-8: Tracks of vessel-based transects conducted during Survey 2008-3
(17 October to 5 November 2008)

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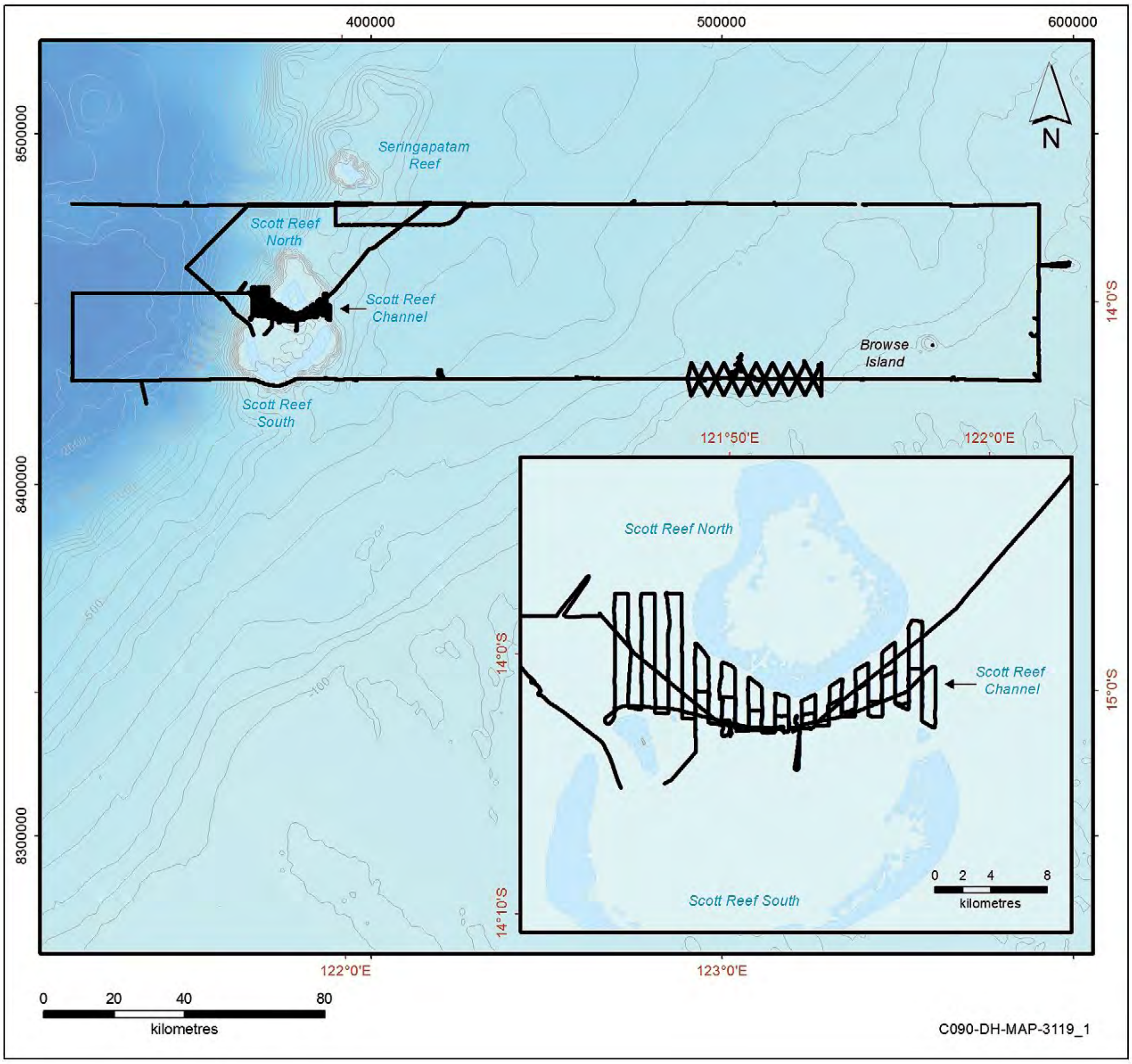

Figure 9-9: Tracks of vessel-based transects conducted during Survey 2008-4 (11–30 November 2008)

Searches were conducted with the naked eye and binoculars. Hand-held (7×50) and ship-mounted (25×150) binoculars were used to identify animals not easily identifiable by the eye alone (Figure 9-10). A hand-held compass, which was calibrated to the vessel compass, was used to determine the bearing of each sighting and its distance from the vessel was estimated. Further details of the survey techniques are described in Jenner, Jenner and Pirzl (2009).

Data analysis

Photographs were taken of all cetaceans which were near the vessel. These photographs were used for later confirmation of in situ species identifications.

Figure 9-10: Ship-mounted binoculars were used to identify animals during vessel-based transects

Acoustic backscatter studies at Scott Reef

Acoustic backscatter from single-beam sonar was used to assess water-column biomass. The density of this biomass was measured during each survey by towing a single-beam sonar (BioSonics DT-X4 transducer) system operating at 120 kHz and 38 kHz and at a depth of 4 m. This targeted zooplankton (e.g. krill) at 120 kHz and fish at 38 kHz and was used as a measure of secondary productivity, indicating cetacean prey abundance.

Acoustic data were processed at Curtin University of Technology, Western Australia, using algorithms developed by the University's Centre for Marine Science and Technology (Parnum 2009). Echograms were generated for each survey day, estimating biomass along the survey track (Parnum 2009). An acoustic backscatter coefficient (ABC), representing relative biomass, was calculated for each 50 m band from 5 m below the transducer to 5 m above the seafloor or (if the seafloor was not detected) to the extent of the record (usually 500–600 m depth).

In order to assess diurnal and seasonal variability in water-column biomass, and to avoid disproportionate survey effort over the wider study area, acoustic data were spatially partitioned into four areas:

- Area 1: within 20 km of Scott Reef
- Area 2: west of Scott Reef
- Area 3: east of Scott Reef and deeper than 300 m
- Area 4: east of Scott Reef and shallower than 300 m.

The ABC for the 38 kHz transducer was integrated between 5 m and 300 m, and for the 120 kHz transducer between 5 m and 150 m. Mean ABC values were then plotted against the time of day for each frequency and for each survey (2008-1, 2008-2, 2008-3 and 2008-4) in order to visualise diurnal variation in biomass detection. Temporal variability between surveys was represented by plotting the mean ABC for the different frequencies for the four different areas and surveys.

ABC 120 kHz values were averaged for 5 km × 5 km grid cells to provide data at a spatial resolution suitable for investigating correlations with cetacean distribution.

RESULTS

The robustness of the 2006 and 2007 survey methods was tested by a preliminary comparison of population densities estimates from vessel-based and aerial surveys conducted between 10 and 13 August 2007. An analysis that corrected the data for diving whales that were not visible to the aerial observers was applied to the data to ensure that the results were comparable. Ground-truthing of aerial observations was accomplished using one aerial transect that overlapped one of the vessel-based transects and had recorded similar densities of whales.

Using the mark–recapture photographic evidence for humpback whales in the Kimberley during the 2006 and 2007 vessel surveys (*n* = 35), it was determined that the average residence time for an individual whale in the region was one to two weeks, thus verifying that two-week sampling intervals between flights were adequate to ensure that whales were unlikely to be counted twice.

Aerial surveys: 2006 and 2007

Humpback whales

During the four flights conducted in August and September 2006, 165 humpback whale pods were recorded, made up of 240 adults and 39 calves (Table 9-5). In the six flights conducted during August and September 2007, 702 humpback whale pods were recorded, made up of 1023 adults and 127 calves (Table 9-6). In 2006, more individuals (both adults and calves) were observed in August than in September. In 2007 a similar number of adults were observed over both August and September, but more calves were observed in September. Overall, the ratio of calves to adults was observed to increase over the course of both survey periods (tables 9-5 and 9-6).

In 2006, humpback whales were recorded between 15.0°S and 17.8°S (from near Prince Regent River to Broome) and at the western bounds of the study site approximately 80 km offshore (Figure 9-11).

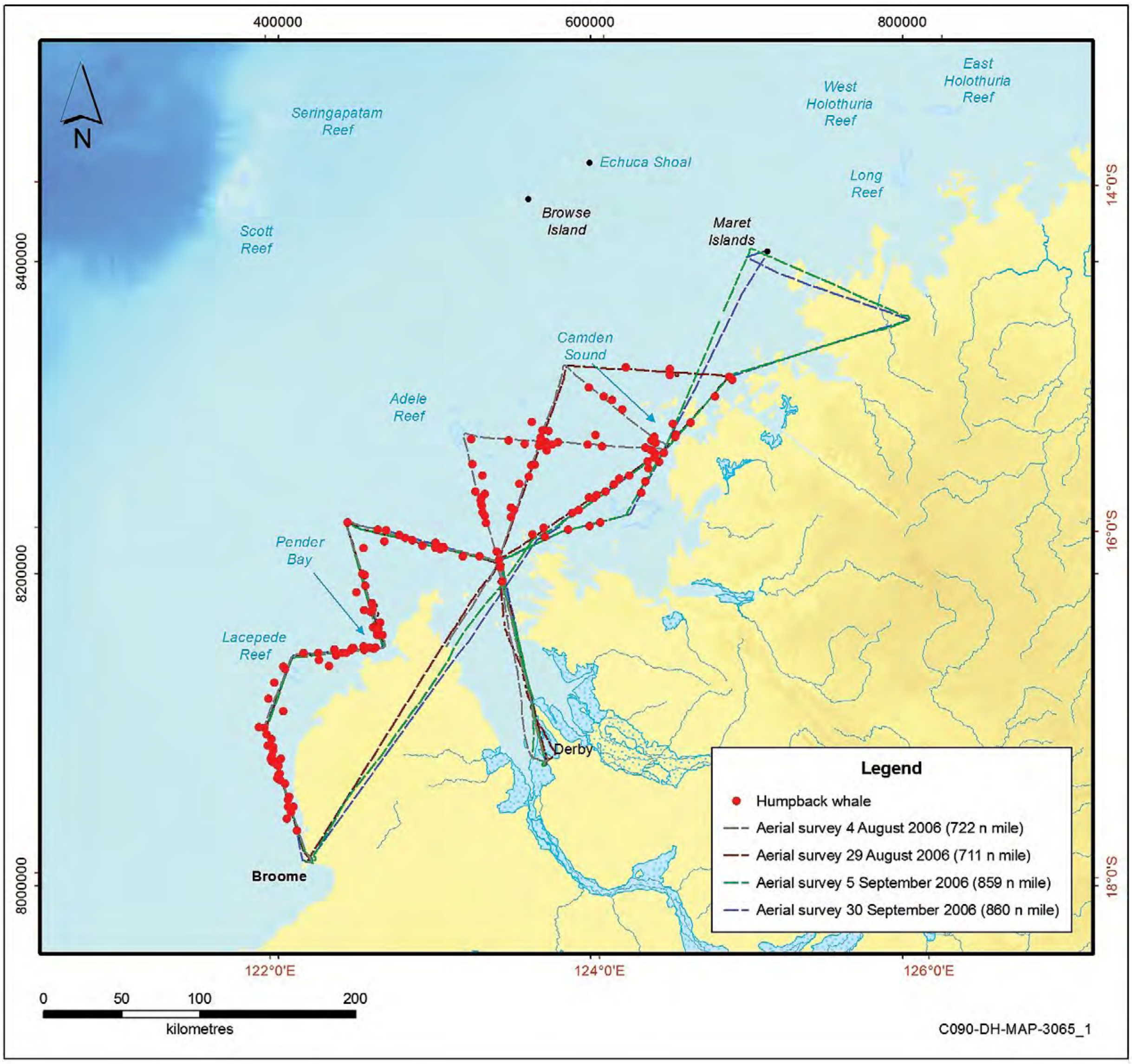

Figure 9-11: Positions of humpback whales observed during four aerial surveys in 2006

Table 9-5: Humpback whale observations from the four aerial surveys conducted during 2006

Date	Pods	Adults	Calves	Ratio of calves to adults
04-08-2006	78	101	12	**12%**
29-08-2006	44	67	11	**16%**
05-09-2006	33	55	11	**20%**
30-09-2006	10	17	5	**29%**
Total	**165**	**240**	**39**	**16%**

Table 9-6: Humpback whale observations from the six aerial surveys conducted during 2007*

Date	Pods	Adults	Calves	Ratio of calves to adults
02-08-2007	124	176	10	**6%**
12-08-2007	116	171	15	**9%**
13-08-2007	158	232	22	**9%**
02-09-2007	131	196	28	**14%**
14-09-2007	124	171	31	**18%**
30-09-2007	49	77	21	**27%**
Total	**702**	**1023**	**127**	**12%**

* Excluding the data from the damaged voice-data recording tape from the flight of 26 August 2007.

Figure 9-12 shows that the northernmost humpback whale observations in 2006 were between 15.0°S and 15.2°S, at the southern end of the Bonaparte Archipelago. No humpback whales were observed in the Maret Islands area (between 14.4°S and 14.6°S) during any of the 2006 aerial surveys. In August, humpback whale densities were highest north of 16°S, and in September the highest density of humpback whales was recorded near Pender Bay (between 16.6°S and 16.8°S).

In 2007, humpback whales were observed as far north as the northern extent of the study area (approximately 13.9°S) (Figure 9-13). Densities were highest in the survey area south of Camden Sound, particularly in areas to its west and north of Pender Bay. Generally, whale densities during all flights were lower to the north-east of Camden Sound.

In 2006, there were large fluctuations in the density of both humpback whale individuals and pods between the surveys, with the greatest density observed during the survey conducted on 5 September. The lowest densities of cow–calf pods in 2006 were recorded during the flight on 30 September (Figure 9-14).

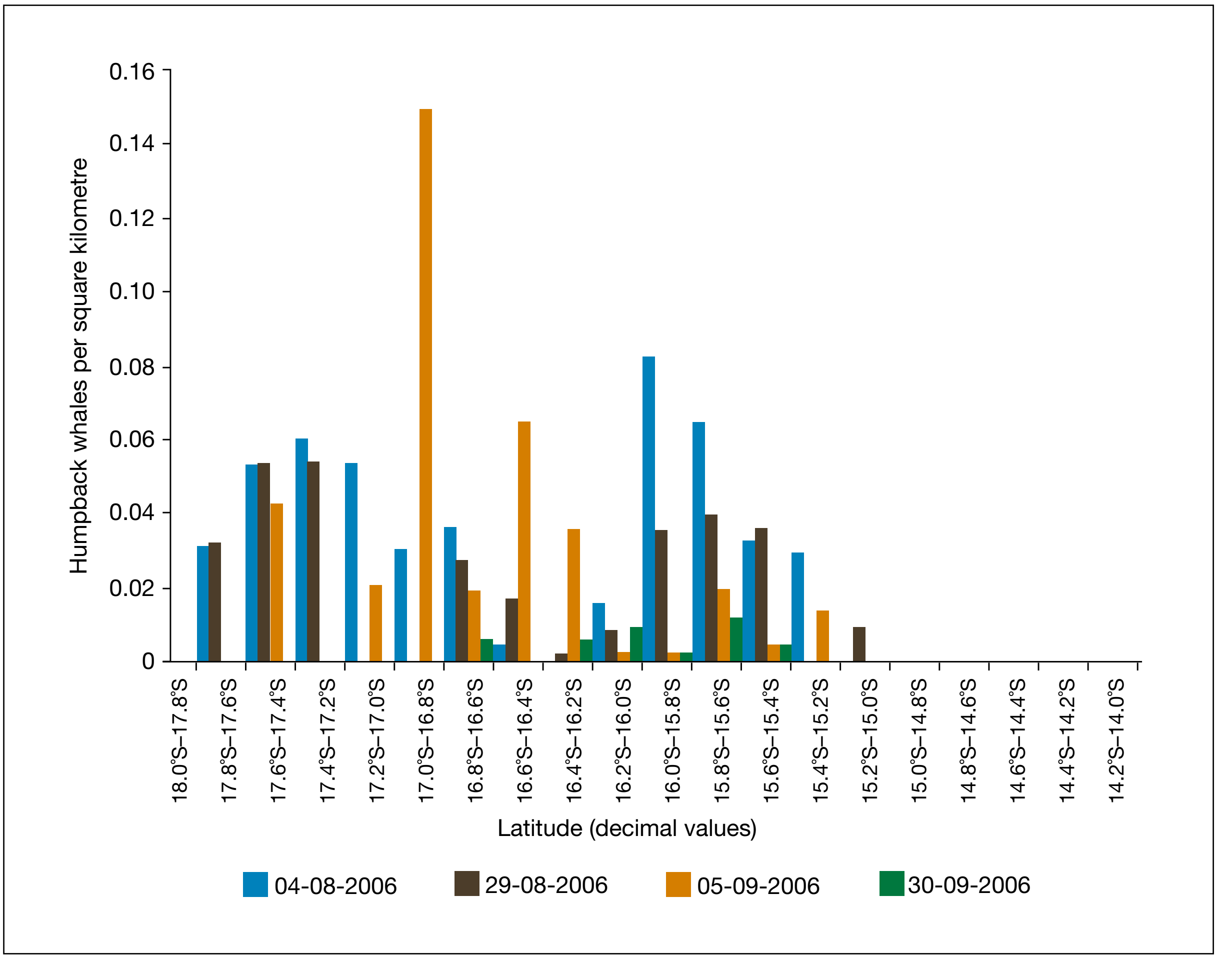

Figure 9-12: Density of humpback whales (number of individuals per square kilometre) recorded for each 0.2-degree latitude band during four aerial surveys in 2006

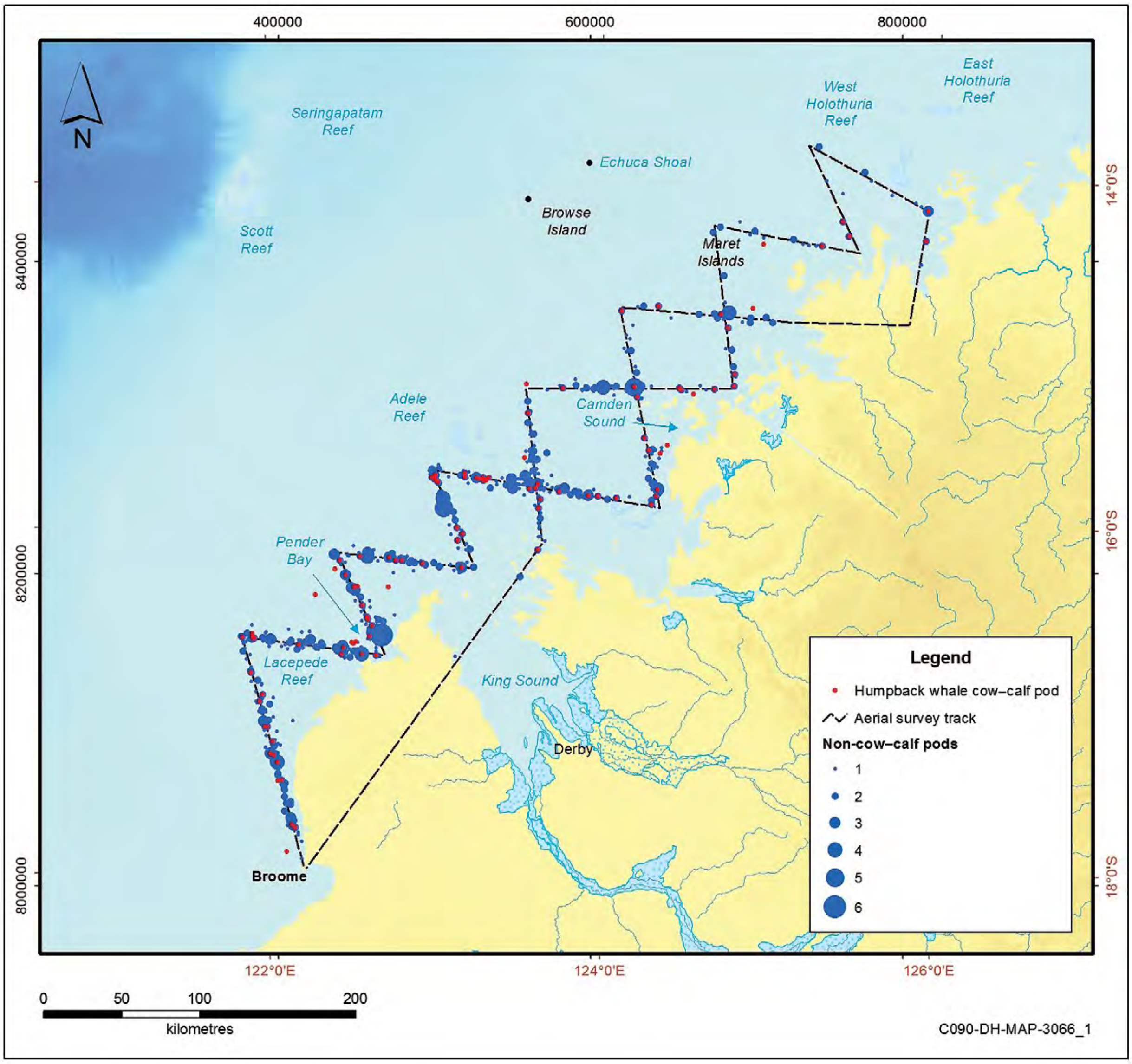

Figure 9-13: Positions of humpback whale pods (including cow–calf and non-cow–calf pods observed during the six aerial surveys in 2007 (excluding the data from the flight of 26 August 2007)

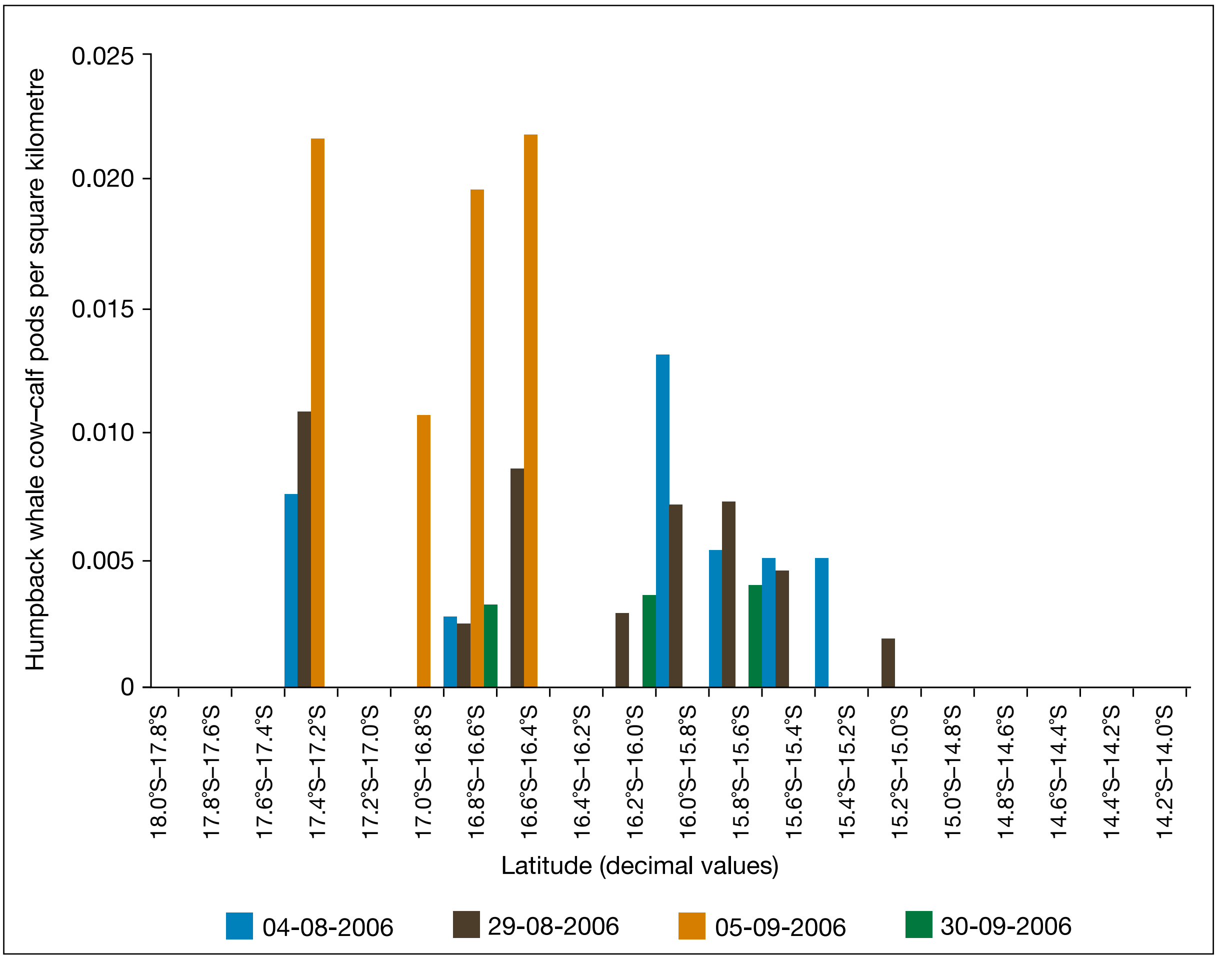

Figure 9-14: Density of humpback whale cow–calf pods recorded per 0.2 degree latitude band during four aerial surveys in 2006

Humpback whale abundances were estimated for each two-week survey period conducted between 2 August and 2 October 2007. The numbers of individuals were estimated to be between 1 and 4 per 100 square kilometres, and the numbers of pods as between 1 and 3 per 100 square kilometres. The uncorrected total population estimate (excluding data from 26 August) was 6446 individuals. The corrected population abundance for the entire season, including extrapolated data for 26 August, was 16 345 individuals. Figure 9-15 shows the estimated total population size of humpback whales in the Kimberley region during the 2007 survey season.

Vessel surveys: 2006 and 2007

Humpback whales were the most commonly observed whale species in the Kimberley region for all surveys. The vessel-based surveys in 2006 (674 hours) and 2007 (252 hours) identified 1128 humpback whales (Table 9-7) over a range extending from 275 km offshore of 13.7°S (55 km north-north-west of Browse Island) to Broome. Humpback whales were observed during all surveys, except for Survey 2006-4, during late October, where only the Maret Islands and Browse Island areas were surveyed (Figure 9-16).

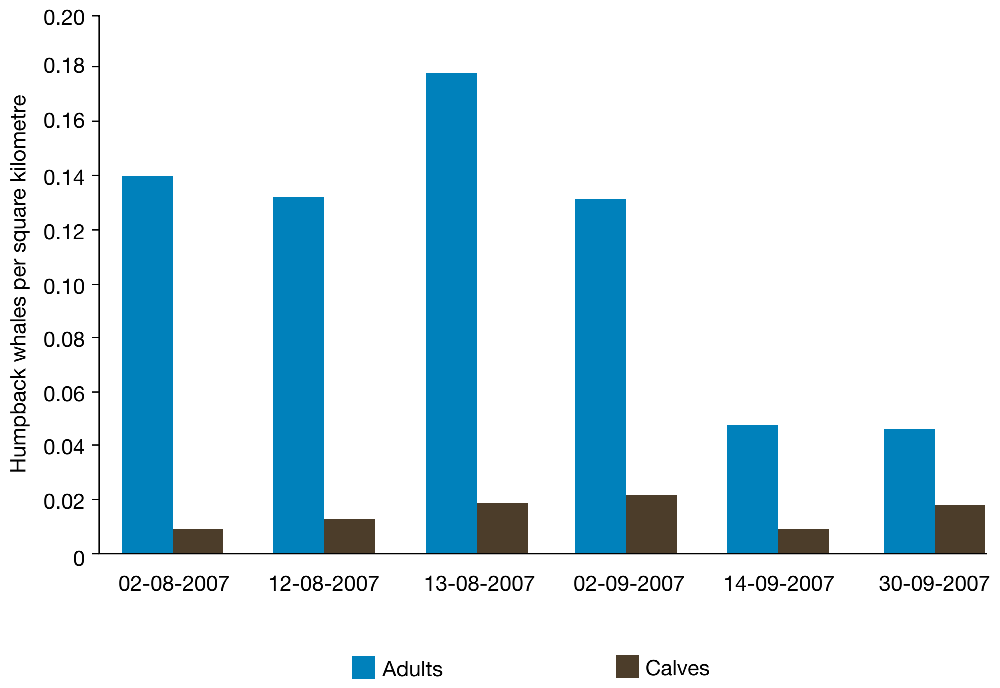

Figure 9-15: The estimated total population size of humpback whales in the Kimberley region during the 2007 survey season

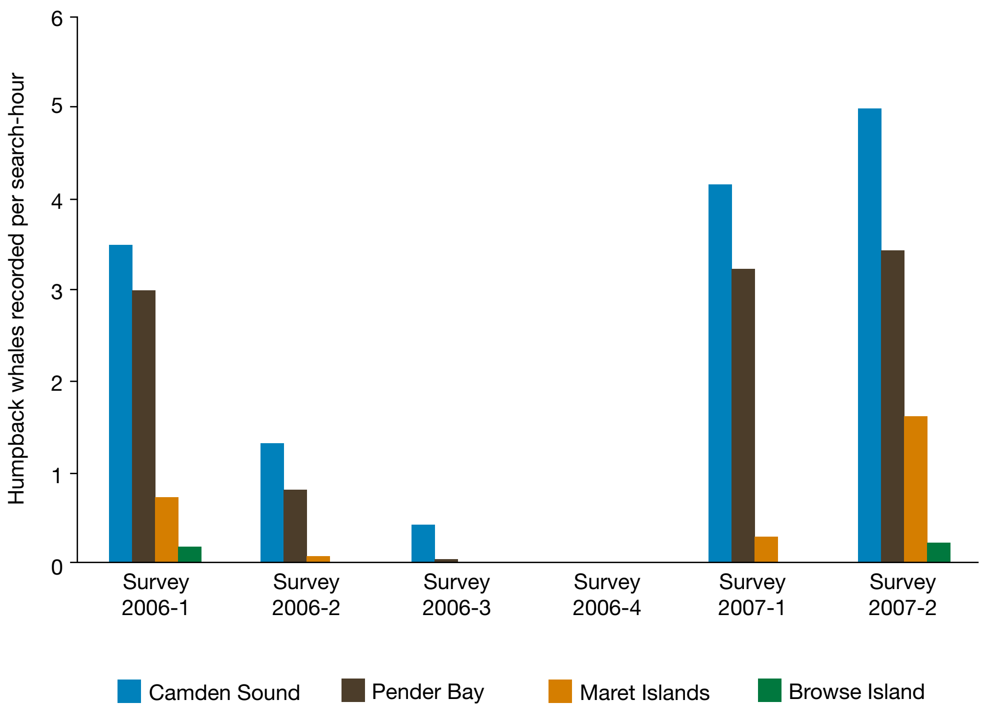

Figure 9-16: Humpback whales recorded per search-hour during each survey

Photograph courtesy of Curt Jenner, Centre for Whale Research

Figure 9-17: Travelling humpback whale calf blowing bubbles from its blowhole

Kernel density estimation (KDE) maps were generated using a consistent smoothing factor (*h*) of 0.1 for three of the four 2006 surveys in which humpback whales were observed (figures 9-18 to 9-20) and for the second of the 2007 surveys (Figure 9-22). Density estimates were not attempted for Survey 2007-1 (from 3 to 23 July 2007) because it was not possible to complete the full survey for this period[3].

The locations of humpback whales sighted during this period are shown in Figure 9-21.

Humpback whale densities were significantly higher in Camden Sound and Pender Bay than in the Browse Basin or around the Maret Islands. Only 21 whales in 13 pods were recorded in the Browse Basin across all surveys, the lowest density of all areas surveyed; this was followed by the Maret Islands where 59 whales in 38 pods were recorded.

Four cow–calf pods were observed around the Maret Islands across both seasons, and only one in the Browse Basin. Camden Sound had the highest numbers of cow–calf pods (25) and generally higher densities, although the density of cow–calf pods in Pender Bay was higher than in Camden Sound during the early August survey (Figure 9-23).

[3] Note: apparent inconsistencies in the dates of the surveys are attributable to the fact that the survey vessel left port on 3 July and only arrived on site to commence the transects on 7 July. The first whale was sighted during the voyage on 5 July.

Table 9-7: Individual humpback whales (with number of pods, number of pods with calves in brackets) recorded during the 2006 and 2007 vessel-based surveys

Survey	Date interval	Browse Basin			Maret Islands			Camden Sound			Pender Bay			Transits			Total		
		Individual humpback whales	Number of pods	Number of pods with calves	Individual humpback whales	Number of pods	Number of pods with calves	Individual humpback whales	Number of pods	Number of pods with calves	Individual humpback whales	Number of pods	Number of pods with calves	Individual humpback whales	Number of pods	Number of pods with calves	Individual humpback whales	Number of pods	Number of pods with calves
2006-1	15-08-2006 to 03-09-2006	9	4	0	17	10	3	158	96	10	87	64	6	76	45	8	347	219	27
2006-2	09-09-2006 to 28-09-2006	0	0	0	2	2	0	75	53	7	39	25	5	38	28	3	154	108	15
2006-3	04-10-2006 to 23-10-2006	0	0	0	0	0	0	22	11	6	1	1	0	10	4	3	33	16	9
2006-4	22-10-2006 to 29-10-2006	0	0	0	0	0	0	–	–	–	–	–	–	0	0	0	0	0	0
2007-1	05-07-2007 to 23-07-2007	–	–	–	6	1	0	58	40	0	52	33	1	96	48	2	212	122	3
2007-2	29-07-2007 to 17-08-2007	12	9	1	34	25	1	173	125	2	84	59	6	79	49	2	382	267	12
Total		**21**	**13**	**1**	**59**	**38**	**4**	**486**	**325**	**25**	**263**	**182**	**18**	**299**	**174**	**18**	**1128**	**732**	**66**

– = no data.

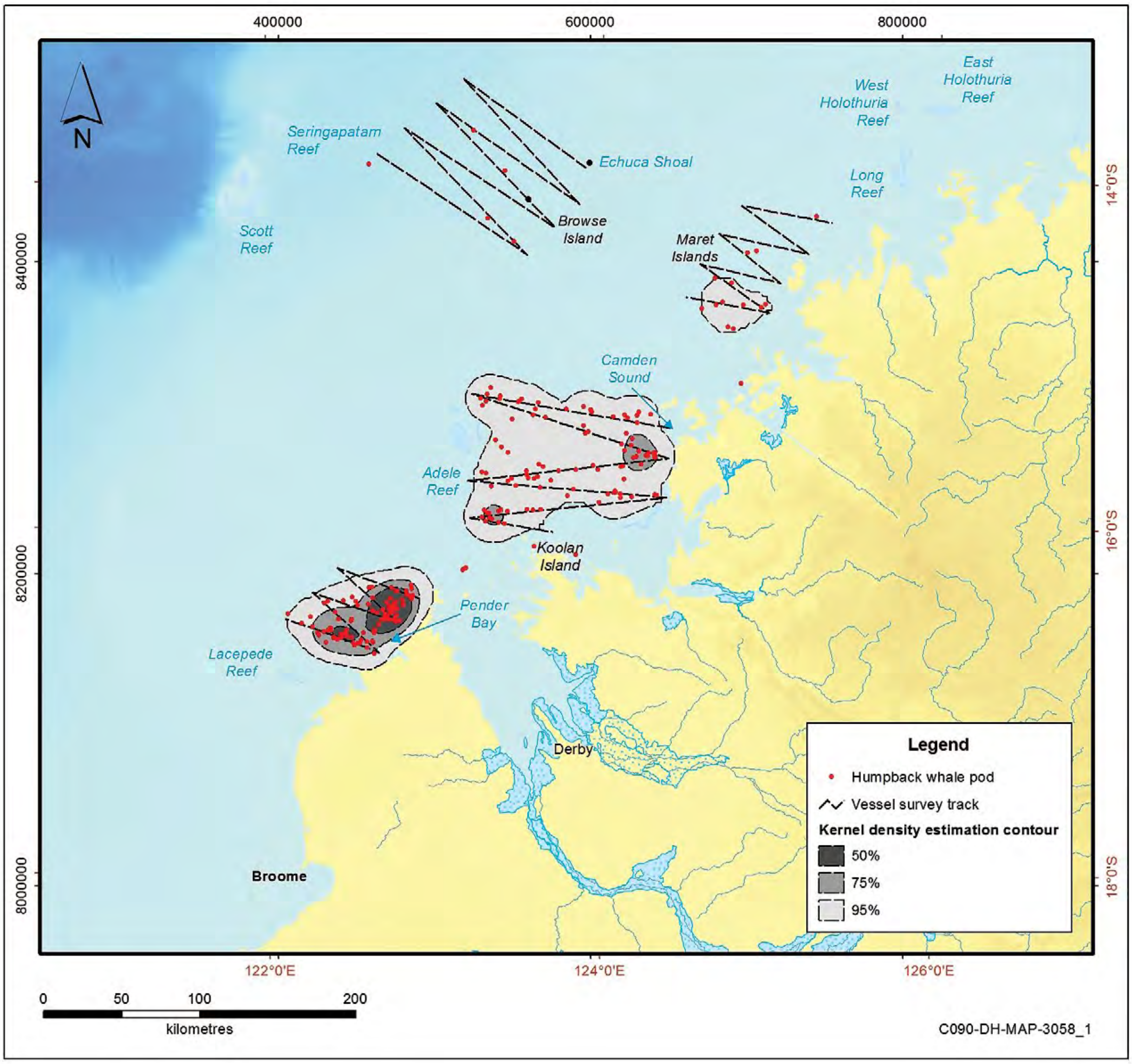

Figure 9-18: Distribution of humpback whales showing the kernel density estimation contours across the four surveyed areas from 15 August to 3 September 2006 (Survey 2006-1)

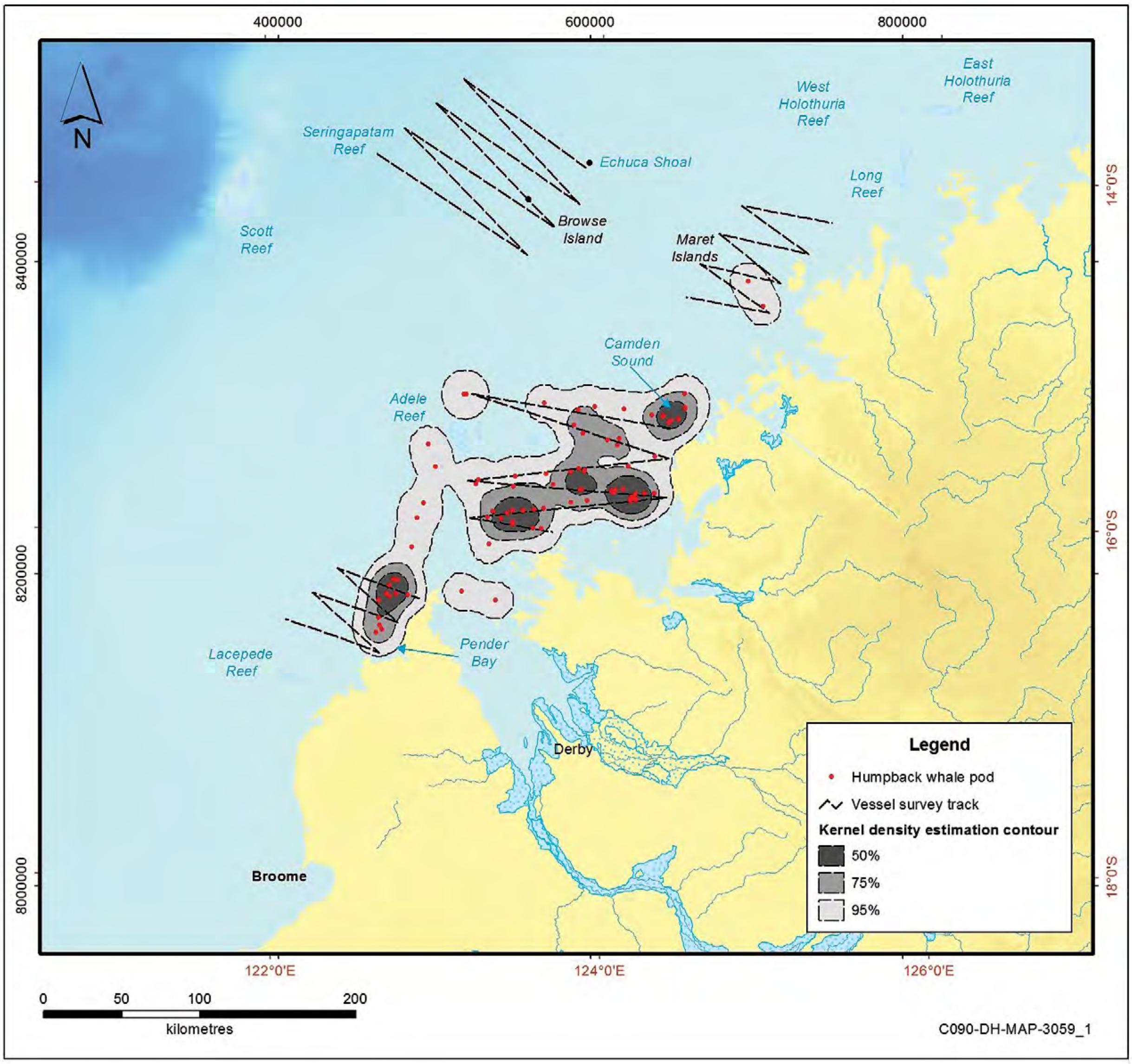

Figure 9-19: Distribution of humpback whales showing the kernel density estimation contours across the four surveyed areas from 9 to 28 September 2006 (Survey 2006-2)

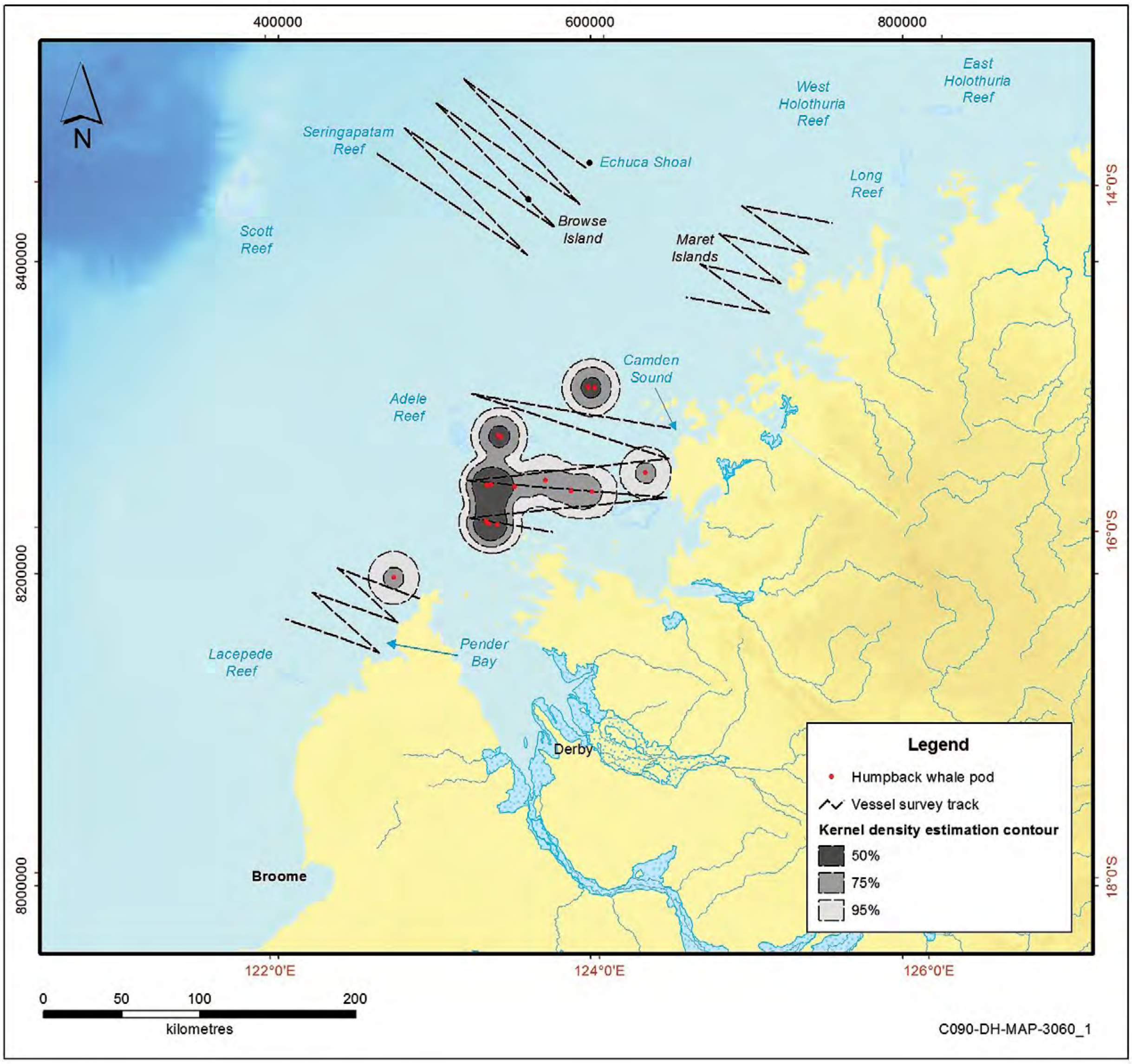

Figure 9-20: Distribution of humpback whales showing the kernel density estimation contours across the four surveyed areas from 4 to 23 October 2006 (Survey 2006-3)

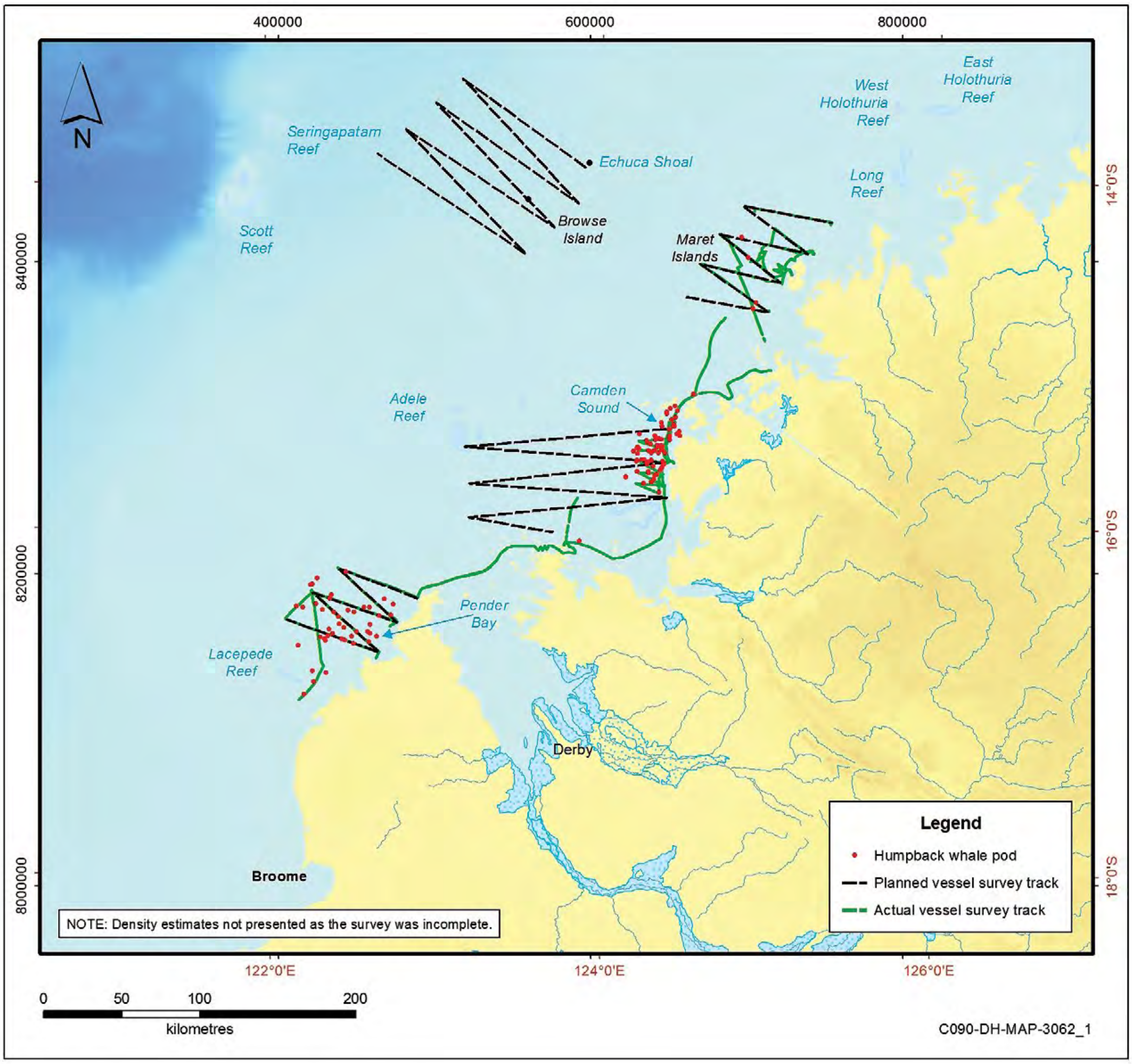

Figure 9-21: Locations of humpback whale pods observed from 5 July to 23 July 2007 (Survey 2007-1). Density estimates are unavailable as the survey was not completed because of bad weather

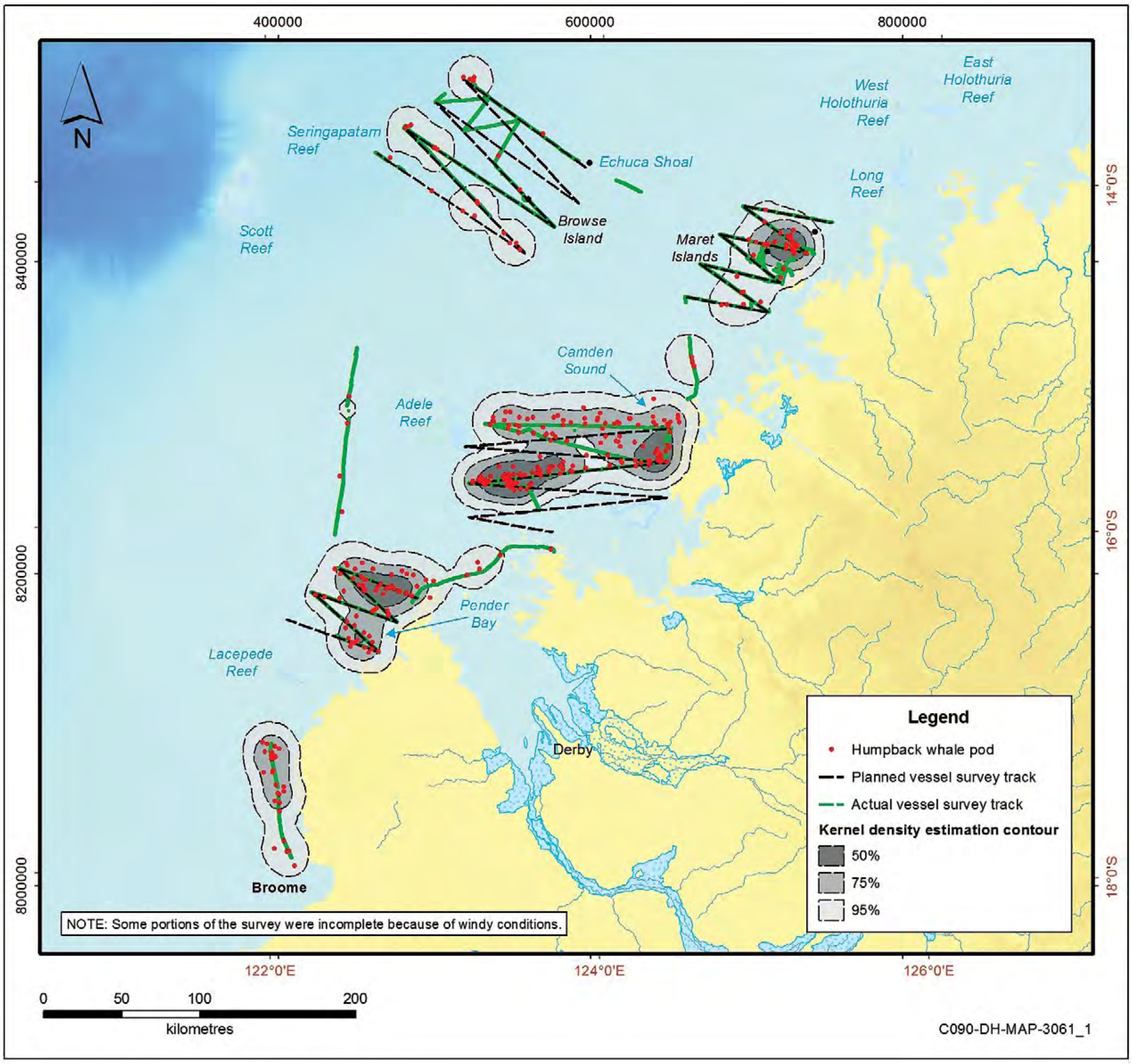

Figure 9-22: Distribution of humpback whales showing the kernel density estimation contours across the five surveyed areas from 29 July to 17 August 2007 during Survey 2007-2

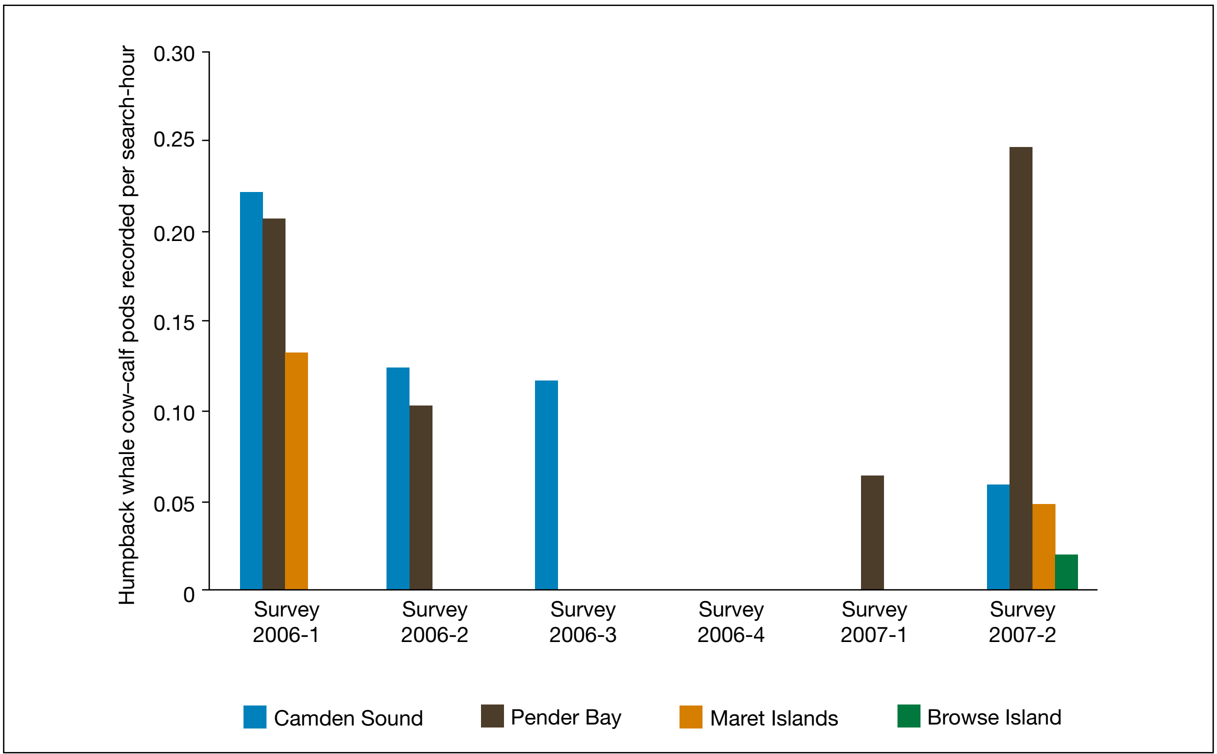

Figure 9-23: Humpback whale cow–calf pods recorded per search-hour for each survey area

The majority of whales recorded at the Maret Islands, Camden Sound, Pender Bay and those in transit displayed "surface-passive" behaviours[4] (figures 9-24 to 9-27). It should be noted that in some instances the behaviour of a single whale was taken to be the dominant behaviour of the entire pod. Comparatively few pods were observed at Browse Island. Among these pods, there was a more even mix of surface-passive and surface-active behaviours. While only 33 whales were recorded during the 2006-3 (4 to 23 October 2006) and 2006-4 (29 October to 7 November 2006) surveys, most of these whales displayed surface-passive behaviour. Note that these data have not been presented here because of the relatively low number of observations.

During Survey 2006-1 (15 August to 3 September 2006), two humpback whales in the south-easternmost sector of the Browse Basin area were observed swimming and diving in a manner consistent with feeding. This occurred where a front of higher temperature (+0.5 °C) was also recorded, along with very high levels of activity from birds and fish.

Similar humpback whale feeding behaviour was again recorded in the Browse Basin area in August 2007, approximately 70 km further offshore than the 2006 observation. Side-lunge feeding by subadult-sized humpback whales (<10 m long) was also observed. Pilot whales also appeared to be feeding in the same area.

[4] Surface-passive behaviours include travelling, resting and milling, while surface-active behaviours include breaching, pectoral-fin slapping and lobtailing.

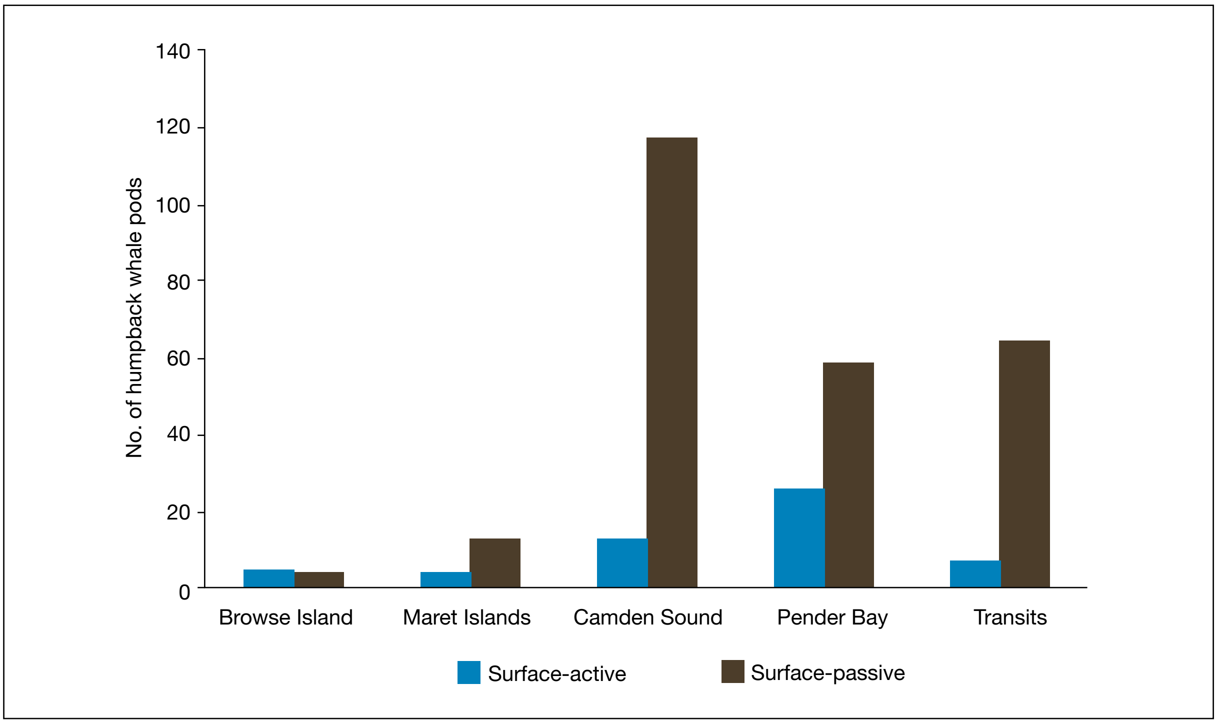

Figure 9-24: Number of pods of whales exhibiting surface-active or surface-passive behaviours from 15 August to 3 September 2006 (Survey 2006-1)

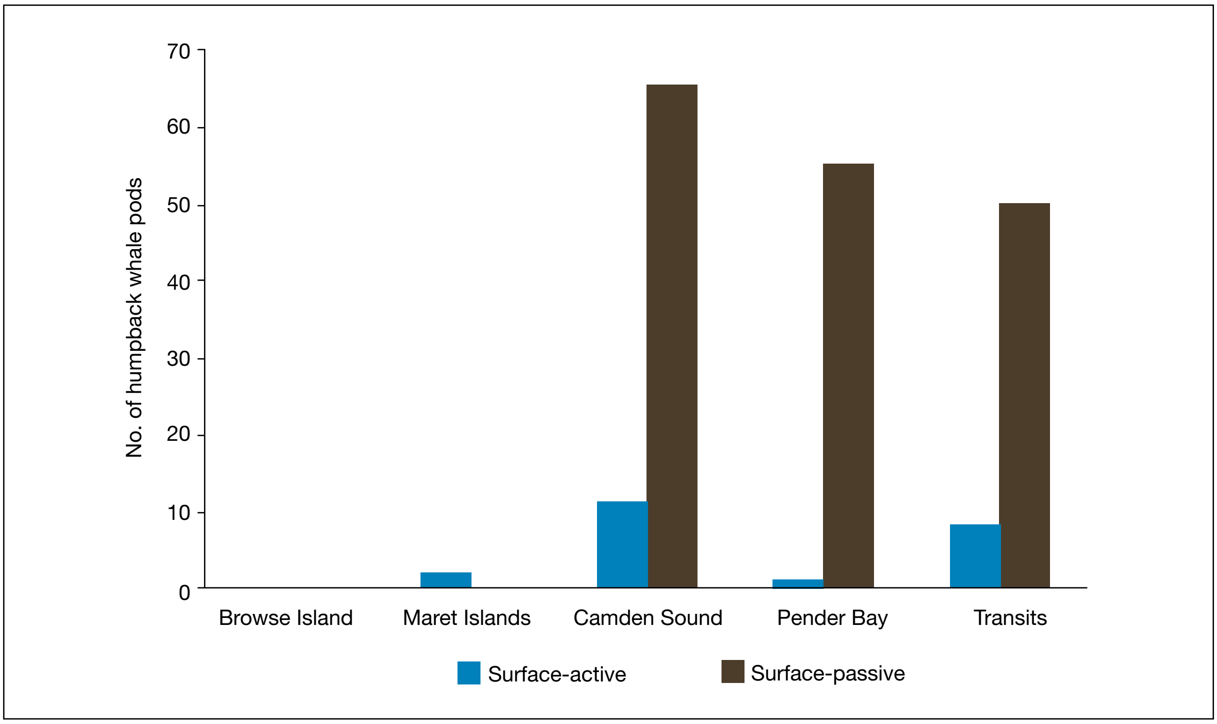

Figure 9-25: Number of pods of whales exhibiting surface-active or surface-passive behaviours between 9 and 28 September 2006 (Survey 2006-2)

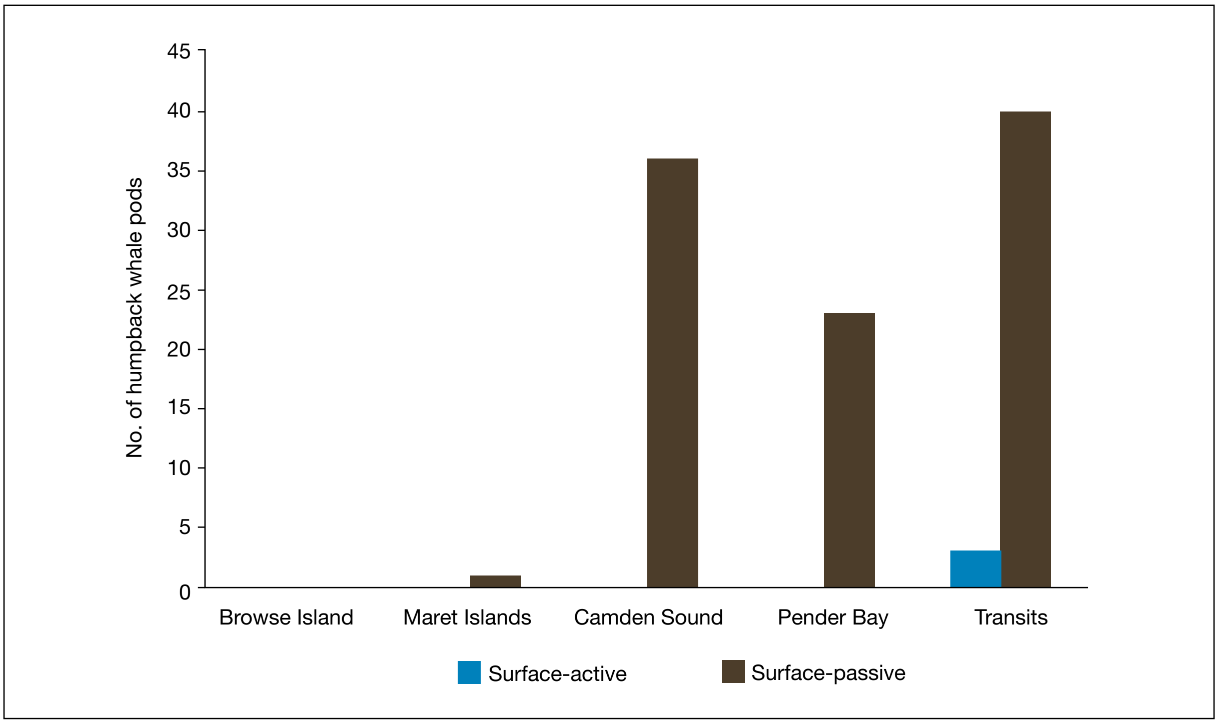

Figure 9-26: Number of pods of whales exhibiting surface-active or surface-passive behaviours between 5 and 23 July 2007 (Survey 2007-1)

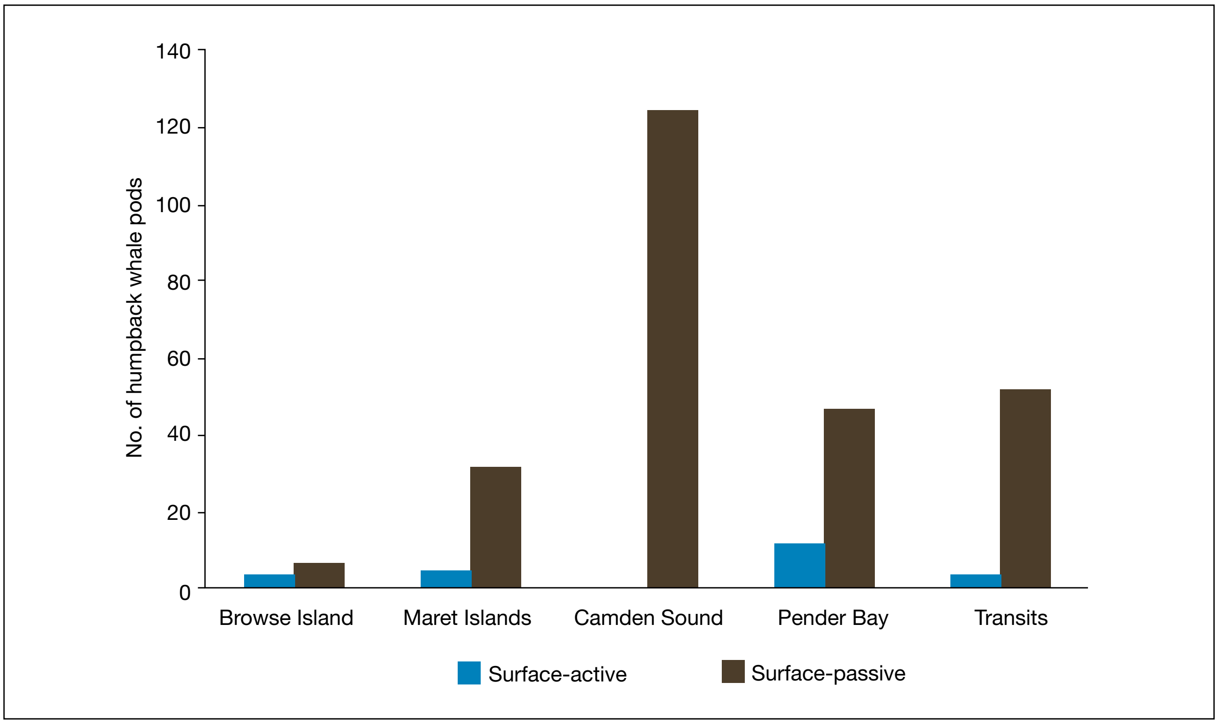

Figure 9-27: Number of pods of whales exhibiting surface-active or surface-passive behaviours between 29 July and 17 August 2007 (Survey 2007-2)

Opportunistic observations

The locations of humpback whales recorded opportunistically (as distinct from those observed from structured transects) within the survey areas, or by transect while the vessel was in transit to and from the survey areas between May 2006 and October 2007, are shown in Figure 9-28.

Blue whale observations: 2006 and 2007

No Antarctic blue whales or pygmy blue whales were observed during either vessel-based or aerial surveys in 2006.

Other cetaceans: 2006 and 2007

During both the 2006 and 2007 vessel-based surveys, 18 species of dolphins and whales (excluding humpback whales) were recorded, comprising 2237 individuals (Table 9-8). Because some sightings were of animals that made only short appearances at the surface or that were too distant from the vessel to be clearly seen, 295 whales and 1127 dolphins could not be identified to species level and were grouped separately based on whether they were thought to be "whale-sized" (>6 m) or "dolphin-sized" (<6 m).

For comparative purposes, in Table 9-8 the species have been grouped into four broader categories:

- inshore dolphins
- offshore dolphins
- small toothed whales
- baleen whales (excluding humpback whales).

The most species-rich area was the Browse Basin with 14 different species observed (or 15 taxa when the two subspecies of the spinner dolphin are included). The highest number of individuals was recorded during Survey 2006-1 (15 August to 3 September 2006) with a total of 1657, of which 1123 were identified and 524 were unidentified.

Large pods of offshore dolphins (Figure 9-29) were commonly observed in the Browse Basin area. Inshore dolphins (Figure 9-30) such as the spotted bottlenose dolphin (*Tursiops aduncus*) were more commonly observed in the Maret Islands area, although some large pods with 50–100 individuals were also found in the Browse Basin area.

Small toothed whales were uncommon, and were mostly observed during surveys 2006-2, 2006-3 and 2006-4 in the Browse Basin area and near Camden Sound (Figure 9-31). One beaked whale of the family Ziphiidae (species undetermined) was seen on 23 August 2006 in the Browse Basin area.

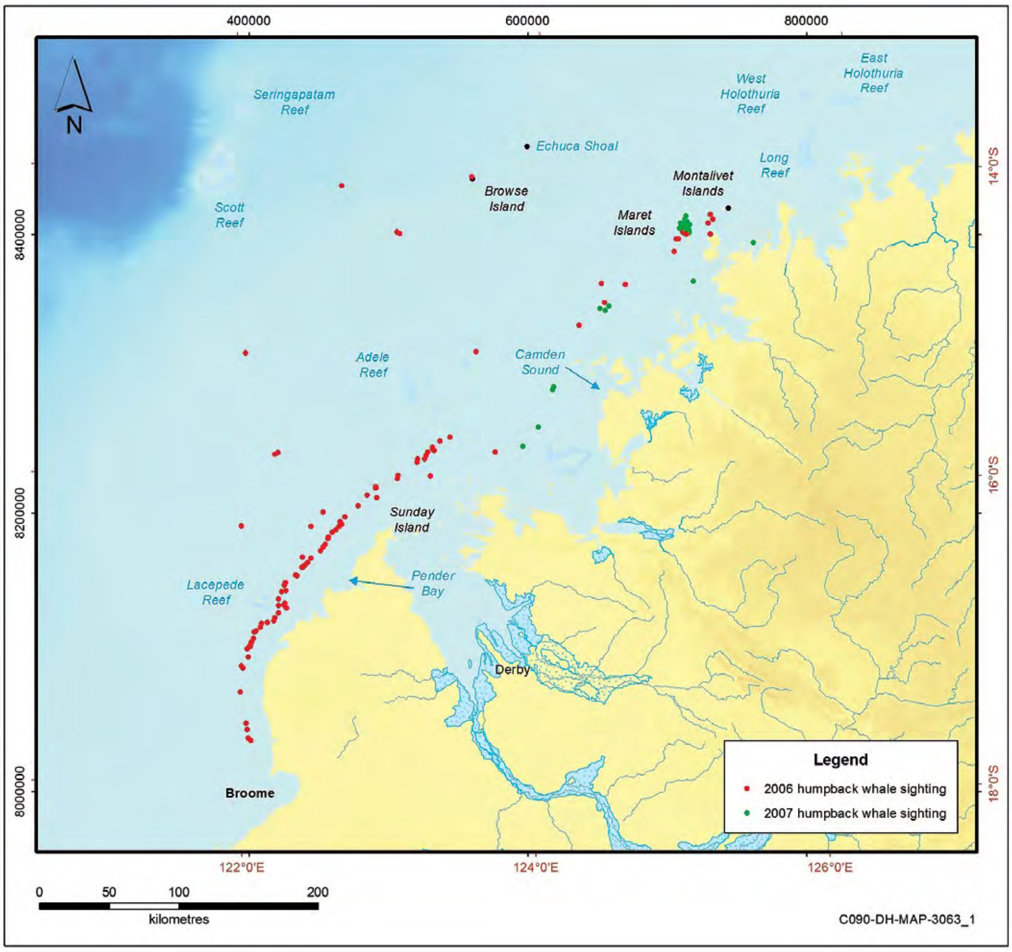

Figure 9-28: Locations of humpback whales observed opportunistically between May 2006 and October 2007

Seven minke whales were seen during the surveys, four of which were identified as the dwarf minke whale (*Balaenoptera acutorostrata*). Unidentified whales were common in all inshore survey areas (Figure 9-32).

The number of cetacean observations per hour in the 2006 and 2007 surveys (other than those for humpback and pygmy blue whales) is provided in Table 9-9.

Table 9-8: Cetacean species recorded in each area during the 2006 and 2007 surveys giving numbers of individuals and numbers of groups

Group	Scientific name	Common name	Browse Basin		Maret Islands		Camden Sound		Pender Bay		Transit		Total	
			Individuals	Groups	Individuals	Groups	Individuals	Groups	Individuals	Groups	Individuals	Groups	Individuals	Groups
Inshore dolphins	*Orcaella heinsohni*	Australian snubfin dolphin	–	–	4	2	–	–	–	–	18	4	22	6
	Sousa chinensis	Indo-Pacific humpback dolphin	–	–	–	–	–	–	2	1	2	1	4	2
	Tursiops aduncus	Spotted bottlenose dolphin	192	5	154	4	52	2	51	5	38	9	487	25
Offshore dolphins	*Delphinus capensis*	Long-beaked common dolphin	200	1	–	–	–	–	–	–	106	2	306	3
	Delphinus delphis	Short-beaked common dolphin	58	1	–	–	2	1	–	–	–	–	60	2
	Lagenodelphis hosei	Fraser's dolphin	12	1	–	–	–	–	–	–	–	–	12	1
	Stenella attenuata	Pantropical spotted dolphin	140	1	–	–	–	–	–	–	10	1	150	2
	Stenella coeruleoalba	Striped dolphin	50	1	61	1	–	–	–	–	25	1	136	3
	Stenella longirostris longirostris	Long-snouted spinner dolphin	434	5	12	1	40	1	–	–	2	1	488	8
	Stenella longirostris roseiventris	Dwarf spinner dolphin	337	2	–	–	–	–	–	–	–	–	337	2
	Tursiops truncatus	Bottlenose dolphin	100	1	–	–	7	1	–	–	–	–	107	2
Small toothed whales	*Feresa attenuata*	Pygmy killer whale	–	–	–	–	5	1	–	–	–	–	5	1
	Globicephala macrorhynchus	Short-finned pilot whale	12	1	–	–	–	–	–	–	–	–	12	1
	Mesoplodon sp.	Beaked whale (species unknown)	1	0	–	–	–	–	–	–	–	–	1	0
	Pseudorca crassidens	False killer whale	38	2	22	1	23	1	–	–	–	–	83	4
	Peponocephala electra	Melon-headed whale	20	1	–	–	–	–	–	–	–	–	20	1
Baleen whales (excluding humpback whales)	*Balaenoptera acutorostrata*	Dwarf minke whale	4	3	–	–	–	–	–	–	–	–	4	3
	Balaenoptera bonaerensis	Antarctic minke whale	3	2	–	–	–	–	–	–	–	–	3	2
Total			**1601**	**27**	**253**	**9**	**129**	**7**	**53**	**6**	**201**	**19**	**2237**	**68**

– = no observations.

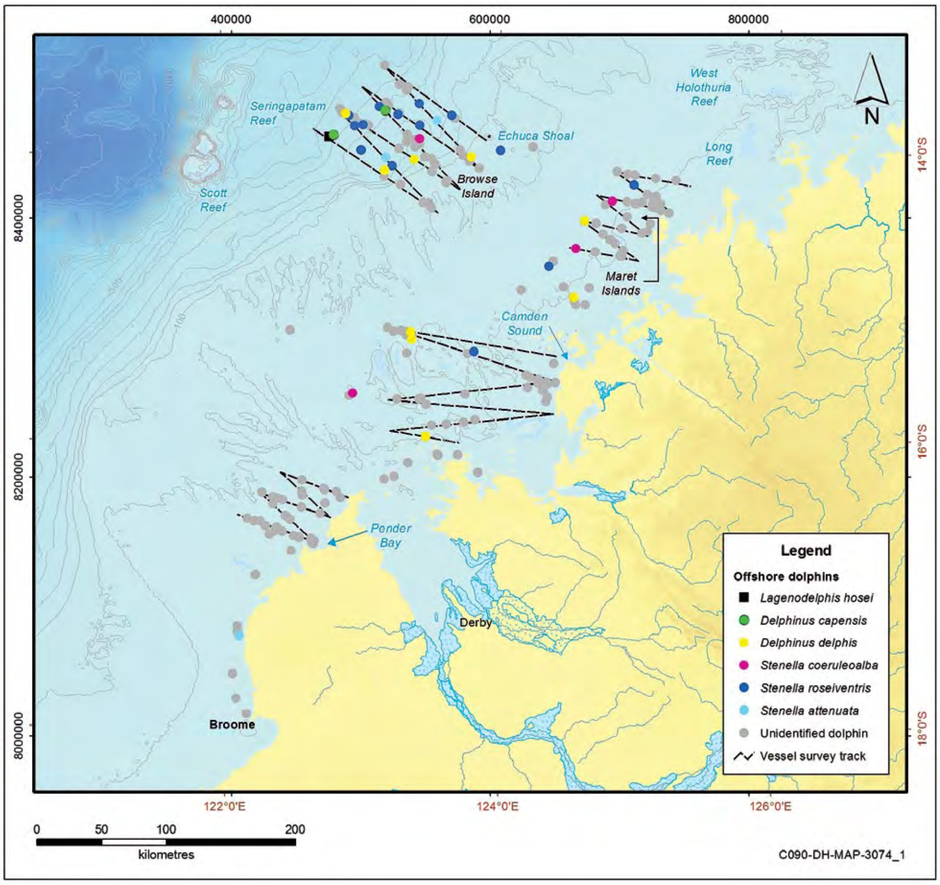

Figure 9-29: The distribution of offshore and unidentified dolphins for all 2006 and 2007 vessel-based surveys

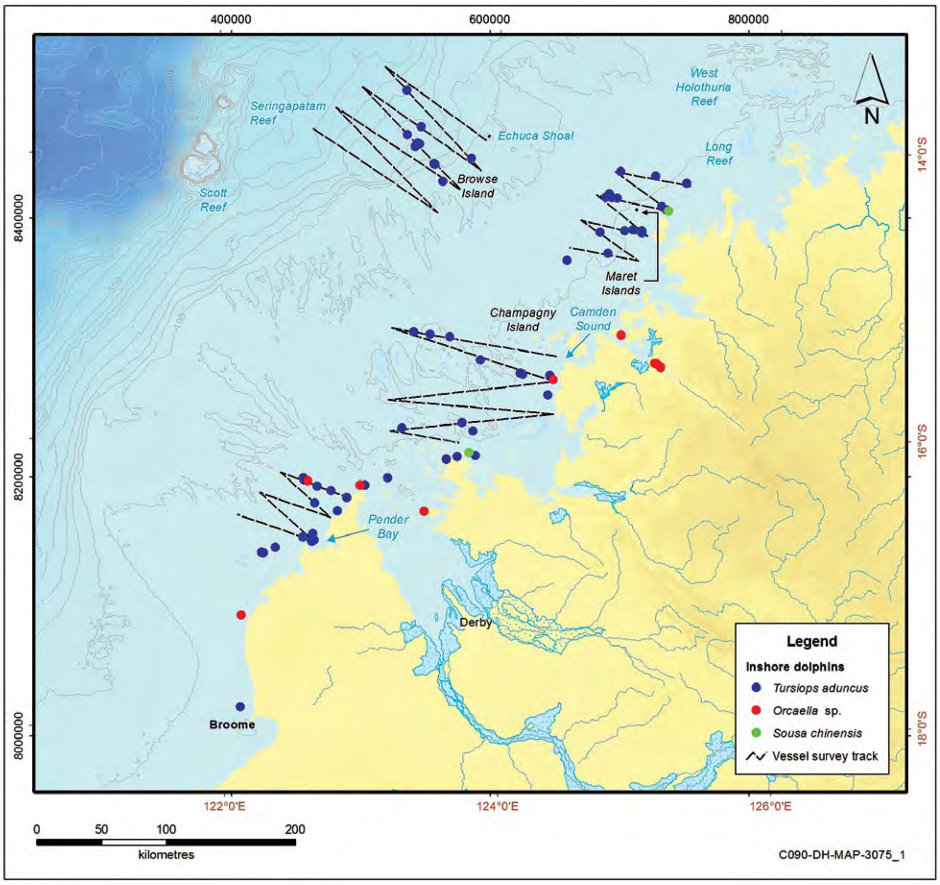

Figure 9-30: The distribution of inshore dolphins for all 2006 and 2007 vessel-based surveys

Figure 9-31: The distribution of small toothed whales for all 2006 and 2007 vessel-based surveys

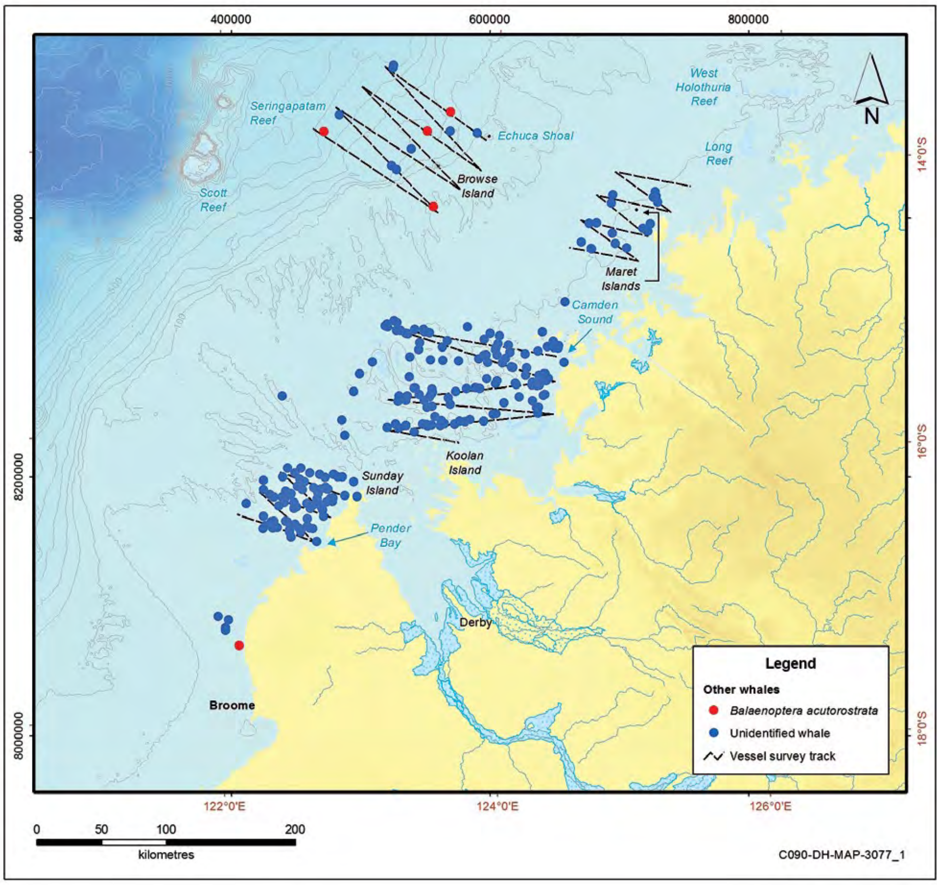

Figure 9-32: The distribution of minke whales and unidentified whales for all 2006 and 2007 vessel-based surveys

Table 9-9: The number of cetacean observations per hour (other than those for humpback and pygmy blue whales) in the 2006 and 2007 surveys

Month	Total hours of transect surveys	Mean no. of observations per hour	Standard deviation	Range	No. of transects
August 2006	28.52	1.56	1.61	0–3.82	13
September 2006	29.72	2.58	2.83	0–6.62	5
July 2007	9.83	1.57	0.78	0–3.70	4

Other vessel-based observations by transect and opportunistic observations

The locations of cetaceans (other than humpback or pygmy blue whales) recorded opportunistically in 2006 and 2007 are shown in figures 9-33 and 9-34. Fewer cetaceans were recorded between Broome and the Maret Islands in 2007.

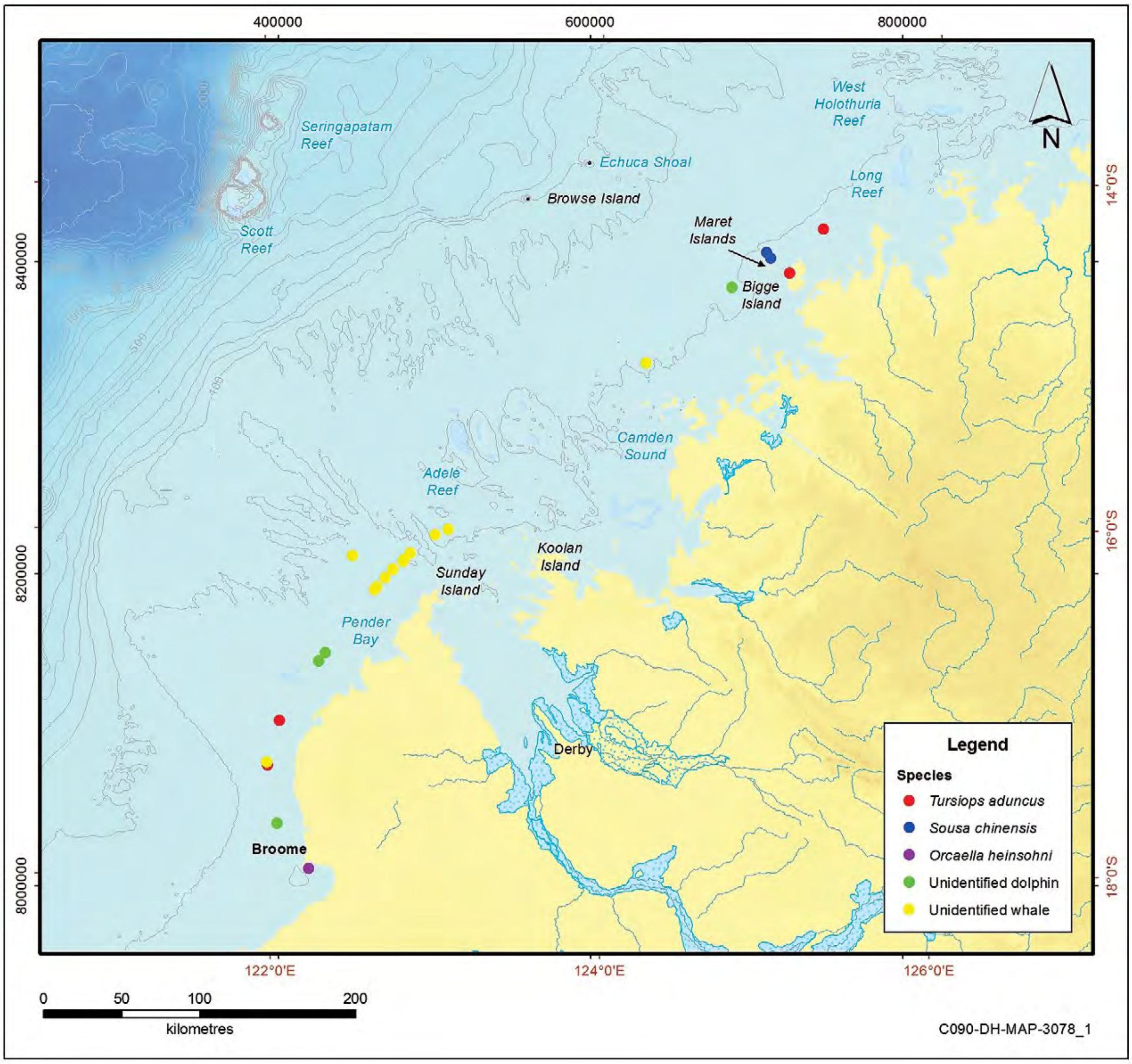

Figure 9-33: The locations of cetaceans (other than humpback or blue whales) observed opportunistically between July and December 2006

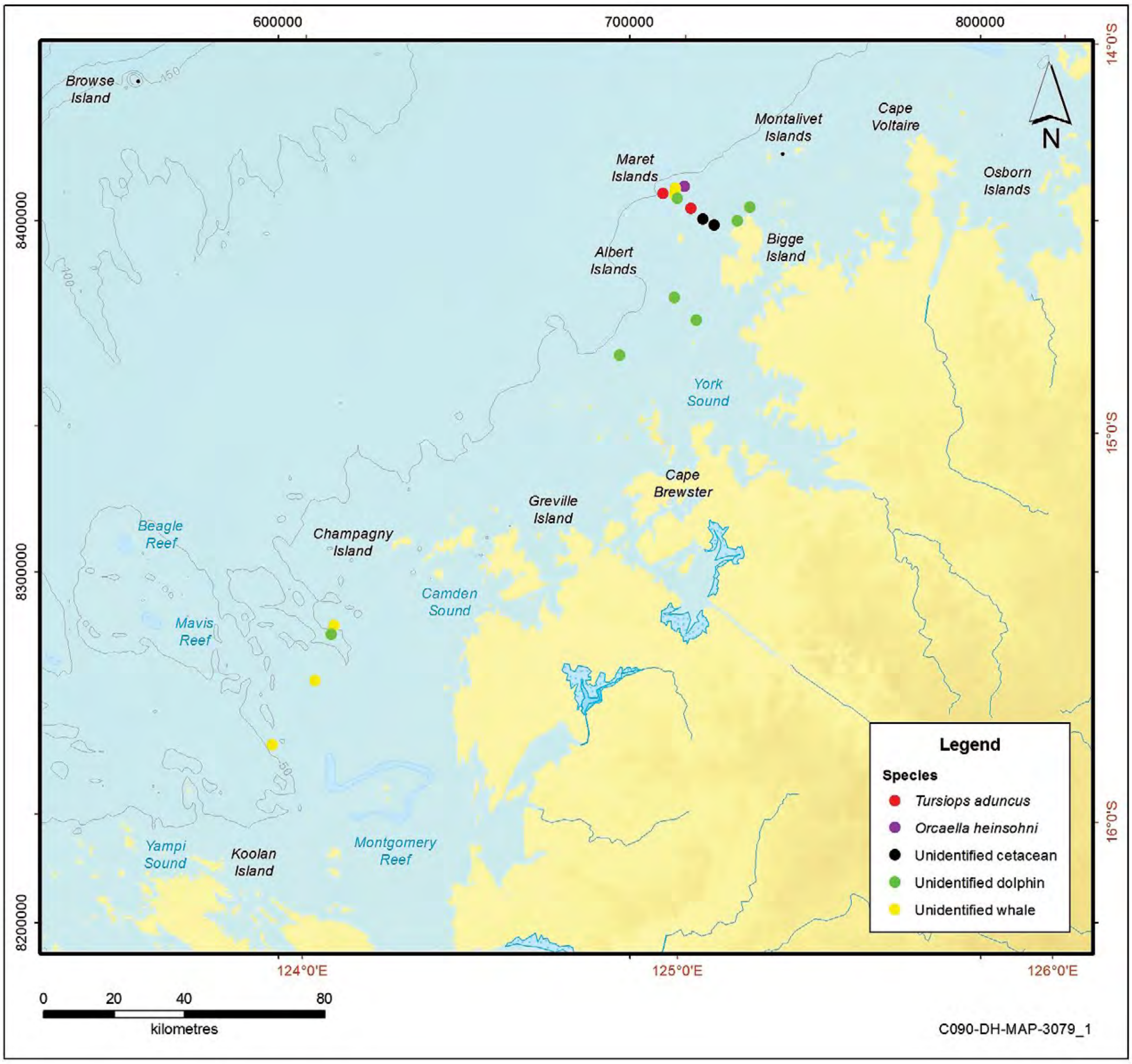

Figure 9-34: The locations of cetaceans (other than humpback or blue whales) observed opportunistically between January and September 2007

Vessel surveys: 2008

Between June and November 2008, four surveys each of 20 days' duration were completed, giving a total of 711.9 survey hours overall (Table 9-4).

In 2008, 642.8 survey hours were conducted within the study area, covering a distance of 8126.4 km. Weather conditions during June and July were generally less favourable for sighting cetaceans (and other animal life) than in October and November. In addition, fewer survey hours were completed in June and July (surveys 2008-1 and 2008-2: 296.8 hours; 46%) than during October and November (surveys 2008-3 and 2008-4: 346 hours; 54%) (Table 9-10).

Cetacean sightings

Between June and November 2008, excluding transit time, 194 sightings were made of 3557 individual cetaceans during 80 days of surveys (Table 9-10). (When transit time is included, 3750 were observed in all.) Of these, 79% were identified to species or genus level, with at least 15 different species being recorded. Sightings of small cetaceans were much more common than sightings of large cetaceans (Table 9-10; figures 9-35 and 9-36). Note that "small cetacean" totals include the "unidentified dolphin" and "unidentified small cetacean" categories and that "large cetacean" totals refer to unidentified whales generally and include an unidentified baleen whale and an unidentified large whale.

The pygmy blue whale was the most common large whale recorded, followed by the humpback whale. These two species accounted for 52% of all individual large-cetacean sightings during the surveys. Of the 2153 small cetaceans identified to species level, the long-snouted spinner dolphin (*Stenella longirostris longirostris*) was the most common, accounting for 61% of the observations.

Only 193 cetacean sightings, around 5% of the total, were recorded outside the study area during the 80-day survey and were excluded from further analysis. However, it should be noted that on 5 July 2008 46 humpback whales were sighted in 24 pods near the Dampier Peninsula and offshore the Lacepede Islands, an area which is outside the study area (Figure 9-37). All observed humpback whales in these pods were northbound.

At least 15 different cetacean species were observed within the study area. The number of species observed was reasonably consistent among all surveys, varying from 6 to 8 (Table 9-10), although only 20% of species were seen during more than two surveys. Most large-cetacean species were observed during only a single survey, with the notable exception of pygmy blue whales which were observed during three of the four surveys. Similarly, most dolphin species were observed during a single survey, with the exception of the long-snouted spinner dolphins and Risso's dolphins (*Grampus griseus*) which were observed during three of the surveys. False killer whales (*Pseudorca crassidens*) and bottlenose dolphins (*Tursiops truncatus*) were seen during two of the surveys.

Cetacean sightings in general were higher during surveys 2008-3 and 2008-4 (October and November) with 934 and 761 individuals sighted per 100 survey hours during 30 and 28 sightings respectively (Table 9-10; figures 9-35 and 9-36). This difference is likely to be driven by sightings of small cetaceans, as small-cetacean sightings were more common in October and November, while large-cetacean numbers were consistent between surveys, with between 4 and 8 being sighted per survey.

Table 9-10: Cetaceans sighted within the study area during the 2008 vessel surveys

Species	Survey 2008-1		Survey 2008-2		Survey 2008-3		Survey 2008-4		Total	
	Cetaceans sighted	Number of sightings	Cetaceans sighted	Number of sightings	Cetaceans sighted	Number of sightings	Cetaceans sighted	Number of sightings	Cetaceans sighted	Number of sightings
Total survey hours	159.7		137.1		169.0		177.0		642.8	
Large cetaceans within study area										
Balaenoptera musculus brevicauda (pygmy blue whale)	1	1	–	–	5	2	1	1	7	4
Balaenoptera edeni (Bryde's whale)	–	–	–	–	–	–	4	4	4	4
Megaptera novaeangliae (humpback whale)	–	–	4	3	2	1	–	–	6	4
Balaenoptera acutorostrata (dwarf minke whale)	–	–	1	1	–	–	–	–	1	1
Unidentified minke whale species	–	–	1	1	–	–	–	–	1	1
Kogia sima (dwarf sperm whale)	–	–	–	–	1	1	–	–	1	1
Unidentified whale	2	2	1	1	–	–	–	–	3	3
Unidentified large baleen whale	–	–	1	1	–	–	–	–	1	1
Unidentified large whale	1	1	–	–	–	–	–	–	1	1

Table 9-10: Cetaceans sighted within the study area during the 2008 vessel surveys (continued)

Species	Survey 2008-1		Survey 2008-2		Survey 2008-3		Survey 2008-4		Total	
	Cetaceans sighted	Number of sightings	Cetaceans sighted	Number of sightings	Cetaceans sighted	Number of sightings	Cetaceans sighted	Number of sightings	Cetaceans sighted	Number of sightings
Small cetaceans within study area										
Globicephala macrorhynchus (short-finned pilot whale)	25	1	–	–	–	–	–	–	25	1
Unidentified pilot whale (genus *Globicephala*)	–	–	–	–	–	–	150	4	150	4
Pseudorca crassidens (false killer whale)	–	–	7	1	135	2	–	–	142	3
Tursiops truncatus (bottlenose dolphin)	25	1	13	1	–	–	–	–	38	2
Lagenodelphis hosei (Fraser's dolphin)	–	–	–	–	80	1	–	–	80	1
Tursiops aduncus (spotted bottlenose dolphin)	4	1	–	–	–	–	–	–	4	1
Delphinus capensis (long-beaked common dolphin)	–	–	46	1	–	–	–	–	46	1
Stenella longirostris longirostris (long-snouted spinner dolphin)	82	3	–	–	651	21	580	13	1313	37
Stenella attenuata (pantropical spotted dolphin)	10	1	–	–	–	–	–	–	10	1
Grampus griseus (Risso's dolphin)	24	1	16	2	–	–	30	1	70	4
Delphinus delphis (short-beaked common dolphin)	–	–	–	–	450	2	–	–	450	2
Unidentified bottlenose dolphin (genus *Tursiops*)	–	–	–	–	125	5	353	5	478	10
Unidentified dolphin	72	7	80	11	258	15	237	12	647	45
Unidentified small cetacean	–	–	–	–	54	2	–	–	54	2
Unidentified whale or dolphin	9	4	4	4	5	4	7	4	25	16
Total count	**255**	**23**	**174**	**27**	**1766**	**56**	**1362**	**44**	**3557**	**150**
Total count (large cetaceans)*	**4**	**4**	**8**	**7**	**8**	**4**	**5**	**5**	**25**	**20**
Total count (small cetaceans)†	**242**	**15**	**162**	**16**	**1753**	**48**	**1350**	**35**	**3507**	**114**
Total count (unclassifiable)‡	**9**	**4**	**4**	**4**	**5**	**4**	**7**	**4**	**25**	**16**

Note: cetaceans were identified to species or genus level where possible and classified as "unidentified" if sighted too far away or in too poor light for an accurate species identification to be made.

* Includes unidentified whale, unidentified large whale and unidentified large baleen whale.

† Includes unidentified dolphin and unidentified small cetacean.

‡ Unidentified whale or dolphin.

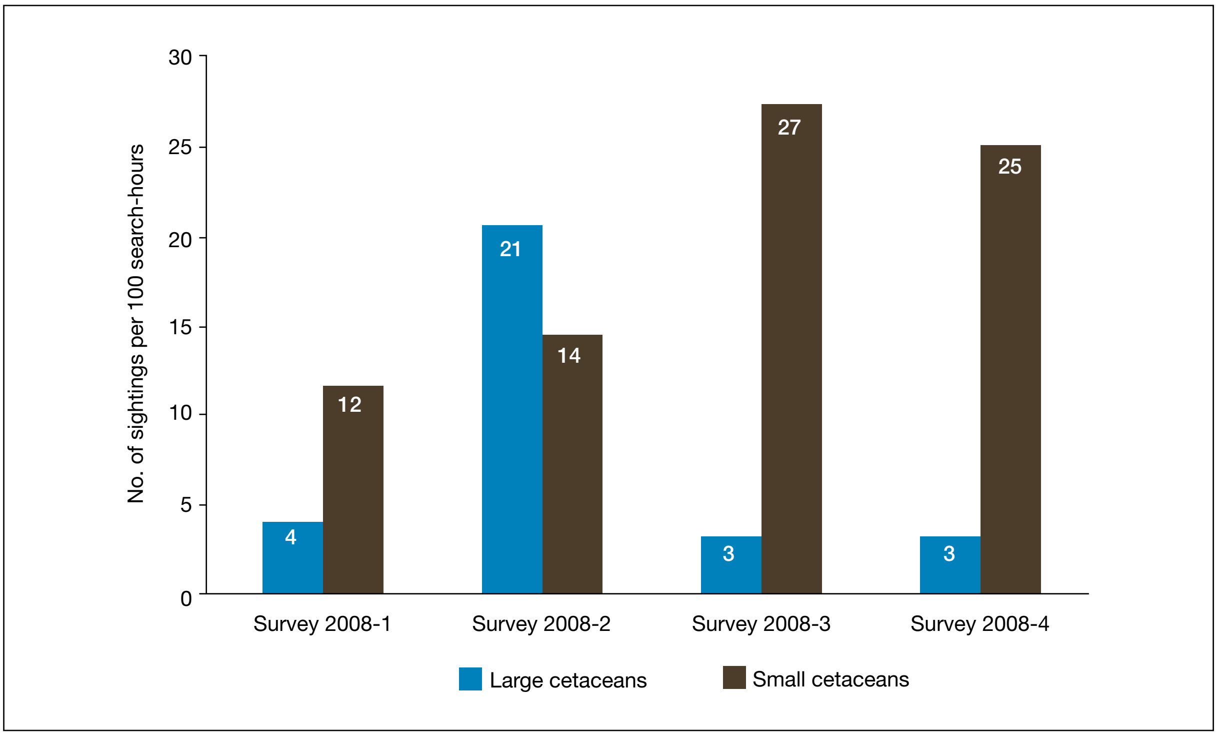

Figure 9-35: Small- and large-cetacean sightings during surveys conducted within the study area and observed during transit to and from the study area

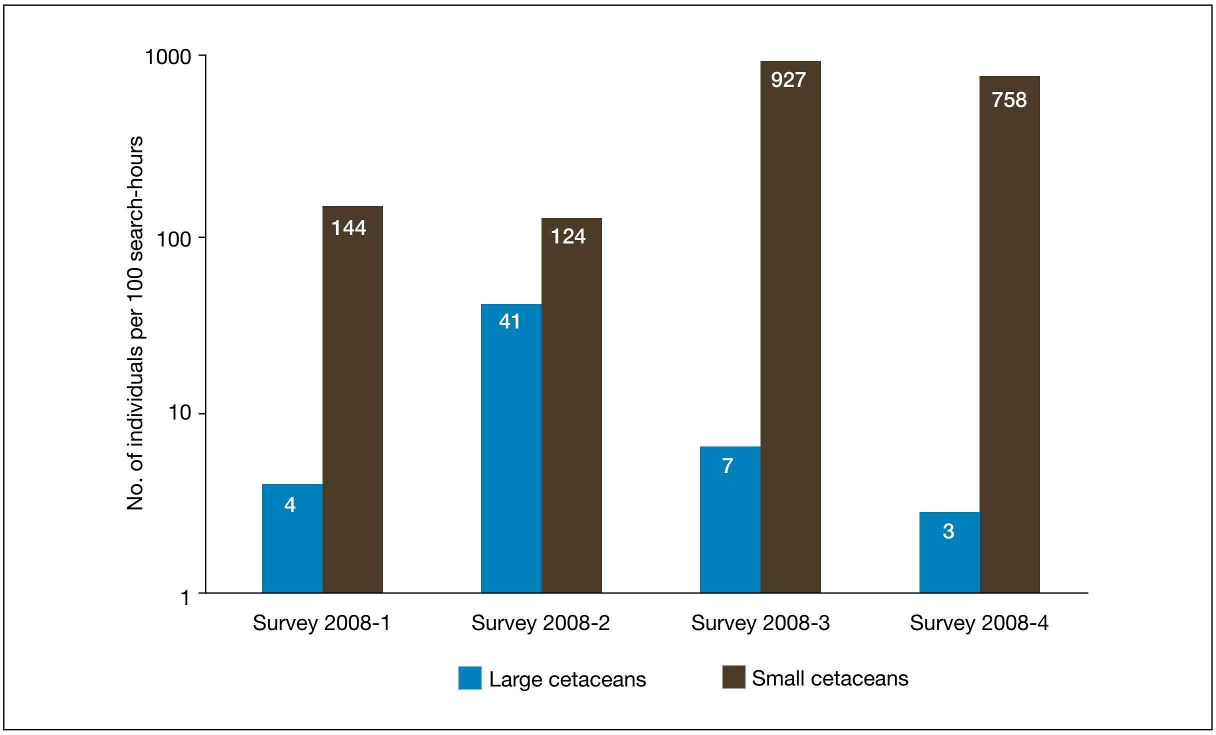

Figure 9-36: Small- and large-cetacean individuals recorded during surveys conducted within the study area and observed during transit to and from the study area

Minimum species richness was similar in the periods June–July and October–November 2008 (Table 9-10). However, the presence of individuals of large-cetacean species varied between these periods, with dwarf minke whales only recorded in June and July and Bryde's whales only in October and November (south-west of Browse Island). One freshly dead juvenile dwarf sperm whale (*Kogia sima*) was recorded in October.

Of the small cetaceans that were recorded the following should be noted:

- Three species were positively identified during all surveys: the long-snouted spinner dolphin (*Stenella longirostris longirostris*), Risso's dolphin (*Grampus griseus*) and the false killer whale (*Pseudorca crassidens*).
- Pantropical spotted dolphins (*Stenella attenuata*) and long-beaked common dolphins (*Delphinus capensis*) were sighted only during June and July.
- Fraser's dolphins (*Lagenodelphis hosei*) and short-beaked common dolphins (*Delphinus delphis*) were sighted only during October and November.
- Bottlenose dolphins (*Tursiops truncatus*), Indo-Pacific humpback dolphins (*Sousa chinensis*) and short-finned pilot whales (*Globicephala macrorhynchus*) were recorded only in June and July. Similar individuals that were not identifiable to species level were observed in October and November. These individuals were recorded as being unidentified, but could also have been presented as *Tursiops* sp. and *Globicephala* sp.

The mean group size for small cetaceans was 37.4 ± 52.8 in October and November (n = 83, range 1–400) compared with 13.0 ± 11.2 in June and July (n = 31, range 1–46), with the median group size being significantly different between the two periods (Mann–Whitney test: $P < 0.05$).

The mean group size for large cetaceans was similar between the two periods (1.1 ± 0.3, n = 11, in June–July, and 1.4 ± 0.7, n = 9, in October–November), with no significant difference in the median group size between the two periods.

Small-cetacean group sizes had high variability around the mean, while large-cetacean group sizes were more consistent with a range of one to three for all surveys. Large pods of spinner dolphins were a prominent feature of the November survey (Survey 2008-4).

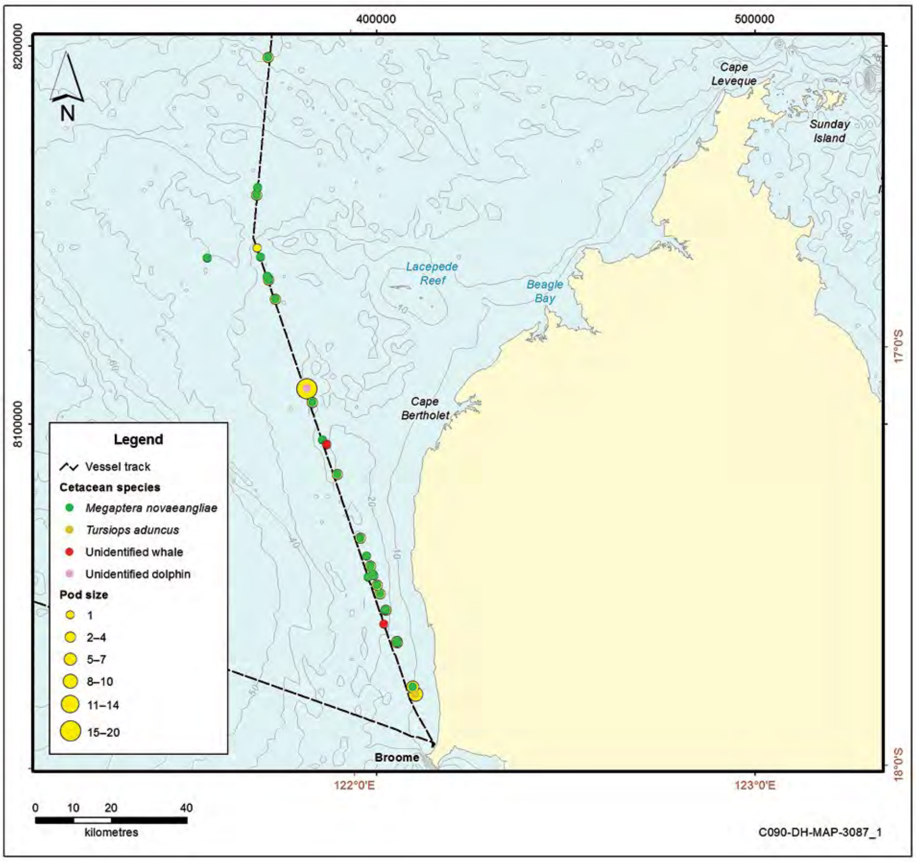

Figure 9-37: Observations of cetaceans made outside the survey area on 5 July 2008 (during Survey 2008-2), between Broome and the 50 m depth contour

The observations of cetacean species recorded during the four 2008 surveys are mapped in figures 9-38 to 9-41.

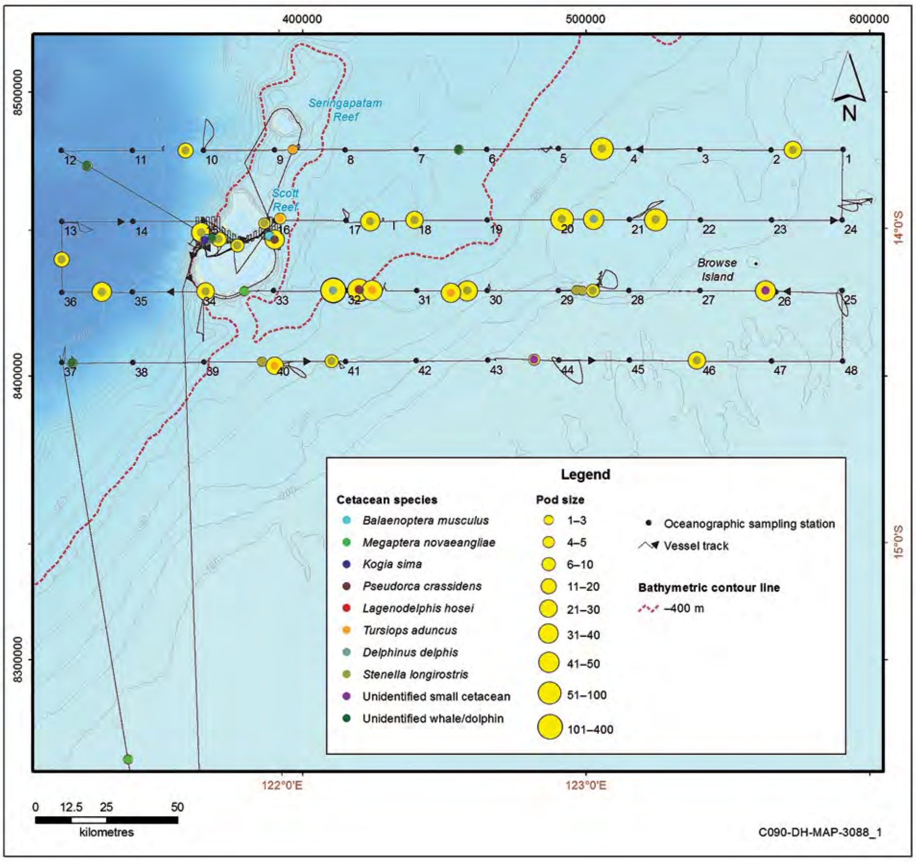

Figure 9-38: Cetacean observations recorded during Survey 2008-1 (June 2008)

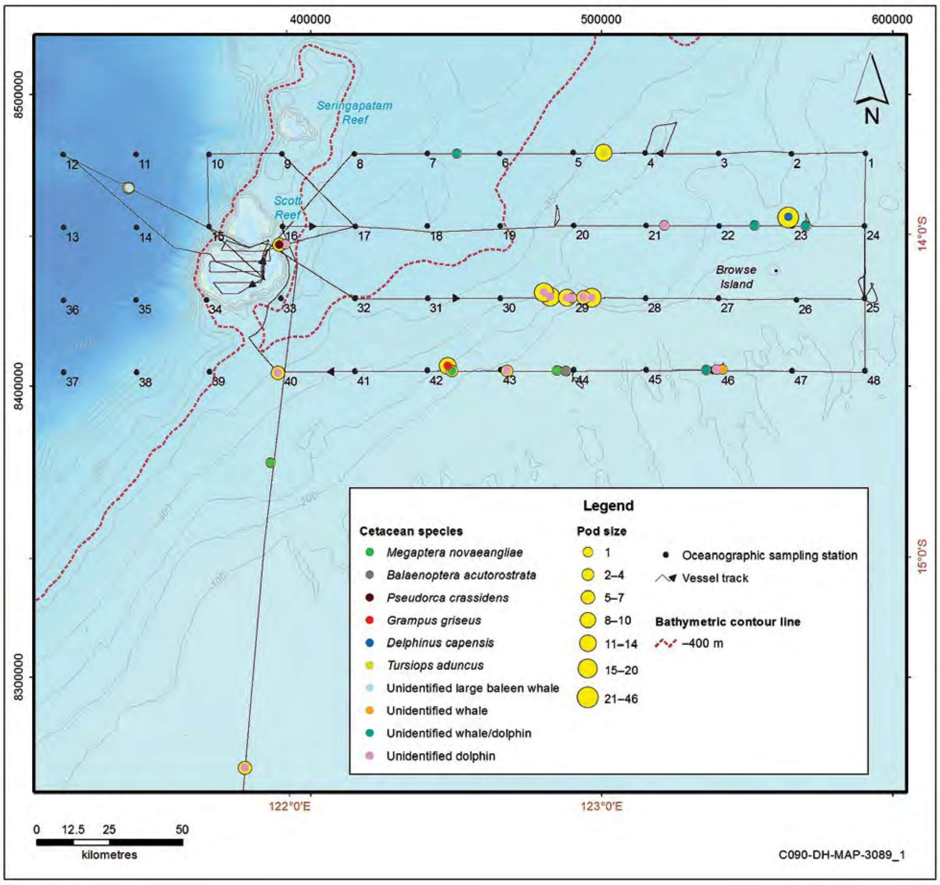

Figure 9-39: Cetacean observations recorded during Survey 2008-2 (July 2008)

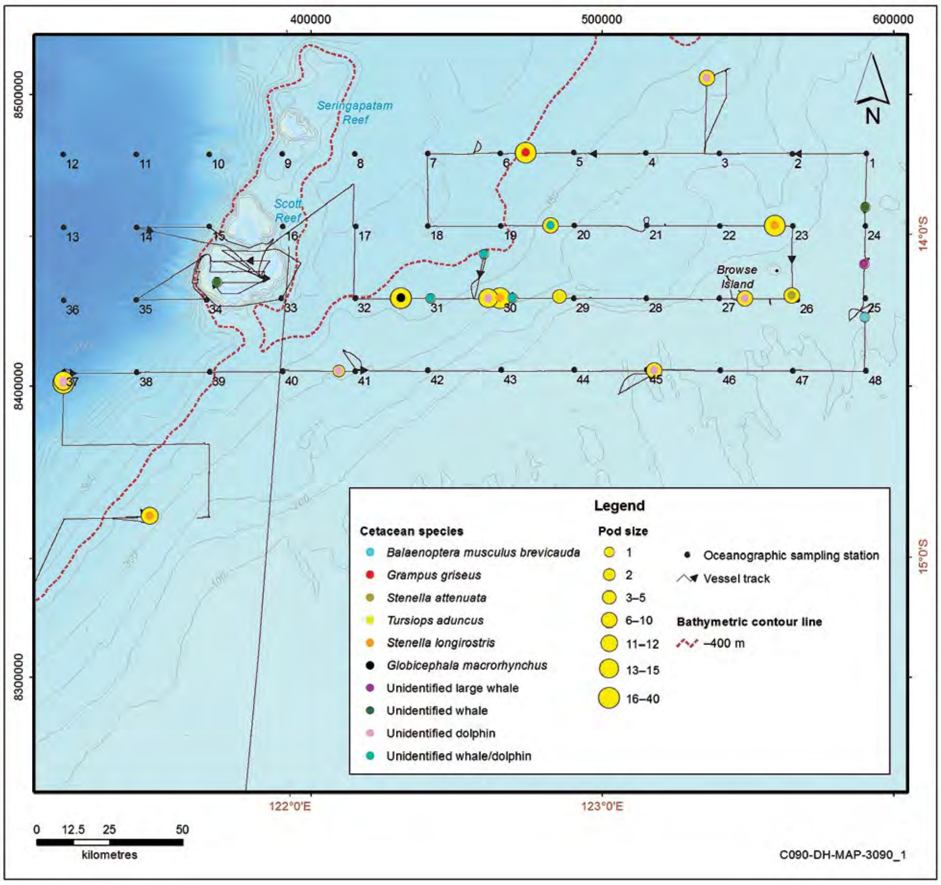

Figure 9-40: Cetacean observations recorded during Survey 2008-3 (October 2008)

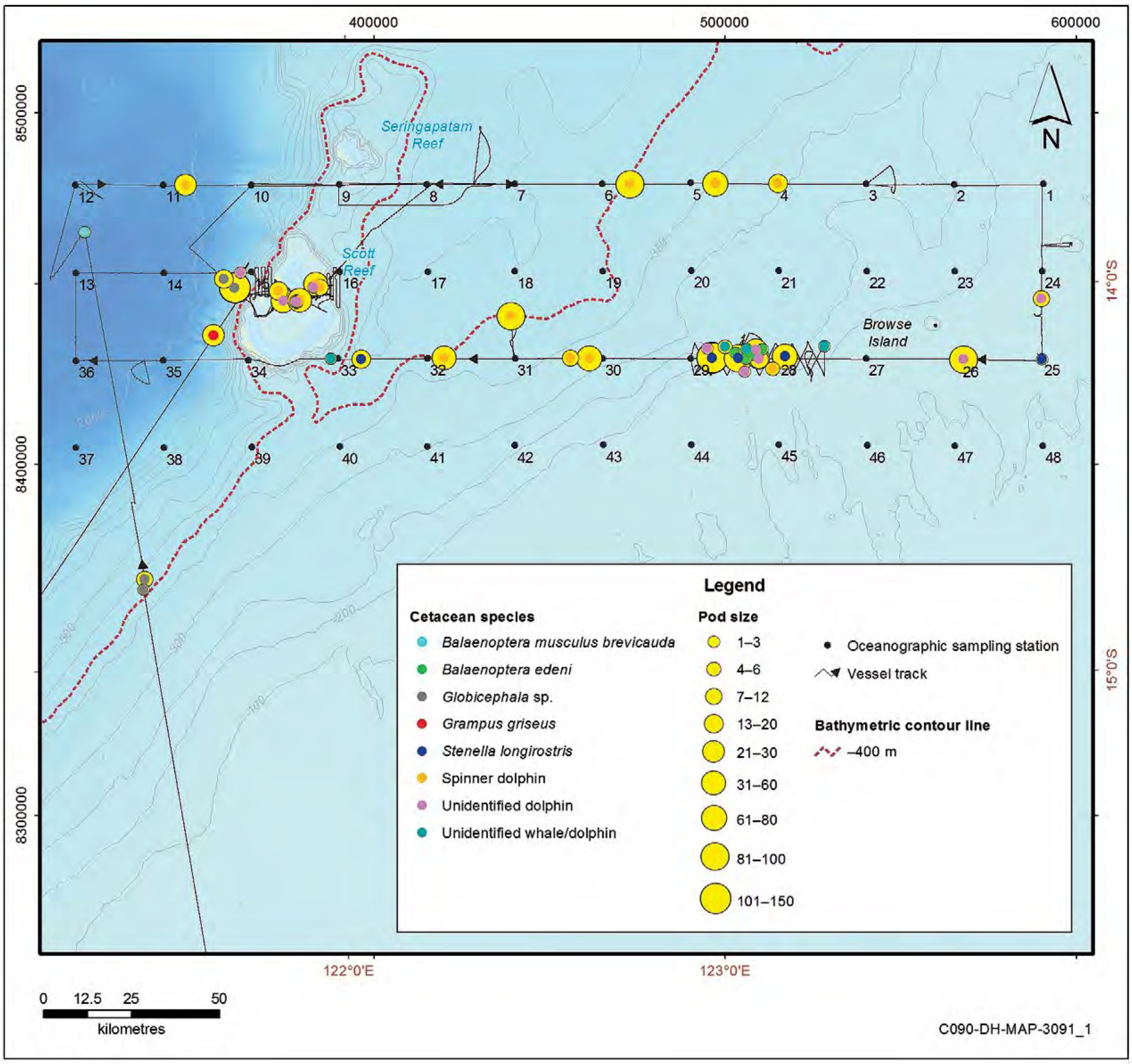

Figure 9-41: Cetacean observations recorded during Survey 2008-4 (November 2008)

During 2008, there were no signs of feeding humpback whales, as had previously been observed during the 2006 and 2007 surveys.

Acoustic backscatter surveys

Acoustic backscatter investigations of varying lengths of time to identify the levels of biomass in the water column were conducted during each survey, including 14 days during Survey 2008-1, 11 days during Survey 2008-2, 17 days during Survey 2008-3, and 15 days during Survey 2008-4.

Most of the data were acquired during the broad-scale transects, although nine days of data were also recorded during the fine-scale transects conducted near the undersea cliffs around 75 km south-west of Browse Island (the “Browse Cliffs”) and in the “Scott Reef Channel” (a deepwater channel between the two major components of Scott Reef known as Scott Reef South and Scott Reef North) which ranges in depth from 200 m to 610 m and is 1.7 km across at its narrowest point (figures 9-9 and 9-42).

Graphs of the ABC for the frequencies 120 kHz and 38 kHz at depth layers of 5–150 m and 5–300 m respectively are presented in figures 9-43 and 9-44.

The high-frequency (120 kHz) echosounder signal sampling the water column appeared to be accurate to approximately 150 m. The 38 kHz signal sampling the water column was accurate to approximately 400 m.

A similar level of ABC, with levels below 1.0×10^{-4}, was observed between areas 1 and 4, with the exception of two samples, Area 4 during 2008-1 and Area 1 during 2008-4. The Area 4 samples taken during 2008-1 only had an elevated ABC using the 120 kHz analysis, while the Area 1 samples taken during 2008-4 had an elevated ABC for both the 38 kHz and 120 kHz analyses.

As expected, biomass distribution across the study area was patchy, with variability in the maximum values of ABC horizontally and vertically in the water column.

Overall, higher levels of biomass around Scott Reef were apparent, particularly within the Scott Reef Channel during October and November, when biomass was detected both in the surface layers and at depth. Substantial biomass was not detected in the surface waters near the Browse Cliffs, south-west of Browse Island, but was detected at depth.

Data were further partitioned into four geographic areas in order to compare biomass readings between seasons (Figure 9-42). In general, biomass was greatest at Scott Reef Area 1 during Survey 2008-4 (November) when ABCs were compared between geographic areas and survey periods (figures 9-43 and 9-44). Biomass was also high in the shallow waters (less than 300 m deep) east of Scott Reef Area 4.

Overall, the highest reading of biomass was recorded at Scott Reef Area 1 in November.

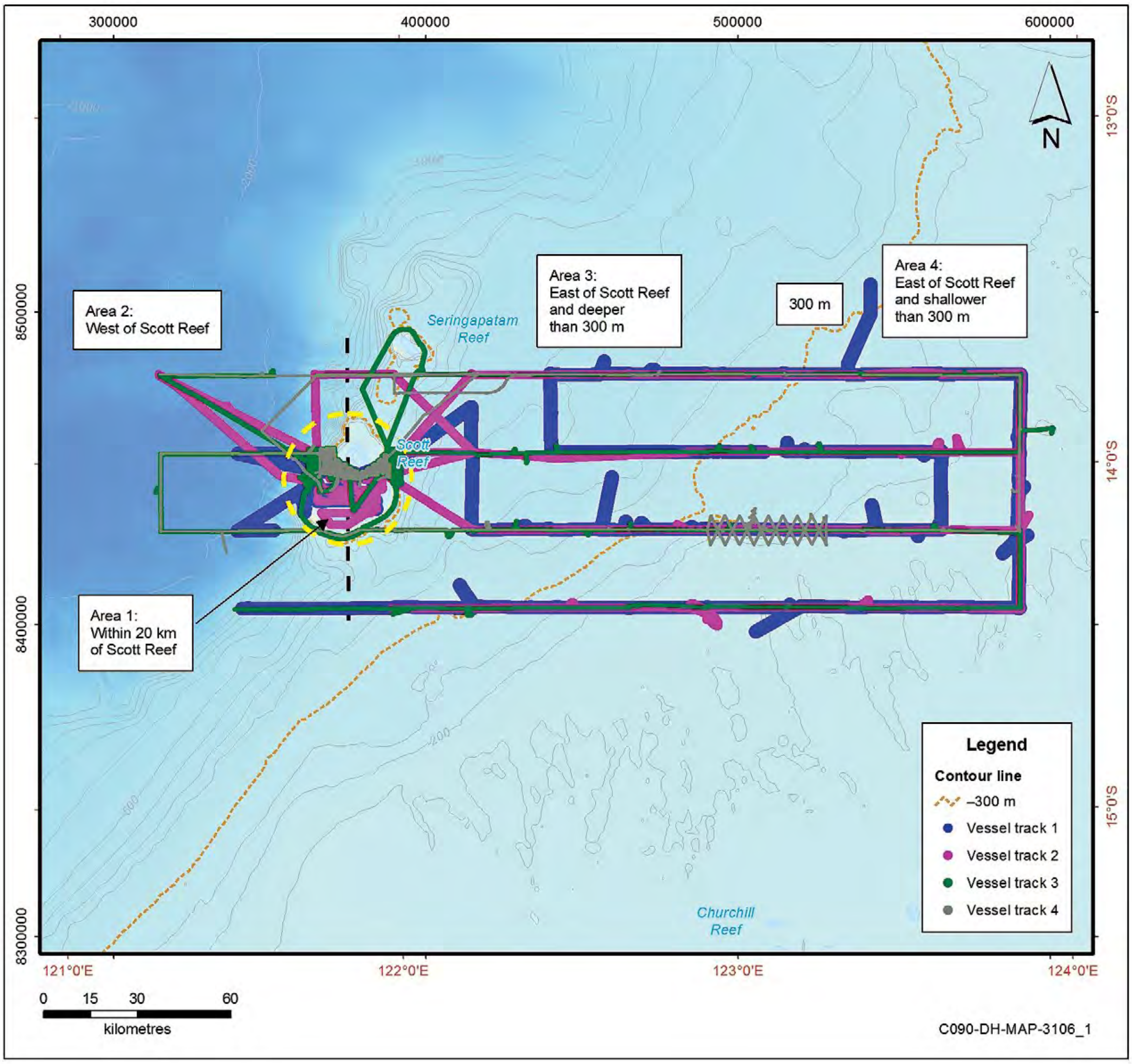

Figure 9-42: Chart of Scott Reef with survey tracks from surveys 2008-1, 2008-2, 2008-3 and 2008-4 showing areas 1–4

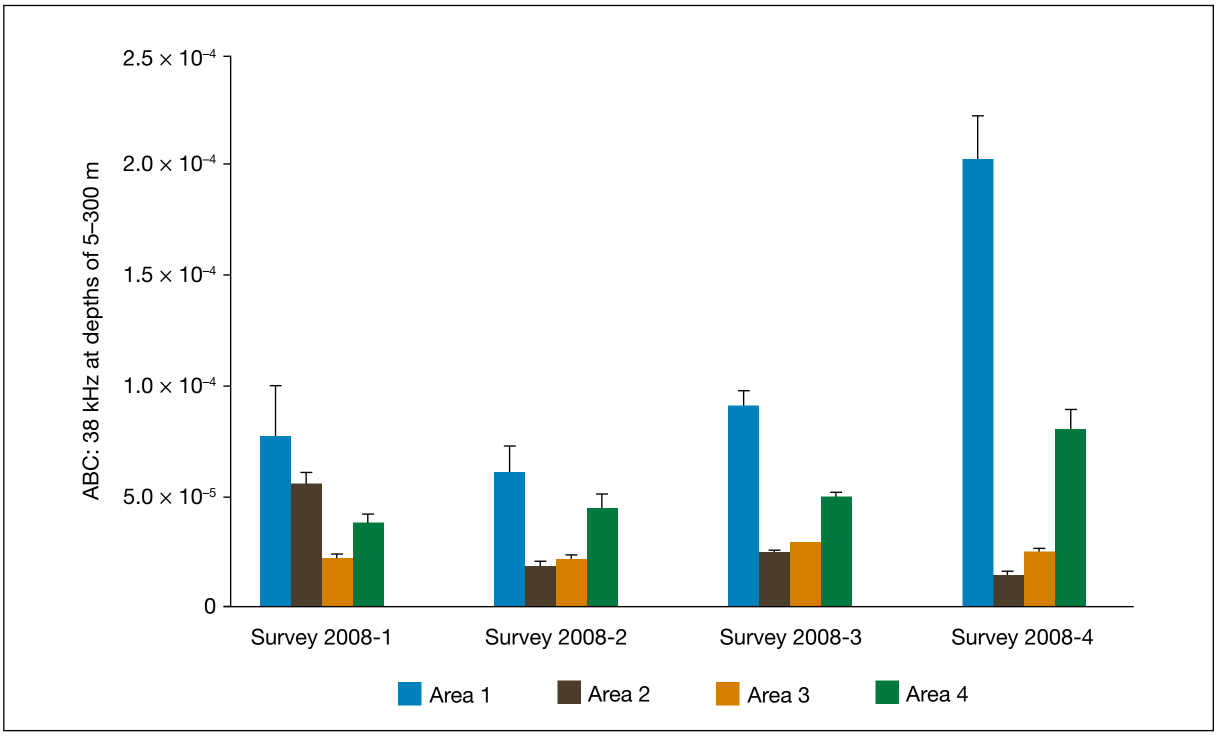

Figure 9-43: Acoustic backscatter coefficients (ABCs) for 38 kHz from 5 m to 300 m depth for Scott Reef areas 1 to 4 with standard error bars

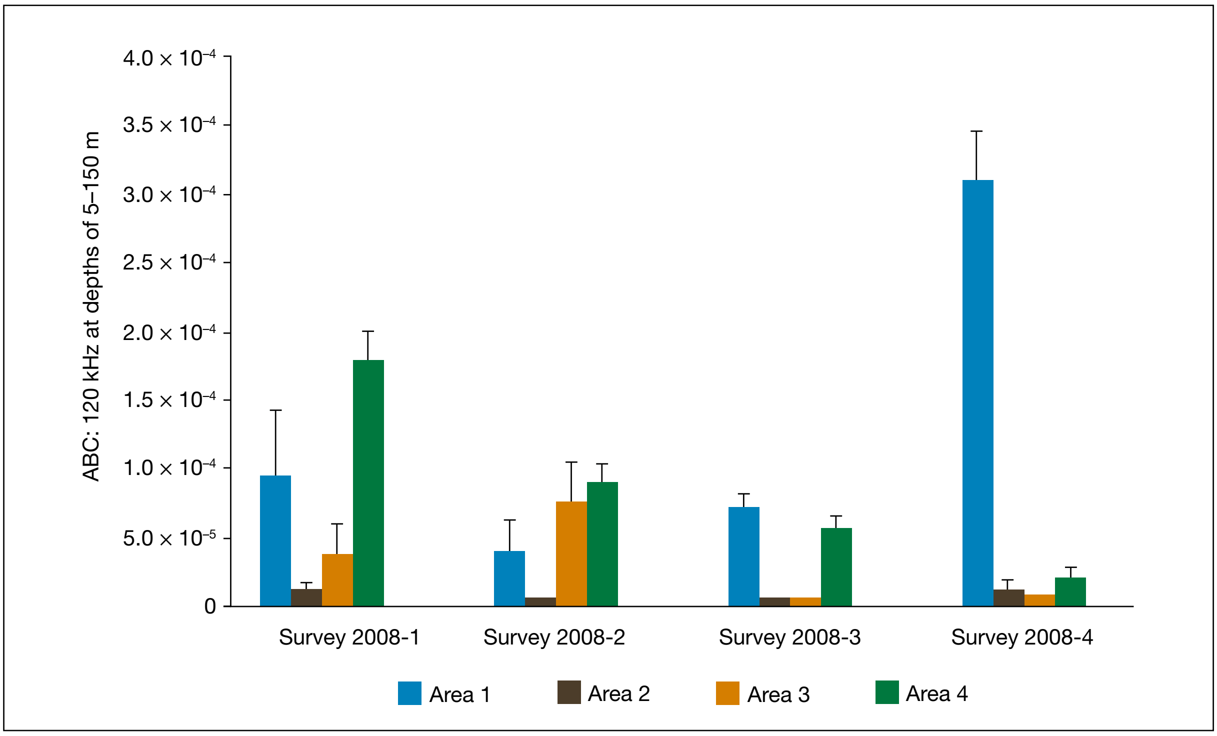

Figure 9-44: Acoustic backscatter coefficient for 120 kHz from 5 m to 150 m depth for Scott Reef areas 1 to 4 with standard error bars

DISCUSSION

This study offers a contribution to the understanding of the distribution and movements of cetaceans in the seas off the coast of Western Australia's Kimberley region.

Cetacean biodiversity

In total, 23 species of cetaceans were observed through aerial and vessel-based surveys in the period 2006–2008. The Browse Basin was the most comparatively diverse site studied, with 20 species recorded, including five species of baleen whales.

Of the large cetaceans, the humpback whale was found to be the most abundant during the more wide-ranging 2006 and 2007 surveys that covered the whole region, while pygmy blue whales were the most abundant in 2008 when the survey plan was altered to selectively target blue whales. The 2008 study differed significantly from the earlier surveys in two ways: only vessel-based surveys were conducted and only the Browse Basin area was studied, with a particular focus on Scott Reef. Consequently, the 2008 results are not directly comparable with the earlier surveys.

It is noteworthy that on 5 July 2008, 46 humpback whales in 24 pods were observed inshore (off survey) near the Lacepede Islands, adding further evidence that the humpback whale is the most abundant large cetacean across the study area.

Fewer cetaceans were recorded opportunistically in 2007 between the Browse Basin and the Maret Islands than in 2006; however, during this time the transit to the survey area was made by helicopter, rather than by boat, thus reducing the time available for opportunistic observations.

Most species appeared to occur seasonally and were observed during only one survey, except for pygmy blue whales, long-snouted spinner dolphins and Risso's dolphins. Since the surveys were only carried out in the second half of each year, complete seasonal trends could not be assessed.

Observations of small cetaceans, including toothed whales and dolphins, were more common in October and November, while the numbers of large cetaceans were consistent between time periods (between four and eight per survey). This could have been the result of seasonal distribution patterns, although better conditions for sightings and a focus on fine-scale studies around features of interest during the October–November surveys would also have been contributing factors. Similar densities of small cetaceans may occur around focal bathymetric features during other months and this part of the study remains incomplete.

Humpback whales

The average residence time for humpback whales, based on photo-identification mark–recapture of individual whales, was found to be one to two weeks (unpublished data, Centre for Whale Research, Fremantle, Western Australia). Based on the results from the 2006 and 2007 surveys, more humpback whales were observed in August than in September. This is consistent with the results of previous surveys conducted by the Centre for Whale Research between 1995 and 1997 (Jenner, Jenner & McCabe 2001). As expected, the ratio of humpback whale calves to adults increased from August to September in both 2006 and 2007. This is attributable to newborn whales and their mothers remaining in the calving grounds during the early nursing period (up to three weeks) of a calf's life.

Most humpback whales were observed in the area between Broome and Prince Regent River. In addition, the densities of both individual whales and pods were higher in the vicinity of Camden Sound and Pender Bay than at the Maret Islands and in the Browse Basin. In 2007, the population of humpback whales was estimated at 6446 individuals for the study period, and extrapolated to 16 345 for the whole season.

Most of the humpback whales observed at the Maret Islands and in the Camden Sound and Pender Bay areas, as well as those whales recorded opportunistically as the survey team travelled to and from the study area, were displaying surface-passive behaviours. This is consistent with the theory that these areas are used for resting and nursing. In the Browse Basin, however, there was a lesser tendency for whales to be surface-passive.

The surface-active behaviour was primarily related to mating activity, although there were two observations during this study of humpback whales feeding in the Browse Basin area, one in August 2006 and another in August 2007. These were the first records of humpback whales feeding in the Kimberley region and were made during the appearance of a +0.5 °C sea-surface temperature front when high levels of bird and fish activity were also recorded. The whales were reported as being of subadult size and, if they were sexually immature, would have been unlikely to have been participating in breeding activity.

Humpback whales are generally thought to feed only in Antarctic waters and to fast during the northern migration for the mating and calving period (Chittleborough 1965). The 2006 and 2007 observations of individual humpback whales feeding in the Browse Basin perhaps indicate that sexually immature whales, which travel the complete length of the migratory path, may feed on swarms of krill in tropical waters. The rich waters of the Browse Basin, which support up to 20 different species of cetaceans, do appear to support krill or fish swarms suitable for feeding humpback and other baleen whales.

It is unlikely that the waters of the Browse Basin or around the Maret Islands are critical calving grounds for humpback whales. Cows with calves born in the vicinity or further north may indeed rest near the Maret Islands, but their numbers are low compared with those found at higher-density resting areas such as Camden Sound. This study confirms that the main calving areas for humpback whales in the Kimberley region are south-west of the Maret Islands, around Camden Sound and Pender Bay. These results are consistent with previous studies of humpback distribution and calving areas off the Kimberley coast (Jenner, Jenner & McCabe 2001) and suggest that core humpback whale aggregation areas and migratory routes have not altered in the past 10 years.

Blue whales

No blue whales were observed during the 2006 and 2007 aerial or vessel-based surveys. The 2008 study was structured more specifically to investigate the anticipated northern and southern migratory period for pygmy blue whales, as this subspecies is likely to migrate between equatorial breeding grounds and temperate feeding grounds and has historically been recorded both north and south of the study area (Branch et al. 2007). As predicted, pygmy blue whales were found both northbound and southbound in the study area; northbound pygmy blue whales were sighted in the shallowest inshore sector of the study area, while southbound whales were sighted only in the furthest west and, in some places, deepest portions of the study area.

In 711 hours of surveys in the period between June 2008 and November 2008, no direct observations of pygmy blue whales mating, calving, feeding or resting were made. However, some evidence of pygmy blue whale feeding was found. This included the sighting of five individuals inside the Scott Reef Channel area during Survey 2008-3 in October (Table 9-10); the whales were observed while acoustic backscatter surveys were being carried out in the Scott Reef Channel and during which strong and consistent biomass targets (presumed to be krill) were being detected. In addition, live krill were drawn into a shipboard desalination plant intake hose filter during a night-time survey in the Scott Reef Channel in November (figures 9-46 and 9-47); the species was later determined to be *Pseudeuphausia latifrons* (D. McLeod, Plankton Biologist, CSIRO, Hobart, Tasmania, pers. comm. 16 July 2010).

Photograph courtesy of Tasmin Jenner, Centre for Whale Research

Figure 9-45: Observers viewing a pygmy blue whale alongside the survey vessel

Photograph courtesy of Curt Jenner, Centre for Whale Research

Figure 9-46: Krill collected from the desalinator intake filter of the survey vessel while at anchor near the central southern edge of the Scott Reef Channel

Photograph courtesy of Curt Jenner, Centre for Whale Research

Figure 9-47: The krill species *Pseudeuphausia latifrons* collected in the Scott Reef Channel

This provides strong evidence that the Scott Reef Channel is likely to be a significant feeding ground for pygmy blue whales and other krill feeders such as whale sharks (which are also known to feed on *P. latifrons* in this channel (Wilson et al. 2006)). However, the low number of hours spent searching the area and the consequently low numbers of whales sighted, together with the lack of direct observations of feeding behaviour, mean that this link, and its importance to the pygmy blue whale population, requires further investigation.

Techniques

The two methods employed to determine the biodiversity and abundance of cetaceans and their critical areas of use in the Kimberley region were aerial surveys and vessel-based surveys. Both techniques have their advantages and disadvantages and they were used in complementary combinations in order to improve the robustness of the survey program. The aerial surveys covered a much greater area than the vessel-based surveys, but as they provided much less time for observing cetaceans, positive identifications of species were more difficult to achieve and a proportionately higher number of sightings were recorded as "unidentified" than was the case with the vessel-based surveys.

The aerial survey methods employed represented a balance between maximising survey coverage, staying within the flight range of available aircraft, and operating within the physical endurance capacities of the observers and pilots. Additional logistic complications associated with the aircraft resulted in observations being recorded from areas of unequal size during each of the four 2006 surveys.

The logistics of data collection by aerial surveys are more complicated than by vessel surveys. For example, the data for the survey flight on 26 August 2007 were lost because of an equipment malfunction, and had to be extrapolated from previous data sets and the number of waypoints recorded on that day.

The physical constraints associated with covering a large survey area also resulted in limitations for the vessel-based surveys. Although 10-day blocks are a standard sample period used for comparing separate areas within and between seasons, the large distances covered by this study allowed each site to be sampled only once every 20 days, resulting in fewer sampling opportunities per season and preventing analyses for trends and patterns on a fine scale. Furthermore, some portions of surveys 2007-1 and 2007-2 could not be completed because of adverse (windy) conditions.

Despite this, these survey methods were found to be consistent and comparable after the data transformation to address gaps in sampling had been applied.

The survey techniques were based on several assumptions:

- Individuals were not counted twice.
- Weather conditions (e.g. cloud, fog, and the angle of the sun) were not considered to have masked individuals from view.
- For the vessel-based surveys, the possibility that cetacean behaviour could have been modified by the presence of the vessel was not considered.

Although these assumptions were not tested, as this survey was largely qualitative, their effects on the findings of the study are thought to be negligible. However, if this study were to be repeated as a quantitative study, then these assumptions would need to be taken into consideration.

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Curt and Micheline Jenner of the Centre for Whale Research led the whale survey research team. They are leading authorities on humpback and blue whales in Western Australia and are experienced in conducting cetacean surveys in the Kimberley region. Dr Peter Gill, an expert in the feeding ecology of blue whales, provided a review on the potential for feeding aggregations in areas of upwelling along the shelf slope.

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Marine noise

10

Robert McCauley

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ABSTRACT

Marine noise sources were investigated at two locations on the western edge of the Timor Sea off the coast of the Kimberley region of Western Australia. Noise loggers were deployed between September 2006 and August 2008 at an offshore site in the Browse Basin 45 km north-west of Browse Island in 240 m of water, and at an inshore site near the Maret Islands in the Bonaparte Archipelago in 45 m of water. Each noise logger was programmed to sample for periods of 200 seconds at 15-minute intervals and at a frequency of 6 kHz. The aim of this survey was to investigate the low-level ambient noise baseline in the Browse Basin and Maret Islands locations, and to detect marine noise above this from both anthropogenic and biological sources, such as vessel activity, seismic surveys, fish choruses and calls from different cetacean species.

Ambient marine noise curves, derived for low sea-state conditions, found that the Browse Basin site received some input of low-frequency energy from the Indian Ocean, amounting to a 12 dB increase at a frequency of 10 Hz and a 5 dB increase at 100 Hz. Under low sea-state conditions, the noise loggers deployed at the Maret Islands site received broadband (10–2800 Hz) ambient noise levels of 85 dB re 1 μPa, and at the Browse Basin site of 90 dB re 1 μPa. Signals suspected to be associated with exploration activities in the Browse Basin (e.g. from rig tenders and seismic-survey equipment) dominated marine noise at the Browse Basin site, raising ambient broadband levels above 100 dB re 1 μPa for 70% and above 115 dB re 1 μPa for 15% of the recording time.

Signals consistent with the calls of several species of great whales were detected by both the Browse Basin and Maret Islands sea noise loggers. These species included the humpback whale (*Megaptera novaeangliae*), the pygmy blue whale (*Balaenoptera musculus brevicauda*), and two species of minke whale, the Antarctic minke (*Balaenoptera bonaerensis*) and the dwarf minke (*B. acutorostrata*). In addition to these, two other great whale signals were thought to have been detected, one of which is likely to have been from a Bryde's whale (*Balaenoptera edeni*).

Pygmy blue whales are known to migrate seasonally between July and August in a northerly direction and between October and December in a southerly direction to the west of the Browse Basin noise-logger site. On one occasion in October 2006, pygmy blue whales were recorded by the Browse Basin logger for a 24-hour period; this was, however, an isolated incident. The presence of pygmy blue whales coincided with a period of intense bioacoustic activity that was produced by nocturnally active planktivorous fishes associated with the deep scattering layer, indicating that secondary productivity at the offshore site was high during this period. Pygmy blue whales were not detected by the loggers deployed at the Maret Islands site.

Humpback whales were recorded by the logger at the Browse Basin site between mid-July and late September each year. At the Maret Islands site, humpbacks were present for slightly longer, from mid-July to early October.

Both Antarctic minke whales and dwarf minke whales were recorded at the Browse Basin site, with dwarf minke calls being recorded during both August and September, and Antarctic minke calls during September only.

Signals believed to be from Bryde's whales were consistently recorded in low numbers at both the Maret Islands and Browse Basin sites throughout the noise-logger deployment period.

Fish choruses were recorded at both the Browse Basin and the Maret Islands sites. At the Browse Basin site, a chorus believed to be associated with foraging fish of the family Myctophidae (lanternfishes) was recorded from the deep scattering layer. This chorus, which is used as an indication of secondary productivity, changed over time; it was intense in late 2006, decreased in early 2007, remained low until late 2007 and then increased during 2008.

At the Maret Islands site a chorus known to be produced by nocturnally active planktivorous fishes of the families Priacanthidae (bigeyes), Holocentridae (squirrelfishes) and Apogonidae (cardinalfishes) was present throughout the full recording period, often at remarkably intense levels and on occasion close to 60 dB above ambient background conditions. This chorus was tightly linked to a half-lunar cycle and varied seasonally, with the highest levels recorded during late summer. The activity of this chorus echoed that of the offshore chorus discussed above, in that it was present at a reduced level during 2007. This may reflect changes to the environmental conditions at the site, and possibly across the Kimberley, during 2007.

A large number of other fish-chorus types and individual calls were recorded, particularly at the Maret Islands site.

INTRODUCTION

This chapter summarises the findings of marine noise surveys conducted off the coast of the Kimberley region of Western Australia between 2006 and 2008 (McCauley 2009).

The surveys were commissioned by INPEX Browse, Ltd. in order to provide baseline environmental data for a proposal by the company to develop the Ichthys natural gas and condensate field in the Browse Basin (see Chapter 1 *General introduction*).

Two locations off the Kimberley coast were chosen for the deployment of underwater noise loggers. Sampling was carried out between September 2006 and August 2008, with three sea noise loggers deployed consecutively at each of the two sites, one offshore in the Browse Basin and one inshore at the Maret Islands in the Bonaparte Archipelago. The purpose of the sampling was to develop an underwater noise baseline for these areas and to define the habits of the major sources of biological noise detected at each site.

Noise is typically variable, often with large fluctuations about a mean level over short time-scales (seconds). To remove this variability, it is standard practice in noise studies to undertake time-averaging and to establish a "mean" noise level over a time period long enough to derive a stable average, so that the derived average will not alter greatly if averaging were to occur over longer periods.

However, there is a trade-off, since variations in the mean noise field over time can also provide valuable information. Therefore, the time period over which the signal is averaged must be long enough to provide a stable noise level, but short enough not to mask any signals.

Discovering the sources of marine noise can be difficult as there are a number of artefacts which can affect the recording process. Natural noise sources that can increase this baseline noise level include wind, which can raise levels by more than 20 dB across the frequency band up to several kilohertz under strong wind conditions, and persistent sounds of biological origin in various frequency bands. In addition, noise caused by movement of the recording equipment can mask the results. The design of the logging equipment and its associated rigging can greatly reduce this effect, for example by ensuring that hydrophones are placed on the seabed and isolating the noise logger from the mooring lines. Even then, artefacts from a variety of other sources will still occur, such as the mooring lines tugging on the loggers despite efforts to decouple them; hydrophones rolling on the seabed; animals bumping or chewing on hydrophone housings or cables; and turbulent flow across the seabed in the vicinity of the hydrophones.

Differentiating between natural background sources and what is considered to be "other noise" (including that from calling whales, fish choruses and human activities) can be complex. Here, "ambient noise" is considered to be the background noise without any distinguishable individual sounds. The disadvantage of this is that some persistent biological noise sources (primarily from fish) can be regularly included in the baseline noise levels and thus not receive further analysis.

Anthropogenic noise sources

Although the Maret Islands and the Browse Basin are remote and uninhabited, in recent years the Browse Basin has been found to be rich in hydrocarbon resources. Consequently, at the time of the marine noise surveys the region was experiencing increasing levels of activity from hydrocarbon exploration enterprises, including drilling and seismic surveys. It was therefore expected that anthropogenic noise sources at the Browse Basin would be predominantly from these operations.

As the Maret Islands are far enough away from the Browse Basin not to be influenced by sounds from these activities, anthropogenic noise was not expected to be recorded there. However, noise from sporadic shipping traffic associated with environmental survey work and from vessels travelling from Broome to the Browse Basin were expected to be detected by the noise loggers stationed near the islands.

Fishes

It is common for marine noise recordings on the Australian continental shelf to be dominated by fish choruses for a few hours each day (Cato 1980; McCauley 2001; McCauley & Cato 2000). While different species produce the dominant choruses in different parts of Australia, there seems to be a consistency in the patterns of choruses and in their function. Choruses from particular species display diurnal patterns that are linked to environmental parameters such as local light levels and are typically (but not always) produced at night.

While an individual fish may be clearly detectable in some environments under low ambient noise conditions (perhaps over a range of as much as a kilometre (McCauley 2001)), a large chorus—or a school with many fish calling almost simultaneously—is often detectable at ten times this range (McCauley 2001; McCauley & Cato 1998, 2000, 2006; Salgado Kent & McCauley 2011). Where choruses from several species occur, they generally do not overlap in time and thereby avoid competition for the local "sound space". The result is a series of choruses over a 24-hour period.

Other species of fish form less dense schools, or have individuals within a school which call less frequently, but may still have the ability to significantly raise time-averaged marine noise levels over periods of hours.

Whales

All of the great whale[1] species vocalise. They generally produce "songs" which may last for prolonged periods (e.g. tens of minutes for humpbacks) and are designed for transmission over long distances in the open ocean. Detection and quantification of the rates of song production can thus be used to arrive at relative abundance estimates.

The general habits of several whale species identified in the recordings described in this chapter are discussed below. Much of this information is based on unpublished passive acoustic data sets collected by the author (R.D. McCauley) around Australia's continental margins and, therefore, unreferenced facts in the text that follows may be taken as being based on these data.

Blue whales

In Western Australian waters, there are believed to be two subspecies of blue whales (Branch et al. 2007), the Antarctic blue whale (*Balaenoptera musculus intermedia*) and the pygmy blue whale (*Balaenoptera musculus brevicauda*).

The Antarctic blue whale summers in Antarctic waters, feeding on the free-swimming open-ocean crustaceans known as krill (mostly *Euphausia superba*). It usually overwinters in southern hemisphere mid-latitude waters (north to approximately 30°S). However, some individuals have been observed to remain in Antarctic waters over the winter period.

The pygmy blue whale overwinters in northern waters, possibly as far north as the equator, and returns to southern Australian waters during summer, usually north of the Antarctic Convergence zone. However, some individuals have also been observed in Antarctic waters.

A proportion of the pygmy blue whale population returns from southern Australian waters north along the Western Australian coast during April and May, and can be observed near Exmouth, about 1300 km north of Perth, during June and July (Branch et al. 2007; Double et al. 2012; McCauley & Salgado Kent 2008). These pods are believed to split in the vicinity of the Montebello Islands north-west of Karratha, with perhaps 16–45% of the pods travelling further north and the remainder fanning out west and north-west across the northern Indian Ocean (McCauley & Salgado Kent 2008).

[1] The term "great whale" is a generic term used for all species of large whale, including the humpback, blue, minke, Bryde's, and sperm whales.

It is believed that many of the pygmy blue whales that follow the North West Shelf edge eventually reach Indonesian waters, possibly heading as far north as the Banda Sea (Double et al. 2012).

At the end of winter the pygmy blue whale pods migrate southward past Exmouth between October and January, with a peak in late November. After passing Cape Naturaliste in the south-west of Western Australia, it is thought that they fan out across southern Australian waters to feed on krill concentrations between summer and early autumn. During autumn and winter they travel north again along the Western Australian coast (McCauley & Jenner 2010).

The pygmy blue whale has a call type distinct from that of the Antarctic blue whale subspecies. Its calls have been recorded along the Western Australian coast from the Browse Basin in the north to the Bass Strait in the east, and as far south as the Antarctic Convergence zone, around 45°S to 55°S (R.D. McCauley, unpublished data).

A depiction of a typical three-component pygmy blue whale call is displayed in Figure 10-1. This signal type is made up of three distinct, complex, long tonal signals, with most of the energy between 18 Hz and 26 Hz (together with harmonics) and a secondary tone with energy up to 75 Hz.

Humpback whales

Male humpback whales (*Megaptera novaeangliae*) produce complex, long and powerful songs, while both males and females are known to make social sounds used in communication (Dunlop et al. 2007). The songs are unique and differ from other vocalisations in that they consist of individual sounds with a duration of 1–5 s that span the frequency range from 15 hertz to several kilohertz. These sounds are called units and are organised into phrases and themes, with each theme being repeated many times to create a song. The songs are stereotypical, with songs among pods along the Western Australian coast having a similar structure at any given time, although there may be sections which vary considerably among individuals. Songs may vary from year to year, either incrementally or through major changes which are possibly gained from animals in other subpopulations (Noad et al. 2000).

Humpback song is usually most intense in the 200–400 Hz band, the sound band that travels best over the continental shelf. Some song components that are weaker and higher in frequency travel over a short range only, while some components at lower frequencies travel better in deep water (<100 Hz) (McCauley, Cato & Jeffery 1996).

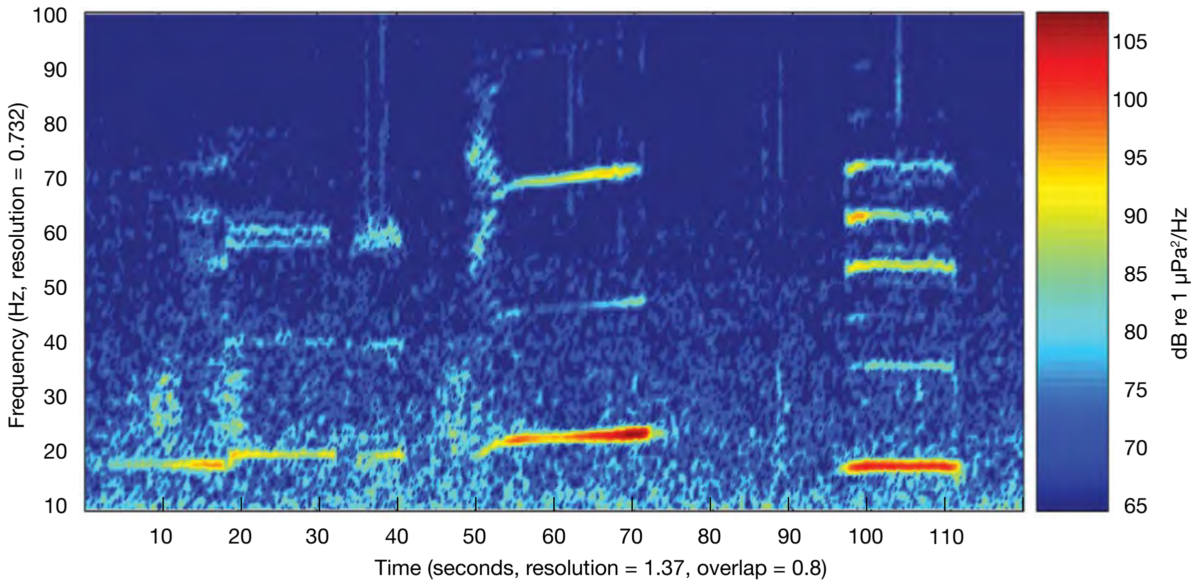

Figure 10-1: Spectrogram of the call of a pygmy blue whale recorded from the Browse Basin site (noise logger 2721) in late October 2006

Minke whales

Two species of minke whales are known to occur in Western Australian waters, the Antarctic minke whale (*Balaenoptera bonaerensis*) and the dwarf minke whale (*Balaenoptera acutorostrata*) (IWC 2001). Although the dwarf minke whale of the southern hemisphere is taken as being conspecific with the northern hemisphere's populations of minke whale, known as the "common minke whale" or "northern minke whale", it is probably separable at subspecies level. Its taxonomic status remains unclear however, pending further study (IWC 2001). It is referred to here as *Balaenoptera acutorostrata*.

The dwarf minke whale is a predominantly tropical species that has been found to emit a characteristic call with a complex and stereotyped sound sequence which has been called the "star-wars" vocalisation[2] by Gedamke, Costa and Dunstan (2001). Although the species has not been studied extensively along the Western Australian coast, this vocalisation has been detected in recordings from Perth to the northern Kimberley (R.D. McCauley, unpublished data). These recordings suggest that this species migrates seasonally.

Antarctic minke whales are widely distributed from the far south of the Southern Ocean in the austral summer to low latitudes in the subtropics and tropics in the austral winter (IUCN 2013). Little is known about the habits of these whales along the Western Australian coast. They are believed to produce a call which is distinctly different from that of the dwarf minke whale, with records from the Southern Ocean suggesting a long pulsed call.

Study area

Two locations were chosen for this study, one in the Browse Basin 45 km north-west of Browse Island in approximately 240 m of water, and the other approximately 8 km west of the Maret Islands at a depth of approximately 45 m (Figure 10-2). The sites of the noise loggers at each location were selected to avoid interference from activities in the surrounding area such as commercial fishing (e.g. prawn-trawling) or offshore development activities (e.g. seismic surveys or drilling).

[2] This vocalisation was so named because of its perceived similarity to the sound effect used for "laser guns" in the American science-fiction *Star Wars* film series that was first released in the late 1970s.

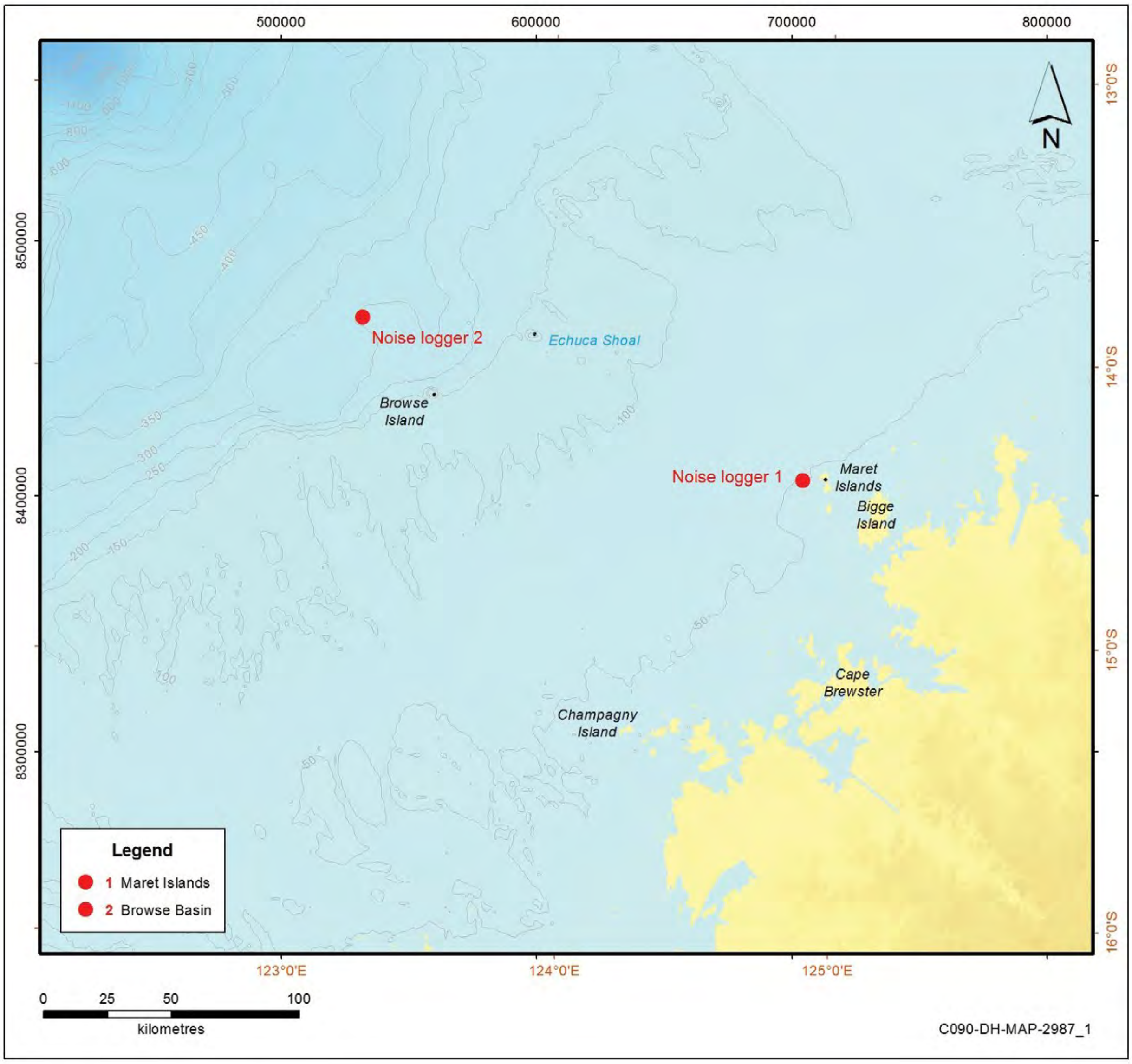

Figure 10-2: Locations of the two noise-logger sites at the Maret Islands and in the Browse Basin 45 km north-west of Browse Island

METHODS

Noise-logger mooring design

Three successive sea noise loggers were deployed at each of the two logger sites between September 2006 and August 2008 (see Table 10-1). The total deployment period lasted for 698.4 days at the Browse Basin site (with 623.3 days of good sampling) and 697.5 days at the Maret Islands site (with 664.8 days of good sampling).

The noise loggers were attached to moorings that were specifically designed to reduce noise interference from the mooring equipment (McCauley 2009). Each mooring had a ground line that was designed to isolate the noise logger from the mooring riser. The ground line was weighted and buoyed to keep it off the seafloor.

Three anchoring devices were deployed in combination to prevent the ground line from tugging on the logger: a 22–30 kg weight approximately 25 m from the logger, an anchor 15–20 m from the logger, and a 6 kg weight 1 m from the logger. The ground line also acted as a mooring line when the acoustic release was activated or as a snag-line for grappling if the acoustic release should fail. While similar in design, the moorings placed at each site differed to compensate for the different water depths; the Browse Basin mooring, for example, had a 440 m ground line and the Maret Islands mooring had a 100 m ground line.

Table 10-1: Details of noise-logger mooring deployments

Set no.	Date (and time) of commencement	Date (and time) of completion	Latitude (south)	Longitude (east)	No. of days of good sampling	Usable data
Browse Basin						
2721	13-09-2006 (0815)	03-02-2007 (1118)	13°50.436´	123°17.625´	143.1	260–14 000
2755	01-04-2007 (1800)	12-11-2007 (2148)	13°50.531´	123°17.707´	225.1	1–21 291
2798	30-11-2007 (1600)	11-08-2008 (1900)	13°50.299´	123°17.833´	255.1	2–24 494
Maret Islands						
2722	14-09-2006 (1015)	01-03-2007 (1518)	14°24.801´	124°53.658´	168.2	368–16 516
2756	01-04-2007 (1800)	29-11-2007 (0448)	14°24.865´	124°53.637´	241.4	1–23 120
2797	30-11-2007 (1600)	11-08-2008 (2115)	14°24.864´	124°53.692´	255.2	2–24 475

Explanation of column headings:

Set no.: Curtin University's Centre for Marine Science and Technology (CMST) reference number.

Date (and time) of commencement: The date and time of the first good sample (Western Standard Time (WST)).

Date (and time) of completion: The date and time of the last good sample (WST).

Latitude (south) and Longitude (east): The noise-logger sites (coordinates provided relative to WGS84[3]).

No. of days of good sampling: The number of days of sampling where data were usable.

Usable data: The logger sample numbers with usable marine noise (samples were often made while the logger was on deck).

Each noise logger consisted of an external hydrophone (High Tech Inc. HTI-90-U or Massa TR-1025C) connected by a SubConn bulkhead connector to the logging electronics (which were designed and serviced by Curtin University). The loggers also incorporated the following features:

- impedance matching for the hydrophone
- low noise amplification of the hydrophone signal
- signal conditioning with anti-aliasing filters and a high-pass filter with low-frequency roll-off in order to flatten the naturally high levels of low-frequency marine noise and thus reduce the input dynamic range while retaining the calibration
- 16-bit analogue-to-digital conversion
- two input channels each, with the option of multiple sampling schedules
- storage capacity for an additional 2.5-inch hard disk
- a fully programmable sampling regime, set up using a serial link and a PC or laptop communications package.

The loggers were designed to operate using minimal power and for low electronic noise. The battery pack, consisting of 42 D-sized alkaline batteries, was capable of filling up to 60 GB of hard-disk space, although the actual logging capability was determined by the sampling schedule chosen. To reduce power consumption, the loggers streamed data on to flash cards. When each flash card was nearly full, the data were then copied on to a hard disk (which used higher power and produced electronic noise artefacts). As a result, each logger had a defined break in recording while data were copied from the flash drive to the hard drive.

All noise loggers were set with identical sampling regimes as follows:

- a duty cycle of 200 s of recording every 15 minutes
- a sampling frequency of 6 kHz
- a roll-off applied below 8 Hz to flatten the naturally high levels of low-frequency noise that increased with decreasing frequency
- an anti-aliasing filter of 2800 Hz
- a 40 dB total system gain.

Each noise logger was calibrated with white noise of a known intensity by using a white-noise generator connected to the noise logger with a capacitor equivalent to the hydrophone capacitance in series with the white-noise input. The resulting system gain curves (Figure 10-3) were calculated and, along with the respective hydrophone sensitivities, were used to calibrate the system.

The onboard clocks of the noise loggers were set to Coordinated Universal Time (UTC) using the time–date stamp transmitted by the global positioning system (GPS). Clock drift was then recorded upon completion of deployment. This was carried out in the laboratory both before and after deployment. The clock drift rates were computed so that each sample could be determined to an accuracy of ±0.25 s.

[3] Coordinates provided relative to the World Geodetic System 1984 (WGS84), utilised by the global positioning system (GPS), have been referenced in this text as relative to the Geocentric Datum of Australia 1994 (GDA94) to provide a consistent coordinate reference system (CRS) throughout this book. For all practical purposes, GDA94 coordinates can be considered to be coincident with those of WGS84.

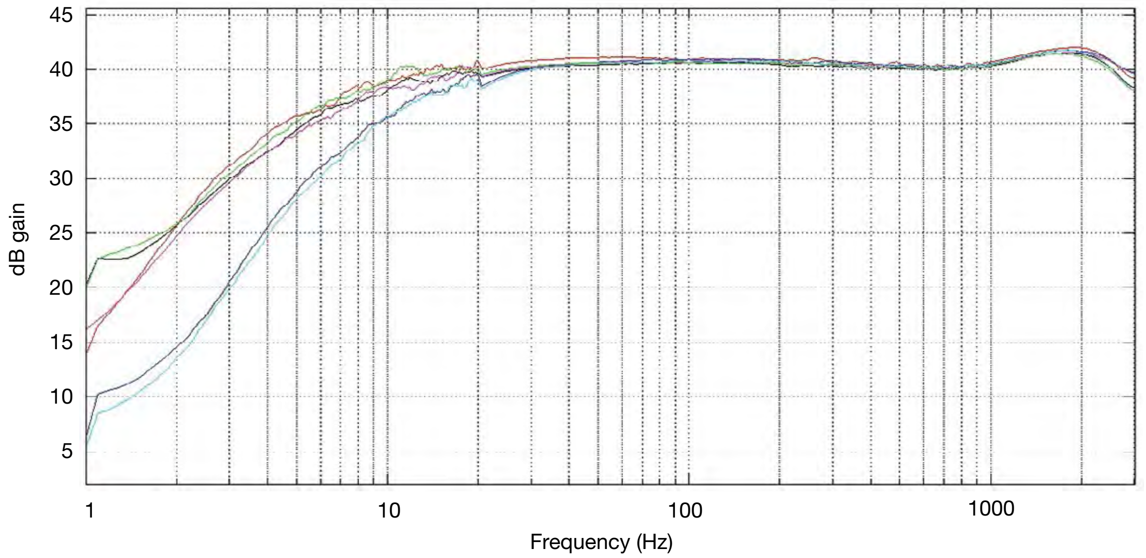

Figure 10-3: System calibration curves for all six noise loggers, with gain as a function of frequency

10 MARINE NOISE

All hydrophone SubConn connector models LBH3F and LPIL3M were replaced with Teledyne Impulse IE55-15 male and female connectors during the sampling regime as a response to observed corrosion of some of the connector pins.

This sampling regime enabled the census of great whales and fish over deployment durations of up to a year. The recording bandwidth chosen was suitable for the bandwidth of vocalisations of all great whales and most fish calls. The calls of small toothed whales are of a higher frequency and have a more limited detection range than those of great (baleen) whales. With the hardware available at the time of deployment, which was state of the art, sampling at frequencies sufficient to capture most toothed-whale calls would have filled the disk memory and consumed all available battery power within several weeks.

Units, removal of noise artefacts, and data analysis

The analyses of long-term trends in noise levels were mostly based on power-spectrum averages over 200 s of recording. A 15-minute increment between recordings was taken as the minimum unit for a change of noise level with time.

Where signals were related to the time of sunset, in particular the fish chorus signals, the daily time was normalised in order to allow for changes in sunset time across a year. This involved setting the time of sunset for each day at each site as zero hours; sunset was taken as the time that the sun's upper limb[4] dipped below the horizon. The time of sunset for each site was obtained using a calculator made available by Geoscience Australia on its website.

Significant noise spike artefacts were removed from records ("de-spiked") during spectral averaging. This technique involved calculating a set of consecutive power spectra within a 200 s recording, with each of these power spectra computed over equal time frames at resolutions of 0.18 Hz (FFT[5] algorithm using 32 678 points, Hanning window[6], no overlap, 1 average), 1.46 Hz (FFT using 4096 points, Hanning window, no overlap, 8 averages), and 23.44 Hz (FFT using 256 points, Hanning window, no overlap, 128 averages). Using the 1.46 Hz resolution spectra, the median spectral value at a reference frequency of 10 Hz was found along with the standard deviation of the mean. Power spectra that exceeded the median plus 1.1 times the standard deviation at the reference frequency were rejected. The average spectral value (in the linear domain) at each frequency from the accepted ensemble of spectra was then used to give the de-spiked power spectra.

The units used in this report are defined as follows:

dB re 1 μPa²/Hz: This is the spectral level unit used to compare the intensity content of different sources. In these units, intensity is presented as the equivalent of a 1 Hz bandwidth, even if the actual bandwidth of computation was not 1 Hz.

4 "Limb" in this sense is an astronomical term for the edge of the apparent disc of the sun, moon, etc.

5 FFT = "fast Fourier transform", an algorithm that converts time or space to frequency and vice versa.

6 A window function is a mathematical function that is zero-valued outside some chosen interval. For this analysis, the Hanning window has been used for the FFT algorithm.

dB re 1 µPa: This unit represents intensity across the measurement bandwidth, although the bandwidth may differ. The bandwidth may be the power spectrum frequency resolution or it may be the source-effective bandwidth, as discussed below.

dB re 1 µPa broadband: This is the integrated intensity across the full frequency bandwidth of the source. Usually exact frequency bandwidths are not stated, so it is assumed that the measurement encompasses the frequency range of dominant energy in the source (i.e. the signal energy outside this frequency range does not contribute to the overall source energy level).

dB re 1 µPa across a ⅓ octave band: ⅓ octaves are logarithmically increasing frequency bands set by international standards. Each band has a defined lower frequency, centre frequency and upper frequency. The dB re 1 µPa intensity is summed over the ⅓ octave band. The ⅓ octave bands are normally referenced by their centre frequencies.

dB re 1 µPa at 1 m: This is the source level. It represents the intensity at some range from a measured source and to which a transmission loss correction for that range and frequency is applied. The source level is then the intensity the source would radiate at 1 m range if it were an infinitesimal point, although most real sources are not infinitesimal points. So for large sources such as vessels and seismic-survey airgun arrays, where the radiated noise is actually the sum of many spatially separated subsources, such source levels are never reached in situ but are useful to predict far-field levels.

dB re 1 µPa^2·s SEL and dB re 1 µPa (MSP): The first measure (dB re 1 µPa^2·s SEL) is widely expressed as sound exposure level (SEL). It is a measurement which is approximately proportional to the signal's energy. This measurement is used to describe impulsive signals (such as from seismic airguns) which are short and sharp. For measuring long-term noise, the mean square pressure (MSP) units are commonly used. As the name suggests, mean square pressure levels are simply the mean value of the squared pressure converted to appropriate dB values. To take a mean value implies an averaging time, which, if the noise in question is stationary and changes little over the time frame of averaging, is not of major consequence. Impulse signals are short, usually less than 1 s, and thus the mean square pressure level of an impulse signal may be critically dependent on, or vary with, the averaging time. Since SEL measures account for time, they are independent of averaging time. Given that SEL is a closer match to the energy delivered by an impulse signal (noting that it is not a correct energy measure itself), the SEL value is now widely accepted as the best unit to define the approximate energy of an impulse signal.

RESULTS

All of the noise-logger battery packs retained adequate power over the duration of the monitoring periods. All data sets, except that from logger 2798, were of high quality (i.e. few noise artefacts were present). In the 2798 data set some interferences thought to be from movements of the mooring and bumping of the logger housing were recorded. These interferences were removed from averaged marine noise levels as described earlier.

Loggers 2798 and 2756 suffered from intermittent failure several months after deployment, with small amounts of water slowly leaking into the connectors, causing them to corrode. This changed the capacitance detected by the preamplifier, resulting in a change in the system sensitivity that was frequency-dependent and particularly affected the lower frequencies. In effect, this acted like a low-frequency filter, impacting frequencies below 1 kHz but with the higher frequencies remaining unaffected. Low-frequency signals that remained above the electronics noise level were able to be recovered.

Over time, as the level of corrosion increased, the impact became more apparent at other frequencies. For logger 2798, this resulted in two impacts on the recorded data: first, it hampered analysis of humpback whale signals that were recorded in late 2008 and, secondly, it hampered the analysis of the Browse Basin 200 Hz fish chorus from 6 March 2008 onwards, although the chorus was detected for a further two months and a correction technique could be applied to the **⅓** octave data to compensate for the slowly changing system sensitivity. For logger 2798, alterations in the data attributable to this effect began 97 days after deployment.

A similar fault was also found with the second deployment at the Maret Islands site, that of logger 2756. One hundred days into the deployment, the energy at low frequencies began to decrease because of corrosion of the hydrophone wires. This data set was still used to find the levels of fish choruses above 500 Hz by correcting the higher frequencies. The correction process involved finding the base noise levels in ⅓ octave bands, and applying a linear time correction for the respective ⅓ octaves, using the normal system response at the start of the recording period and a reduced response at the end (McCauley 2009).

Following these failures, all bulkhead connectors were removed from the sea noise loggers and the hydrophone cables were hard-wired to the housing end caps using special fittings.

The dominant noises recorded at each site were from great whales and fish choruses (Table 10-2).

Table 10-2: Major biological noise sources at the Browse Basin and Maret Islands noise-logger sites

Noise source	Browse Basin site	Maret Islands site
Pygmy blue whale	**Detected:** This species was detected only once, over several days in late October 2006, and was believed to be from southerly migrating animals. The main migratory route of the pygmy blue whale is thought to be to the west, between the 500 and 1000 m depth contours. Its occurrence in this area is thought to be rare and to be dependent upon food availability.	**Not detected:** It is considered that it would be unusual, but not out of the question, to encounter pygmy blue whales so close to the coast in this location.
Humpback whale	**Detected:** The occurrence of humpback whales in the area was from approximately 16 July to 26 September, peaking in August. Most recordings were at a low level, indicating that the animals were distant from the logger.	**Detected:** The occurrence of humpback whales in the area was between mid-July and early October, peaking in August, with many animals recorded close to the recorder (i.e. within several kilometres).
Bryde's whale	**Detected:** Signals from calling Bryde's whales were recorded year-round.	**Detected:** Signals from calling Bryde's whales were recorded year-round.
Dwarf minke whale	**Detected:** This species was recorded only in August and September.	**Not detected.**
Antarctic minke whale	**Detected:** This species was recorded only in September, although it was possibly present in August.	**Not detected.**
Nocturnal planktivorous fish type 1*	**Detected:** The chorus of this type of fish was associated with the deep scattering layer, either at the shelf edge or in the open ocean. It is believed to be associated with seasonal plankton feeding.	**Not detected:** The deep scattering layer was not within the listening range of this noise logger.
Nocturnal planktivorous fish type 2†	**Not detected:** The noise logger was not located within the listening range of suitable habitat (shallow and rocky areas near reef systems) for these fish.	**Detected:** The chorus was present year-round and displayed seasonality: strong over summer, weakest over winter. The chorus was very intense and was strongly linked to a half-lunar cycle, possibly associated with seasonal plankton feeding.
Terapontid fish choruses	**Not detected:** The logger was too deep to detect these fish, which are normally only found in coastal waters to depths of around 50 m.	**Detected:** Terapontid choruses are normally heard over summer, late in the evening.

* The nocturnal planktivorous fish type 1 signals may be attributable to lanternfishes of the family Myctophidae.

† The nocturnal planktivorous fish type 2 signals may be attributable to fishes primarily of the families Holocentridae, Priacanthidae and Apogonidae.

The Browse Basin site was dominated by signals thought to be from anthropogenic noise sources for 623.3 days of the total 698.4-day recording period (figures 10-4 to 10-7). These signals were thought to be predominantly from construction vessels and seismic surveys. They made the determination of the natural ambient noise regime difficult, being louder and more persistent than the ambient noise and reducing the availability of suitable recording periods that could be analysed for ambient noise.

At the Browse Basin site, persistent biological noise that was detected with, typically, energy above 1.8 kHz was thought to be from snapping shrimp. Other persistent noises recorded included fish calls and choruses, as well as low-frequency presumably biological signals that were possibly from Bryde's whales. Seasonal, mostly distant, noises consistent with humpback whale songs were also detected, along with calls consistent with pygmy blue whale vocalisations (in October 2006 only).

Marine noise was recorded at the Browse Basin site by three noise loggers deployed in succession between 13 September 2006 and 11 August 2008 (Table 10-1). In order to visualise the sound data collected by each logger, colour plots were created using the summary stacked marine noise spectra in 50-day increments, starting from midnight on 13–14 September 2006. Each plot was generated by taking the de-spiked time-averaged power spectra of each 200 s recording at three frequency resolutions, averaging these over 10 recordings (150 minutes), and stacking a series of the averaged spectra through time on a colour plot. The figures were displayed on a logarithmic frequency scale, from 10 Hz to 2800 Hz (the upper limit of the recording that was calibrated), and a fixed colour scale, ranging from 55 to 110 dB re 1 μPa²/Hz. The colour-scale range was fixed to standardise the plots and optimise the colour-dynamic range, with extreme values set to the colour bounds.

The colour plots tend to highlight signal types which were either intense or persisted over the 200 s recording length, attributable either to a long signal duration or to the occurrence of multiple signals within a recording. This was because of the data averaging involved for display purposes (within a 200 s recording and over the 10 consecutive averaged recordings). Thus, signals such as humpback whale calls, which are short in relation to the recording length of 200 s, might have been missed or might not have been well displayed by the colour plots although these were all comprehensively searched for in analysis.

This level of noise from biological sources can influence long-term ambient noise, and sources which are prolonged can raise averaged ambient noise levels in certain frequency bands persistently for many months on end.

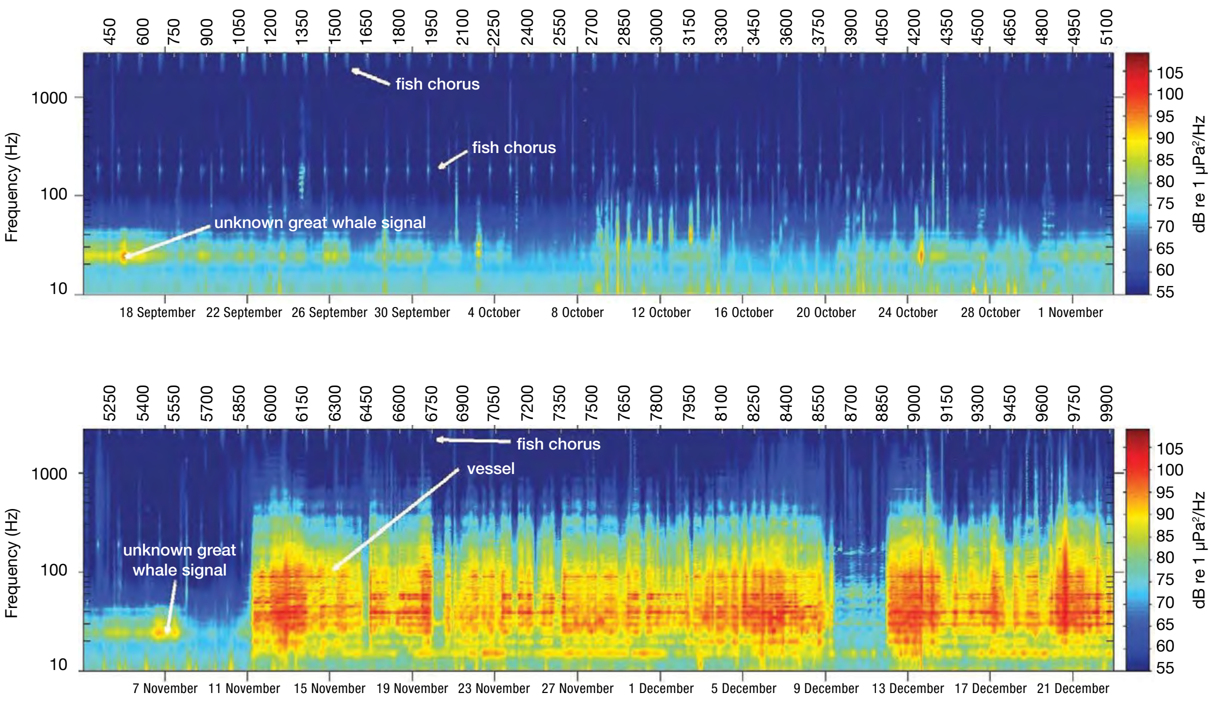

Figure 10-4: The Browse Basin noise logger 50-day stacked marine noise spectra from 14 September to 22 December 2006. A logarithmic frequency scale has been used and the colour bounds were fixed between 55 and 110 dB re 1 μPa²/Hz. Vessel noise dominates the plot from 11 November 2006 onwards. The unknown great whale signals were most likely from Bryde's whales

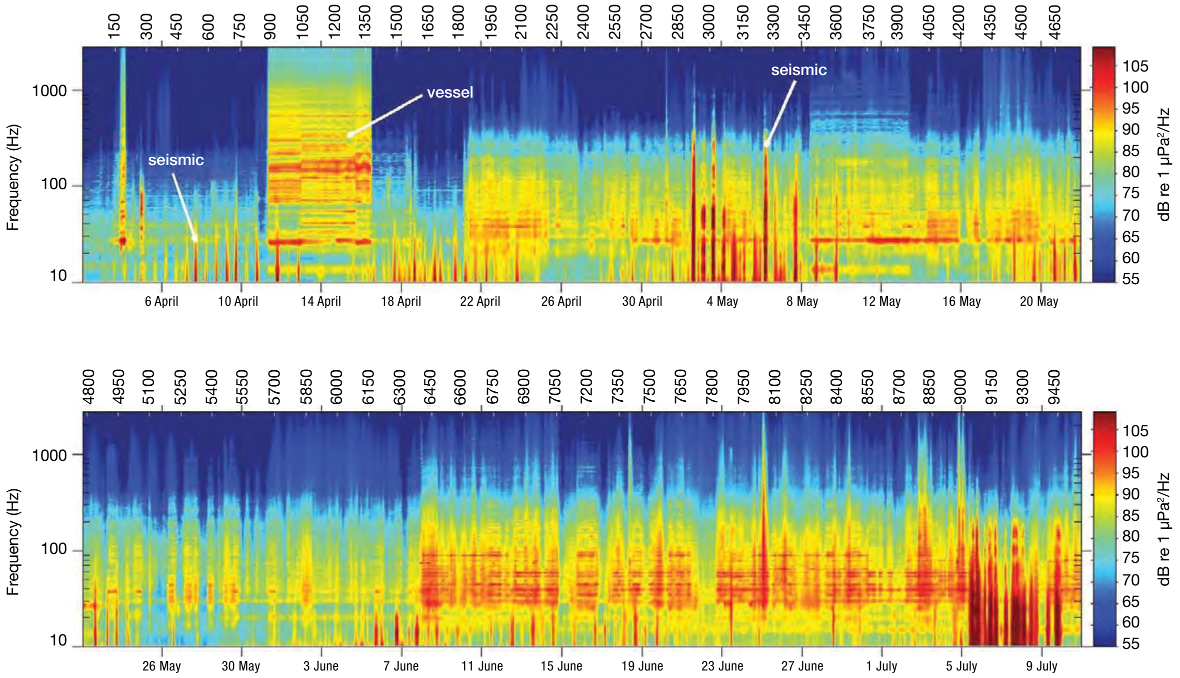

Figure 10-5: The Browse Basin noise logger 50-day stacked marine noise spectra from 2 April to 10 July 2007. A logarithmic frequency scale has been used and the colour bounds were fixed between 55 and 110 dB re 1 µPa^2/Hz. Vessel (horizontal tones) and seismic survey noise (vertical spikes of varying intensity, typically over a 4–12 hour period) dominate the full period shown

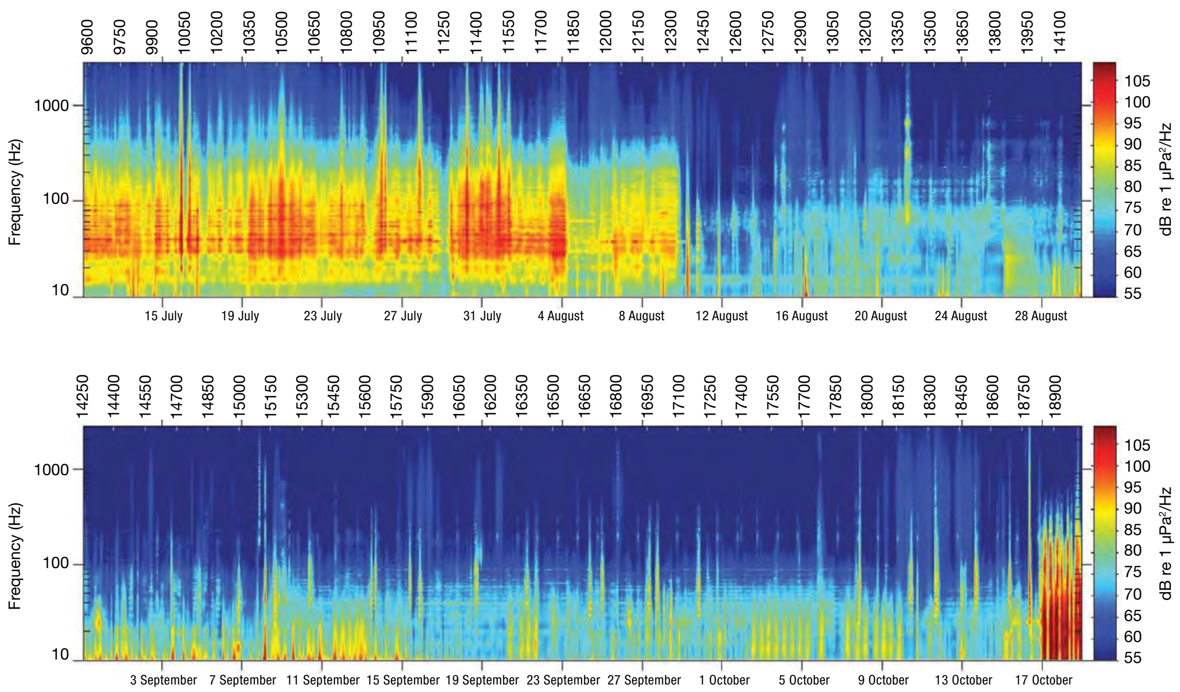

Figure 10-6: The Browse Basin noise logger 50-day stacked marine noise spectra from 11 July to 18 October 2007. A logarithmic frequency scale has been used and the colour bounds were fixed between 55 and 110 dB re 1 µPa^2/Hz. Vessel noise was prevalent prior to 10 August 2007, after which distant and nearby seismic survey noise, as well as lower-level background vessel noise, can be seen. Evidence of humpback whale calls can be seen as the weaker energy bands between 50 Hz and 400 Hz between mid-August and early September 2007

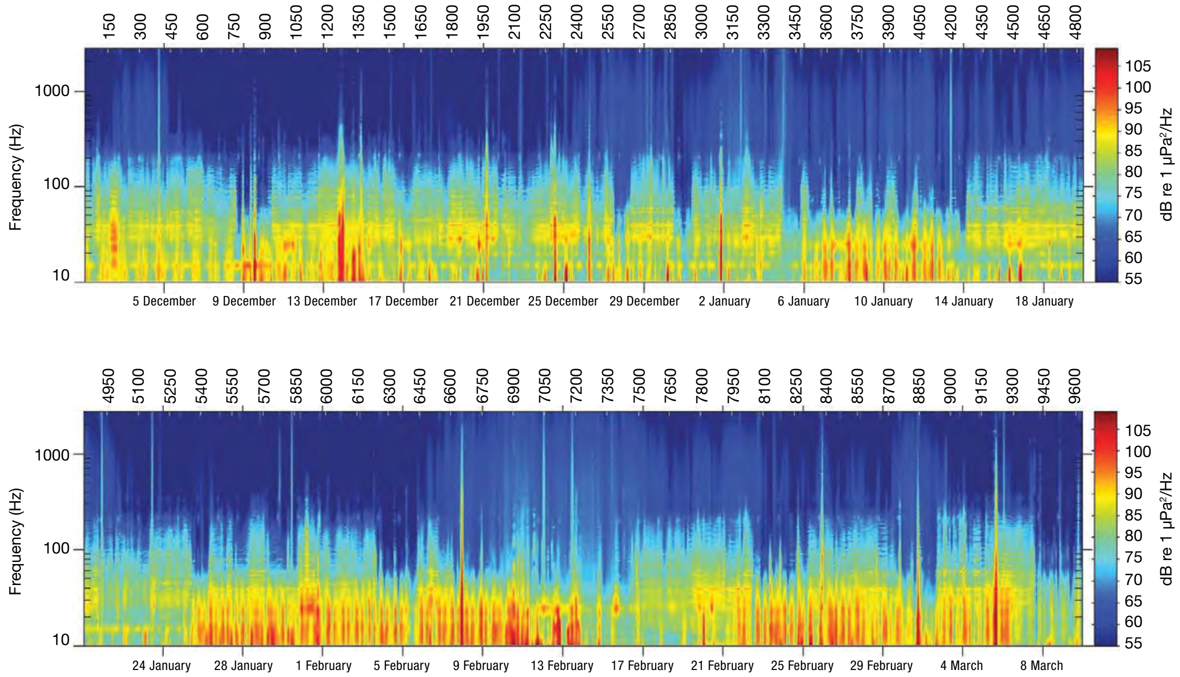

Figure 10-7: The Browse Basin noise logger 50-day stacked marine noise spectra from 1 December 2007 to 9 March 2008. A logarithmic frequency scale has been used and the colour bounds were fixed from 55 to 110 dB re 1 µPa²/Hz. Nearby vessel and seismic survey noise was prevalent across the full recording period

The marine noise detected at the Maret Islands site differed substantially from that at the Browse Basin site in that it was much more consistent. The colour plots of stacked marine noise spectrograms for these recordings are presented in Figure 10-8. These colour plots only display the first 100 days of the recording period, as this was representative of the entire data set. The marine noise recorded by these loggers was dominated by signals consistent with fish calling, with at least four different fish choruses detected together with numerous individual fish calls that did not form choruses. Early each evening, one fish chorus dominated the marine noise spectra from 500 Hz to 2 kHz. On the basis of the results of previous work by McCauley (2001), this is believed to have been produced by nocturnal planktivorous fishes of the families Holocentridae (squirrelfishes) and Priacanthidae (bigeyes).

On a seasonal basis, other biological noises were also detected. A second fish chorus, filling the 500 Hz to 2 kHz band later in the evening, was recorded seasonally throughout the study period. This chorus was thought to have been produced by grunters of the family Terapontidae. Humpback whale calls, some very close to the hydrophone as indicated by the intensity of the signals, were also evident between August and September of each year.

Only sporadic small-vessel traffic, consistent with passing vessels (i.e. with no vessels holding station nearby), was evident from the noise-logger recordings.

The low-frequency portion of the ambient noise spectra was significantly different at the Maret Islands site from that at the Browse Basin site. This was attributable to a lack of noise energy reaching the Maret Islands logger from the deeper parts of the Indian Ocean (McCauley, Cato & Duncan in prep.).

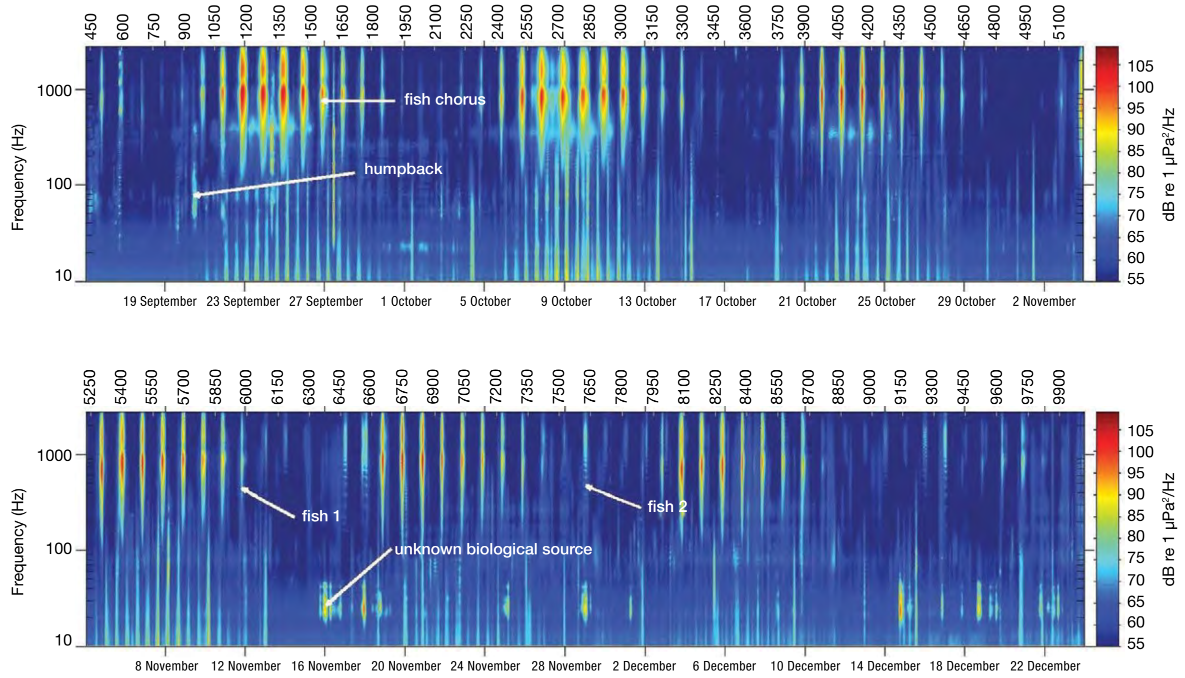

Figure 10-8: Panels of 50-day stacked marine noise spectra for the Maret Islands site. The top panel represents the data for the first 50 days with the most dominant fish choruses and humpback whale calls highlighted. The bottom panel represents the subsequent 50 days with two different fish choruses and an unknown biological source labelled

Ambient noise

To obtain an estimate of the lowest level of ambient noise at the Browse Basin site, several periods, which were largely free from whale calls and vessel and seismic survey noise, were chosen. Fish calls were always present to a small degree and could not be eliminated, meaning that some fish calls were included as ambient noise. The averaged spectra of this selection of low ambient noise curves are shown in Figure 10-9.

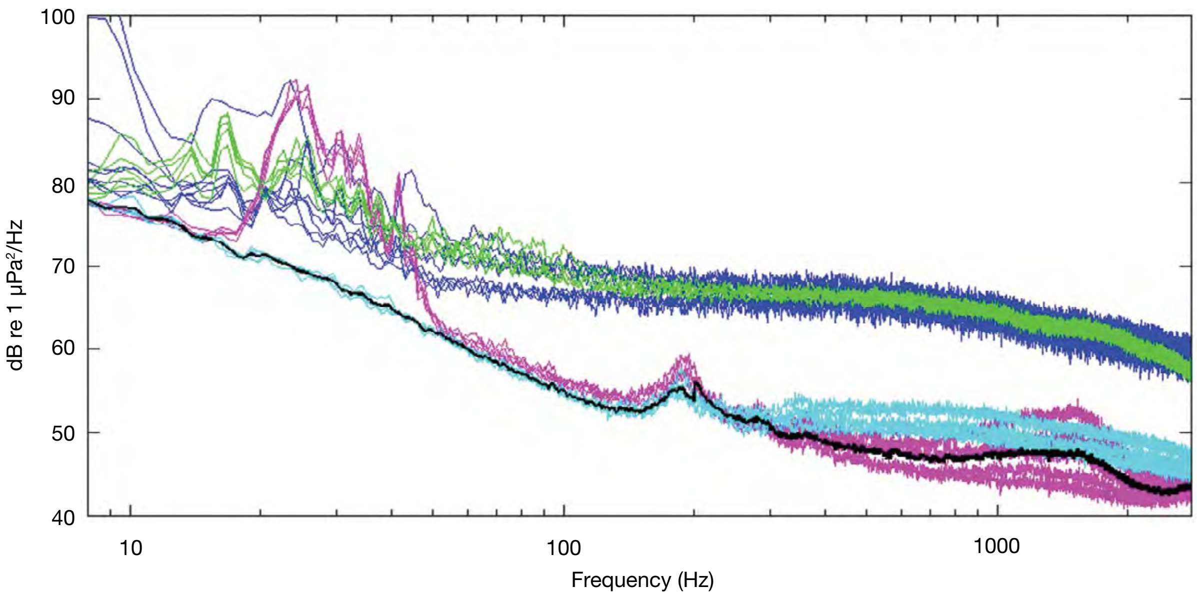

Figure 10-9: Low ambient noise curves from the Browse Basin site. Selections of five to eight sets of 200 s averages were chosen from periods with common noise regimes and little overlapping anthropogenic noise. The cyan, green, blue and magenta curves were consecutive samples shown at the same colour to highlight different source contributions. Magenta was low wind noise with some humpback and high Bryde’s whale signals; cyan was low noise; and blue and green were high wind noise. The black curve represents the lowest ambient noise state detected at the Browse Basin site

The following observations apply to Figure 10-9:

- Many low-frequency sources (<60 Hz) are present in the averaged spectra, with some spectra having contributions from distant vessel noise as well as from a source presumed to be a Bryde's whale.
- Above 10 Hz, there was as much as a 20 dB difference in ambient noise between the "base" curve and the contribution of various biological sources.
- Fish and some distant humpback whales contributed to an ambient noise spike at 200 Hz for a selection of curves.
- Little or no noise from snapping shrimps was evident when the frequency was less than 1800 Hz.
- Periods of sea-surface wind-generated noise were evident as the ambient noise increased above 20 Hz.

Using the low ambient noise curves, a minimum ambient noise curve was fitted for the Browse Basin site (represented by the heavy black line in Figure 10-9). Without the influence of anthropogenic noise sources, this curve can be considered to be the lowest potential marine noise level likely to be met at the Browse Basin site. A comparison of this lowest level noise curve and the mean curves for low marine noise states measured near Browse Island is shown in Figure 10-10 along with a selection of marine noise predictions based on the work of Cato and Tavener (1997).

The base marine noise curve was much higher than that predicted from wind noise alone, meaning that the Browse Basin site had considerable low-frequency input (below 100 Hz). This is thought to be attributable to an input of noise from the deep waters of the Indian Ocean (Cato & Tavener 1997; McCauley, Cato & Duncan in prep.).

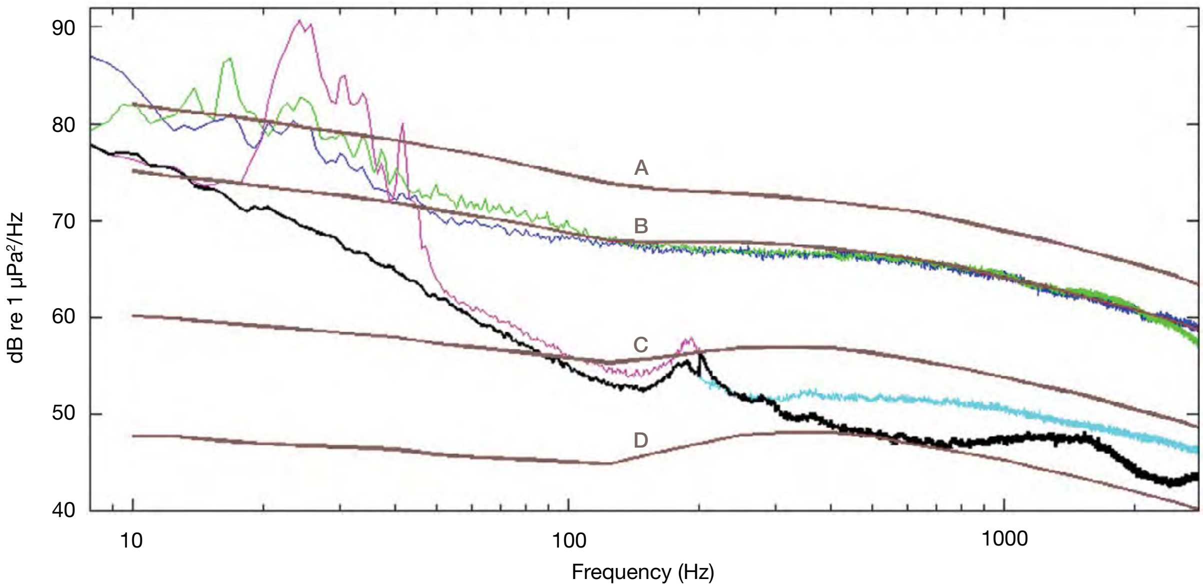

Figure 10-10: A selection of mean marine noise curves for differing states of wind and biological noise sources from the Browse Basin site. The lowest ambient noise is indicated by the black curve while the marine noise prediction curves from Cato and Tavener (1997) are grey. Note that the grey curves do not include low-frequency ocean noise sources. The wind speeds for the marine noise prediction curves are as follows: A = 25 knots; B = 15 knots; C = 5 knots; D = 1 knot

A selection of ambient noise curves from the Maret Islands site is displayed in Figure 10-11. These curves were derived from recordings of the following types:

- a low marine noise state with almost no biological inputs except for snapping shrimp which bend the curve up slightly above 1.5 kHz
- a moderate wind condition state with no biological input apart from snapping shrimp
- a strong fish chorusing centred near 800 Hz, attributed to nocturnal planktivorous fishes.

Figure 10-11 displays an almost 60 dB shift above the lowest ambient levels which is attributable to the fish chorus, meaning that wind and biological sources can greatly change the ambient noise conditions.

A comparison of the lowest averaged ambient noise curves for the Browse Basin and the Maret Islands sites (Figure 10-12) shows that the former received a greater input of low-frequency energy (from the Indian Ocean); this increased the noise spectra, in particular below 1 kHz. The broadband levels of these lowest ambient noise curves were as follows:

- Browse Basin site: 90 dB re 1 μPa
- Maret Islands site: 85 dB re 1 μPa.

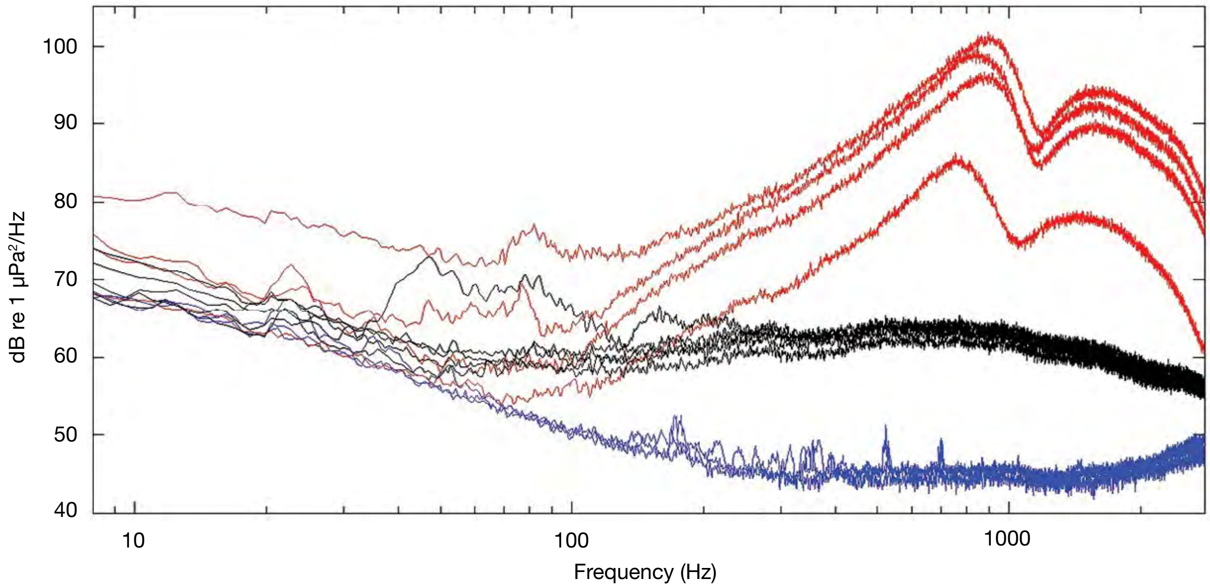

Figure 10-11: A selection of ambient noise curves from the Maret Islands site, with instances of low marine noise state represented by blue curves, moderate wind by black curves, and strong fish chorusing by red curves

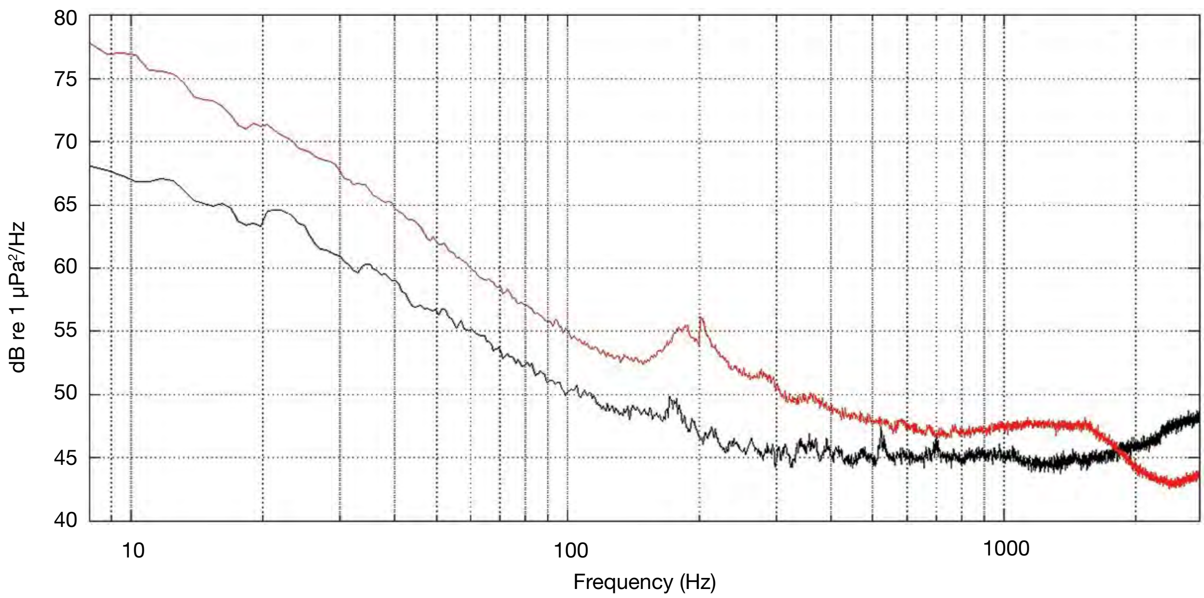

Figure 10-12: Comparison of ambient marine noise curves from the Browse Basin noise-logger site (red) and the Maret Islands noise-logger site (black)

Site comparison

The noise-level distribution at the Browse Basin site displayed significantly elevated ambient noise levels that were thought to be attributable to vessel and seismic-survey noise (figures 10-4 to 10-7 and Figure 10-13). The maximum intensities of averaged ambient noise during periods of vessel and seismic noise fell within the boundaries of those experienced at the Maret Islands site where natural fish choruses dominated, but were louder for longer periods at the Browse Basin site. On occasion, vessel noise raised the overall marine noise levels by 25 dB above natural ambient conditions.

The highest and most persistent broadband marine noise levels detected by the Browse Basin noise loggers were thought to have been produced by vessels. It is believed that rig tenders or work vessels using dynamic-positioning systems produced the most sustained periods of elevated marine noise. Figure 10-13 compares the distribution of marine noise for three scenarios:

- the noise recorded at the Browse Basin site during a period of high and persistent broadband marine noise believed to have been produced by vessel activity between 19 April and 10 August 2007 (113 days) (represented by blue bars)
- the noise recorded at the Browse Basin site over the period 19 April 2007 to 10 August 2007, encompassing a period when no vessel noise was thought to have been recorded (represented by orange bars)
- the noise recorded at the Maret Islands between 19 April and 10 August 2007 when the recordings were dominated by natural sea noises only (represented by black bars).

When the sites were compared using natural ambient noise without anthropogenic inputs, broadband marine noise levels below 100 dB re 1 µPa were higher at the Browse Basin site than at the Maret Islands site (Figure 10-14). This is thought to be attributable to low-frequency noise input from deeper parts of the Indian Ocean from natural noise sources, which were detected by the Browse Basin noise logger but not by the Maret Islands logger which was further inshore and in shallower water.

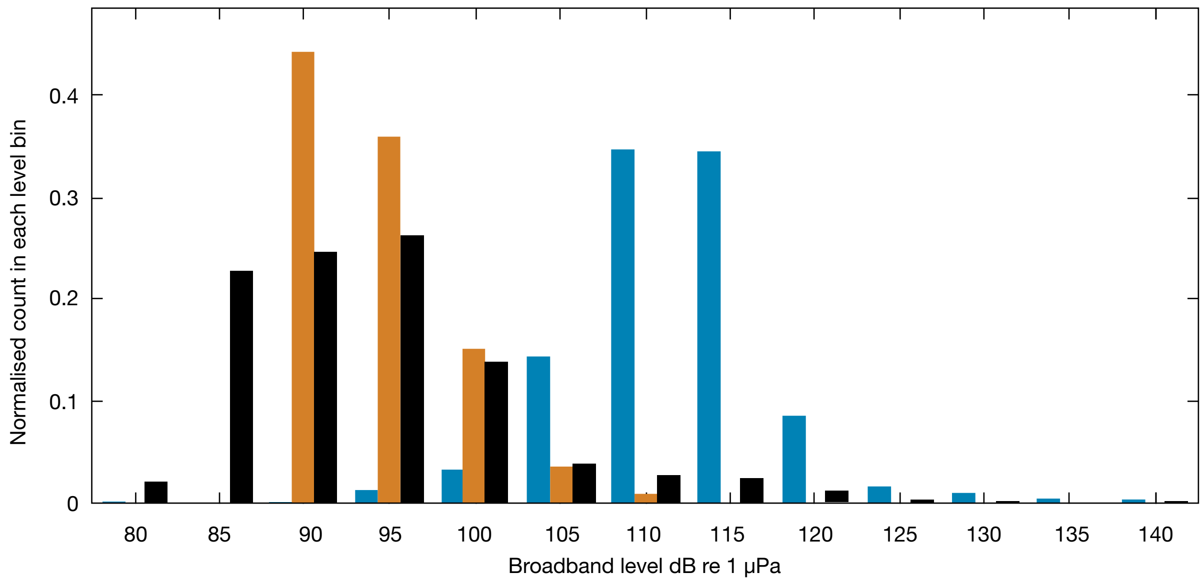

Figure 10-13: The normalised distribution of broadband noise at the Browse Basin site during a period of anthropogenic (vessel) noise (blue bars), at the Browse Basin site during a period with no significant anthropogenic noise (orange bars), and at the Maret Islands site with natural sea noise sources only (black bars)

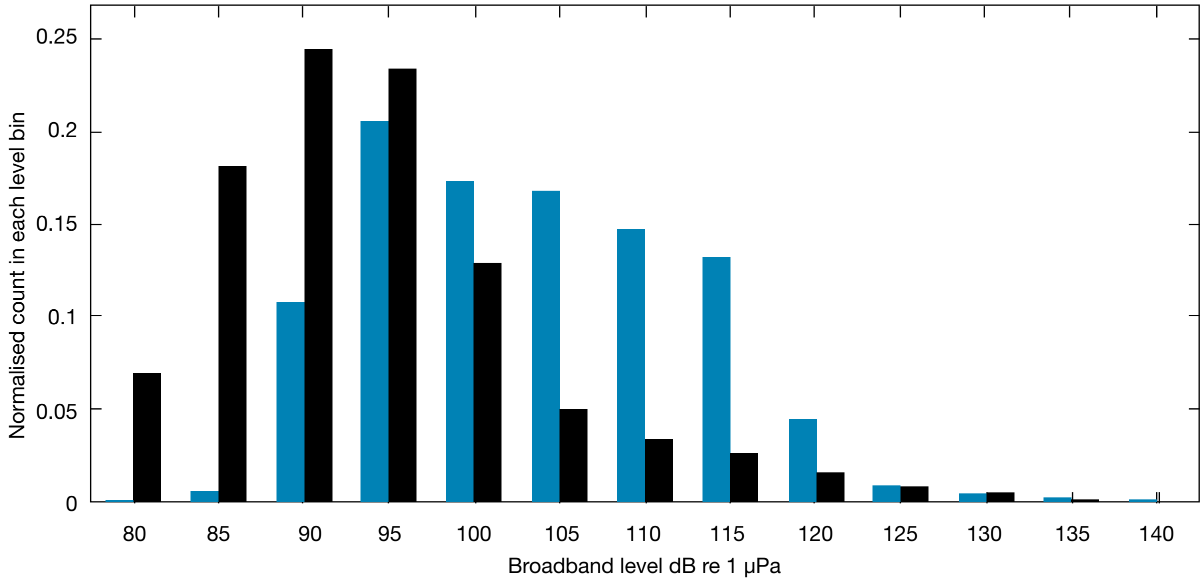

Figure 10-14: The distribution of all broadband noise measurements from the Browse Basin site (blue bars) during a period without anthropogenic influences, and from the Maret Islands site (black bars)

Great whales

Humpback whales

Recordings at the two study sites showed that humpback whale songs varied from year to year. Over the study period, the most dominant component recorded was a broadband signal ranging from 50 hertz to several kilohertz with a short up- or down-sweep centred at 300 Hz. The panels presented in Figure 10-15 depict humpback whale songs. The top panel also depicts a period where an individual humpback whale sang close to the noise logger, as determined from the intensity of the signal.

Humpback whale vocalisations that were not song-related were recorded at the Maret Islands site but were not analysed in detail as they are typically of low level and so did not transmit far (perhaps only up to 3 km). The repertoire of such vocalisations is highly varied and largely unstudied.

More detailed spectrograms of humpback whale songs from the Maret Islands on 27 September 2006 are presented in Figure 10-16.

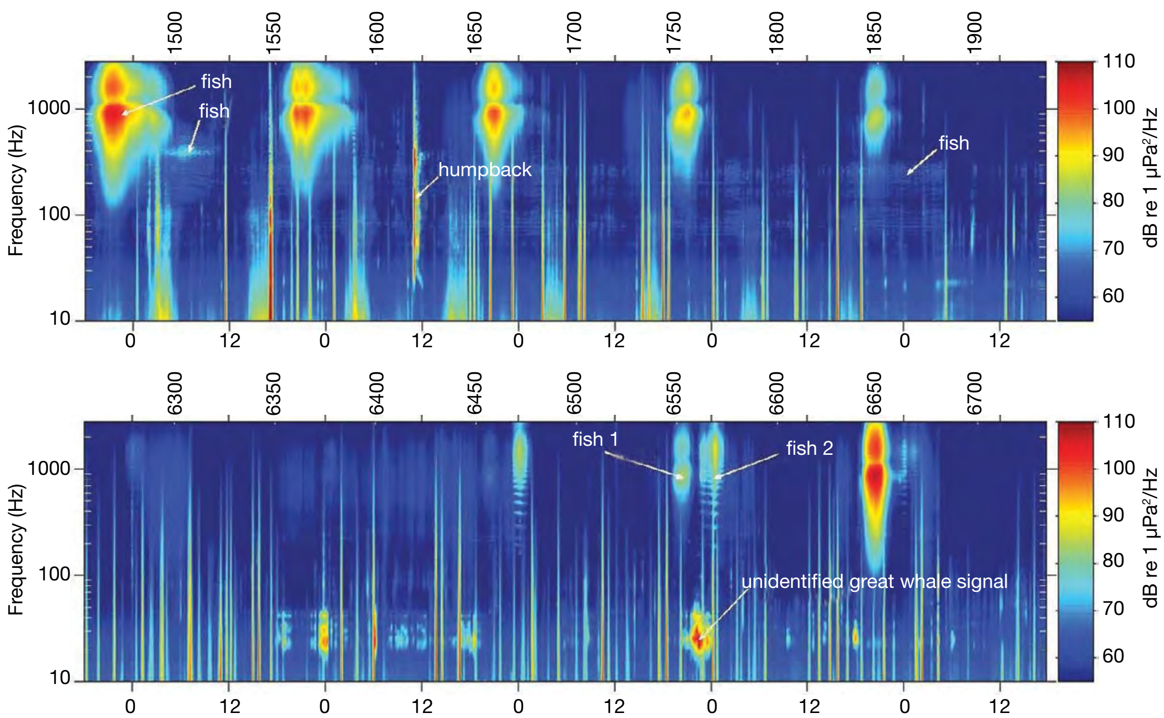

Figure 10-15: Five-day sequences of stacked marine noise spectra from the Maret Islands site, highlighting several sources. The top panel represents data gathered between 25 and 30 September 2006; the bottom panel represents data gathered between 14 and 19 November 2006. The daily periodicity in fish choruses is evident

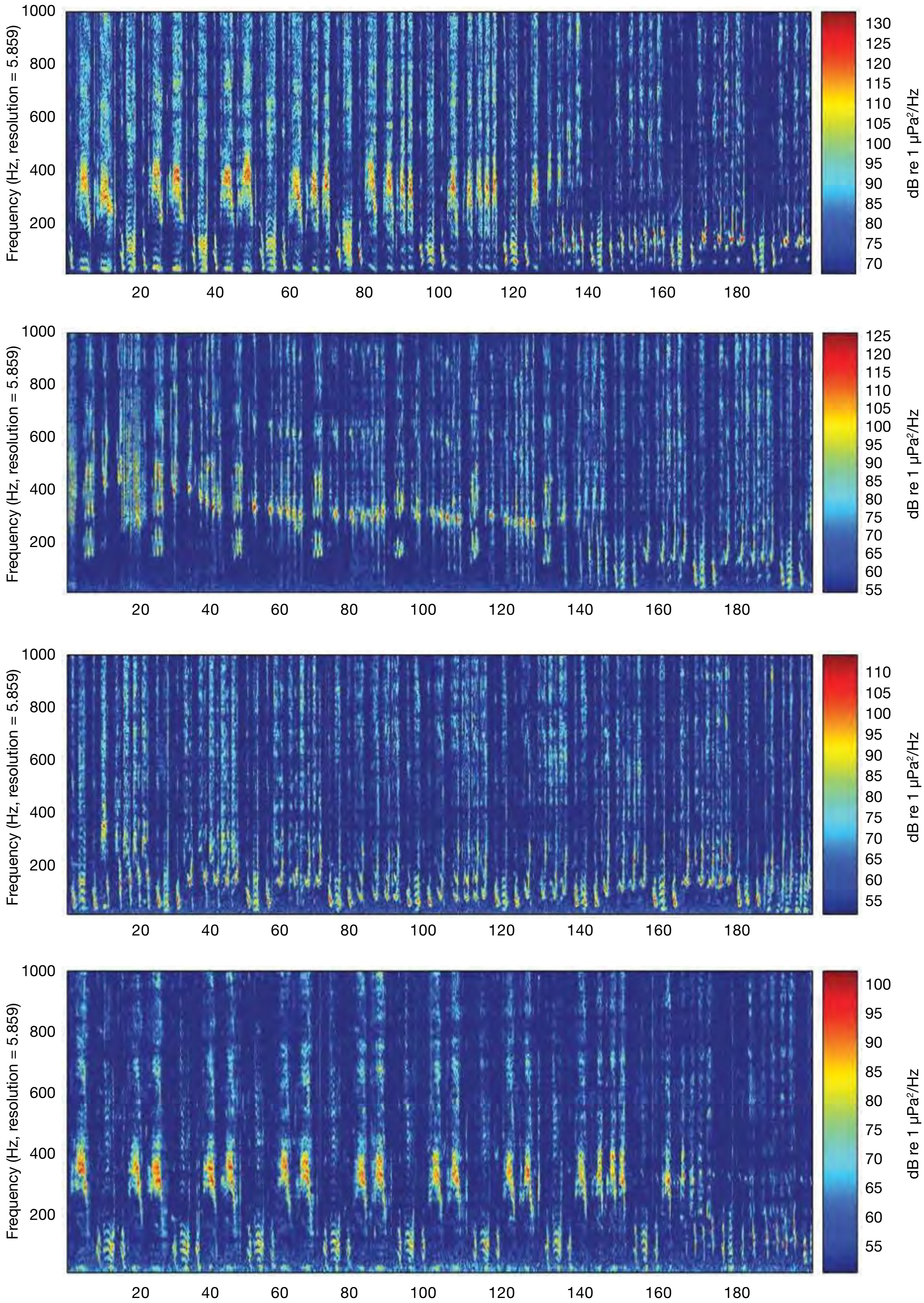

Figure 10-16: Spectrograms of four consecutive recordings made at the Maret Islands on 27 September 2006 between 1100 hours and 1148 hours WST (x-axis in seconds) depicting nearby humpback whale songs

The seasonal presence of humpback whales was determined by an algorithm that was derived from the number of instantaneous humpback whale calls across all samples. However, when this algorithm was carried out, a large number of false detections were discovered. These were due both to the dominant song components being broadband signals with a similar energy content to fish calls (the Maret Islands site) or seismic signals (the Browse Basin site), and to significant periods of vessel noise at the Browse Basin site, which either masked the humpback calls or triggered the detection algorithms and resulted in large numbers of false detections.

All detections were manually checked so that the false detections could be removed from the data set.

The analysis of the data for humpback whale calls focused on determining the start and end dates of the period that humpback whales were present within the study area. This was primarily because the deployment and retrieval dates for the noise-logger equipment stationed at each site coincided with the period that humpback whales were observed in the study area. In addition, two of the logger sets (loggers 2756 and 2798) had lost sensitivity in the frequency of humpback whale calling because the hydrophone connectors began to fail.

The maximum number of humpback whales singing at any one time at either of the noise-logger sites was three individuals (as determined by counting the number of simultaneous song components). However, the median number across all recordings was one. Figure 10-17 depicts the counts of individual humpback whale songs averaged over a 24-hour period. The 2008 data from the Maret Islands site (bottom panel) indicate that the humpback whales calls were cyclical in nature, with each cycle lasting approximately 10 days.

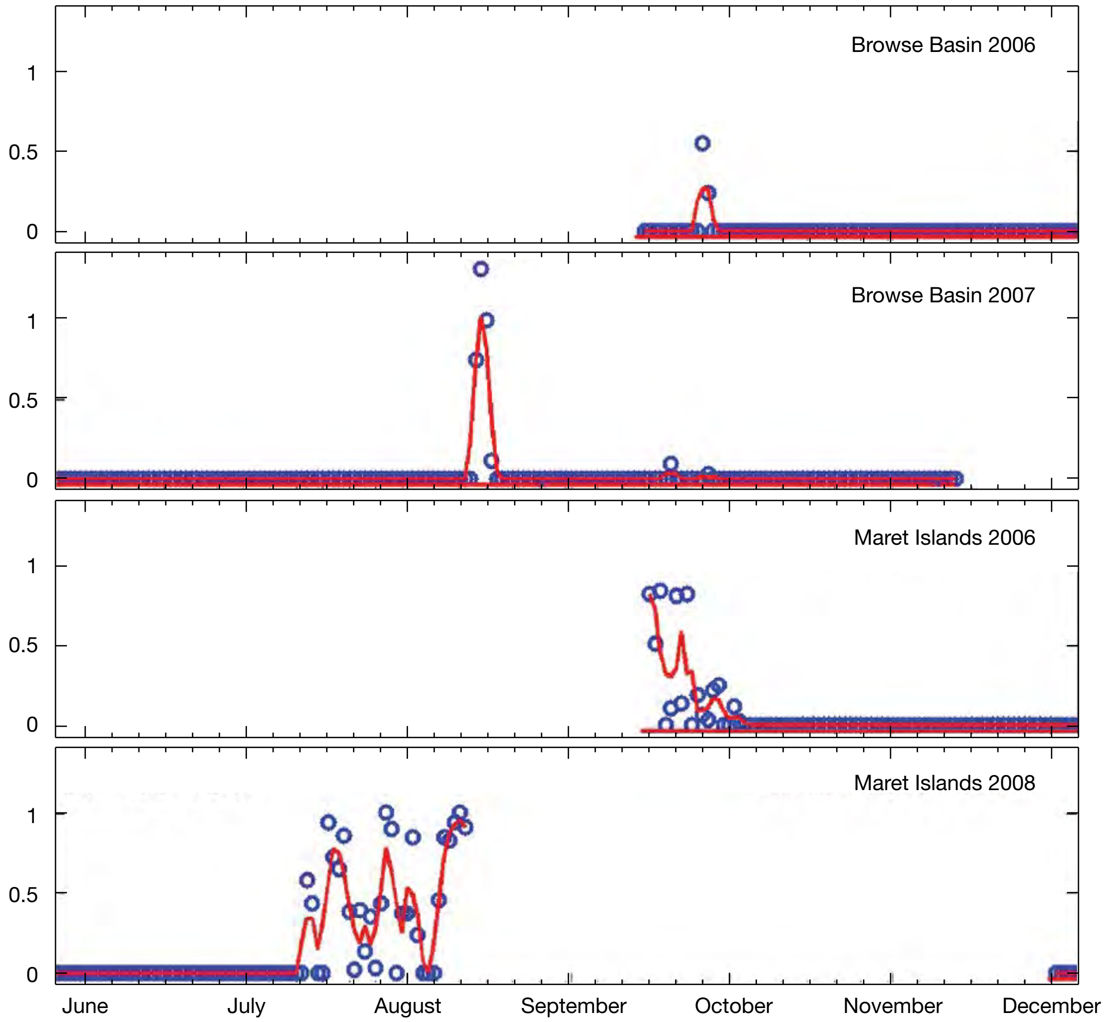

Figure 10-17: Mean counts of instantaneous humpback whale calls averaged over 24-hour periods (1200 hours to 1200 hours) for the Browse Basin site (2006 first panel; 2007 second panel) and the Maret Islands site (2006 third panel; 2008 fourth panel). Note that the records for each data set are not comprehensive. The gaps in the data are due to other (vessel) noise interference etc. Red lines represent the 3-day moving average; blue circles represent instantaneous humpback whale calls

This has commonly been observed in similar data sets at other sites, with periodicities in calling ranging from three to 14 days (R.D. McCauley, unpublished data).

Transmission of humpback whale signals at the two sites was not determined. Based on sound transmission modelling carried out for a site to the south-east of Scott Reef for the transmission of humpback whale signals (McCauley & Salgado Kent 2008), the listening range for humpback whales at the Browse Basin site would be almost 50 km in quiet ambient conditions. There were a few instances of calling humpbacks near the noise logger, although most were at a moderate (10–20 km) to very long range as determined by the intensity of the signals. There were numerous instances of humpbacks close to the noise logger (<1–2 km) at the Maret Islands site and lengthy periods with humpbacks within 10 km of the logger. However, single noise loggers are not directional and therefore the direction from which the whale calls were coming could not be ascertained.

Minke whales

Signals were recorded by the noise loggers at the Browse Basin site that were consistent with vocalisations of both species of minke whale: the "star-wars" call of the dwarf minke whale (*Balaenoptera acutorostrata*) (Gedamke, Costa & Dunstan 2001) and the "boing" call of the Antarctic minke whale (*Balaenoptera bonaerensis*) (Rankin & Barlow 2005).

The dwarf minke whale call was common at the Browse Basin site from mid-August to early September 2007. Only one year's worth of data was suitable for analysis over this period, with the noise logger being deployed in mid-September 2006 and recovered in August 2007. Large numbers of calls per 200 s sample were detected, varying from 1 to 14. The repetition interval for an individual dwarf minke whale call is believed to be approximately 20 s based on measurements collected by R.D. McCauley (unpublished data) at the Montebello Islands in 2006. Assuming a 20 s repetition interval, a broader range of calling individuals may have been detected. A representation of sounds recorded by Browse Basin logger 2755, including a sound that was attributed to a dwarf minke whale, is depicted in Figure 10-18.

The data were not studied extensively for signals consistent with the calls of Antarctic minke whales because of analysis time constraints and the small number of calls found. However, from the analysis that was conducted, they were only detected by the Browse Basin noise logger in September 2006. Several variations of these calls were recorded during this time (Figure 10-19).

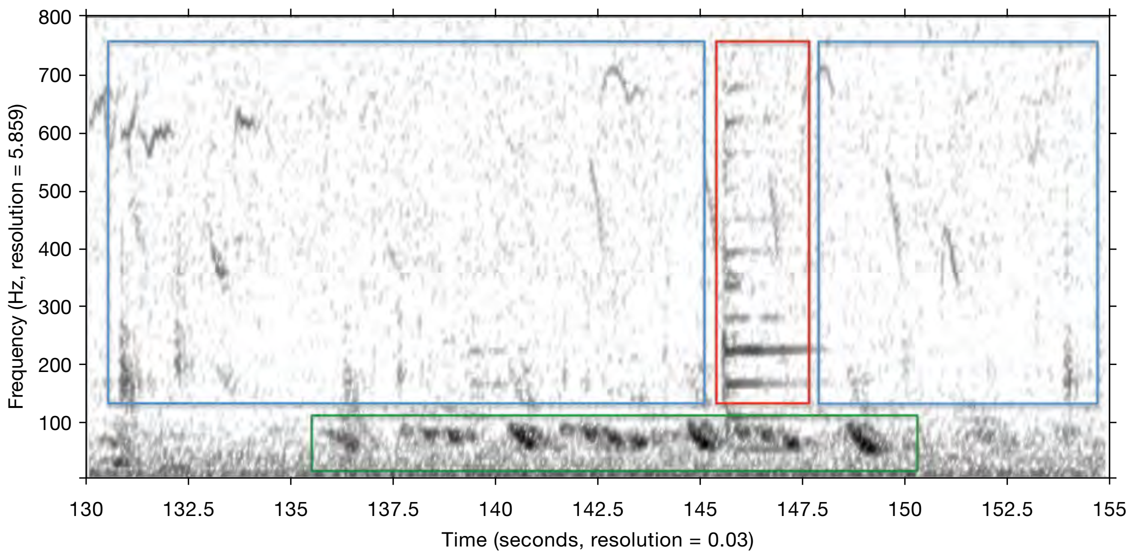

Figure 10-18: Spectrogram from the Browse Basin site depicting calls from a dwarf minke whale, several humpback whales, and an unknown source that was most likely to have been a Bryde's whale, at 2200 hours on 12 August 2007 (sample number 12721). The red box represents the dwarf minke whale call, which was 145–148 s in length with energy mostly less than 100 Hz and harmonics to 700 Hz. The blue boxes represent the humpback sweeps above 100 Hz. The green box represents the source thought to be a Bryde's whale, 135–150 s in length and less than 100 Hz

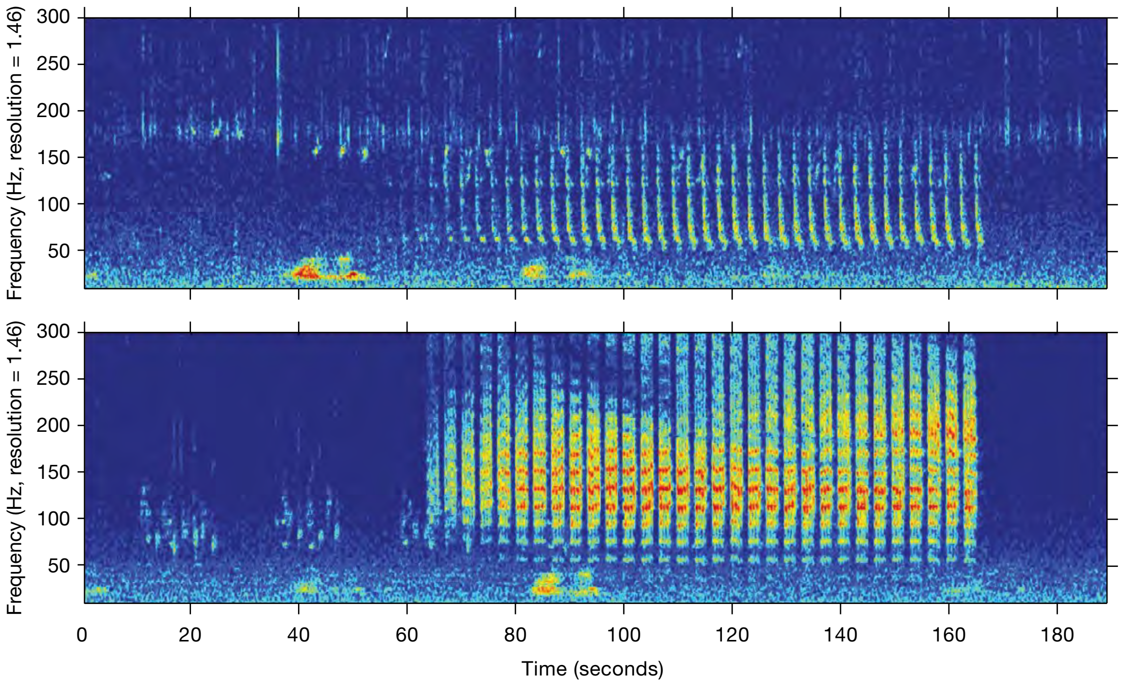

Figure 10-19: Spectrograms of variants of possible Antarctic minke whale signals (60–170 s length in each plot) between 2000 hours on 23 September and 1430 hours on 24 September 2006 (sample number 1267) from the Browse Basin site. Weaker humpback whale signals are evident in the background (energy over 50–200 Hz), and the call of an unknown whale (likely to be a Bryde's whale) is evident in the 25–50 Hz range

Pygmy blue whales

During examination of 5-day stacked marine noise spectra for all data sets, signals from pygmy blue whales were identified in October 2006 at the Browse Basin site (Figure 10-20). Subsequently, all Browse Basin data sets were systematically searched for pygmy blue whale calls using an algorithm that would identify the 68–75 Hz segment of the second call component of the pygmy blue whale call.

The detections made by the algorithms were checked for false or missing detections by bracketing five samples. This process was repeated until no new records were returned and all verified detections were surrounded by at least five samples that did not include any signals that could be attributed to pygmy blue whales. The period of 200 s was the minimum repeat cycle for a pygmy blue whale call in these samples. Therefore the number of individual calls identified within any 200 s period indicated the number of calling whales at any point in time.

Pygmy blue whales were detected only by the Browse Basin logger and not by the inshore Maret Islands logger. At the Browse Basin site, pygmy blue whales were detected only between 0700 hours on 27 October 2006 and 0700 hours on the following day.

The summary of all detections from the three Browse Basin loggers is shown in Figure 10-20 using a 24-hour mean count of individual calling whales taken between 1200 hours on one day and 1200 hours the following day. The 24-hour mean is used to account for day–night differences in call rates, as pygmy blue whales are known to call approximately 2.2 times more often at night (McCauley et al. 2001).

Only a small proportion of the samples were found to include pygmy blue whale calls—43 out of a total of 59 525 samples. The maximum number of individual calling whales was three during any 200 s recording, and the mean number detected was one. It was determined from a series of calculations that these whales were between 2 and 8 km from the noise logger when they were recorded (McCauley 2009). Thus it was likely that only low numbers of pygmy blue whales were in the vicinity of the Browse Basin logger and, then, only for a short time.

Unknown call—possibly from a Bryde's whale

A persistent low-frequency biological signal was frequently recorded at both the Browse Basin and Maret Islands sites. Examples of this call are depicted in Figure 10-21.

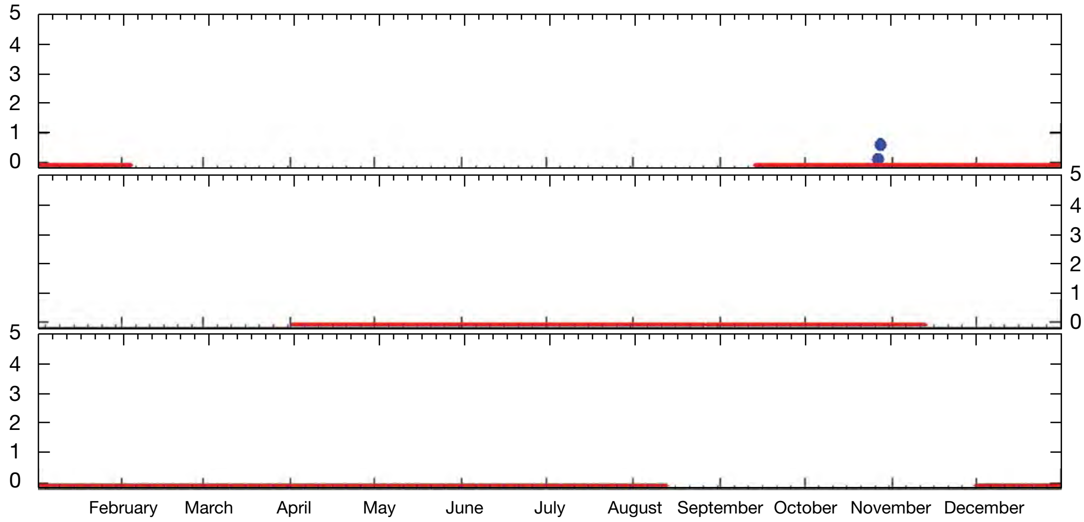

Figure 10-20: The 24-hour-averaged number of pygmy blue whales detected (blue dots) from the three Browse Basin noise-logger sets. The red lines indicate when the noise loggers were recording. The time scale was zeroed to 1 January and wrapped, resulting in the data being presented against months rather than years in order to depict seasonality. The top panel represents the data from noise logger 2721, deployed between September 2006 and February 2007; the middle panel represents the data from noise logger 2755, deployed between April 2007 and November 2007; and the bottom panel represents the data from noise logger 2798, deployed between December 2007 and August 2008

The signal had two parts, lasting approximately 10 s in total (although the signal length varied with its signal-to-noise ratio) and spanning a frequency range of 20–100 Hz (see the lower panel of Figure 10-21). It was distinct in that it was of low frequency and dispersed across a comparatively wide frequency band with a poor harmonic structure but strong intensity. It could not therefore be attributed to fish choruses as fish calls typically display strong and distinct harmonics because of the fish sound-generation mechanism which operates by pulsing the swim bladder. The signal had the greatest similarity to the signals that were reported by Heimlich et al. (2005) from the eastern tropical Pacific and that were attributed to Bryde's whales (especially calls *c* and *d* in that paper).

The apparent Bryde's whale signals were found in all of the recordings studied. Based on its regularity, its signal-to-noise ratio and the typical inter-call spacing from individual animals, it is believed that all of the signal pairs shown in Figure 10-21 (top panel) were from different individuals, indicating that the whale source of the call is relatively common in the study area.

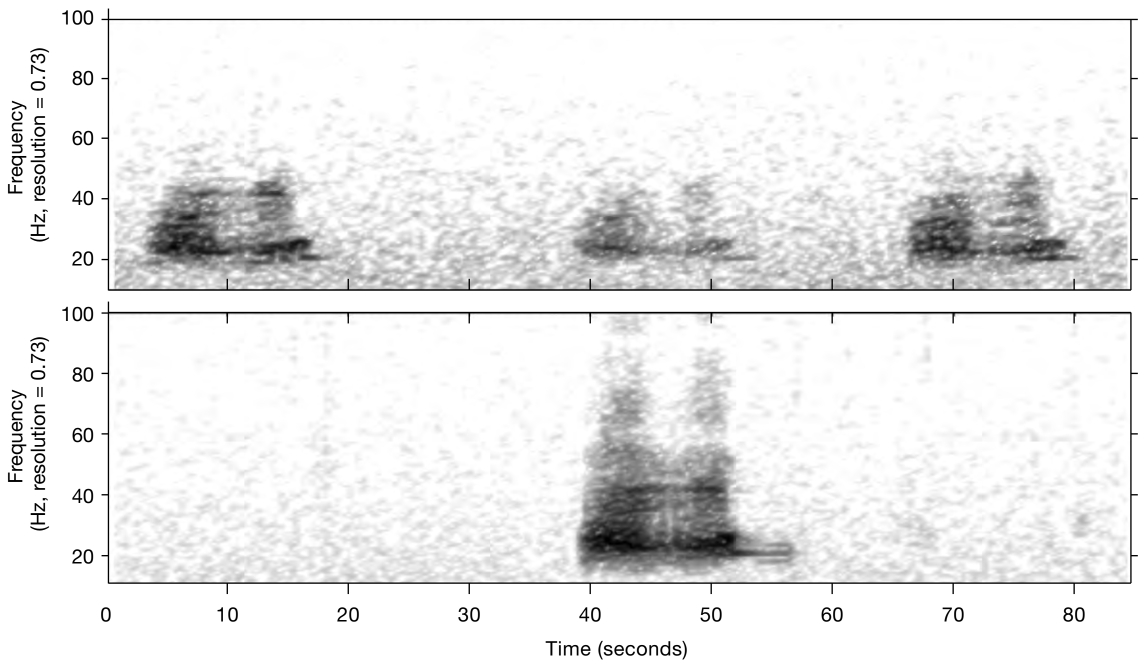

Figure 10-21: Spectrogram of the unknown signal (possibly a Bryde's whale call) recorded at the Browse Basin site (top panel) and the Maret Islands site (bottom panel) recorded at 0115 hours on 16 September 2006 and 2230 hours on 17 November 2006 respectively

Other calls of unknown great whales

At least one further unknown signal type was recorded by the Browse Basin noise loggers. Figure 10-22 depicts an example of three songs from these recordings. Each song consisted of six or seven down-sweeps, each beginning between approximately 60 Hz and 100 Hz and sweeping down to 50–60 Hz over 1–2 s, with a further 1–2 s between down-sweeps. At this stage, the source of the call is unknown, but it has attributes that are consistent with great whale calls, such as low frequency, power, and a complex frequency structure; in addition, it is not repeated in a clear daily pattern.

Browse Basin fish choruses

High-frequency fish choruses

At the Browse Basin site, each evening after dusk a signal between 1500 Hz and 2800 Hz (the upper limit of the logger bandwidth) was recorded that was attributed to a fish chorus (depicted in Figure 10-23). Choruses similar to this have been previously recorded by noise loggers in the Perth Canyon, where the signals were attributed to lanternfishes of the family Myctophidae (McCauley et al. 2004).

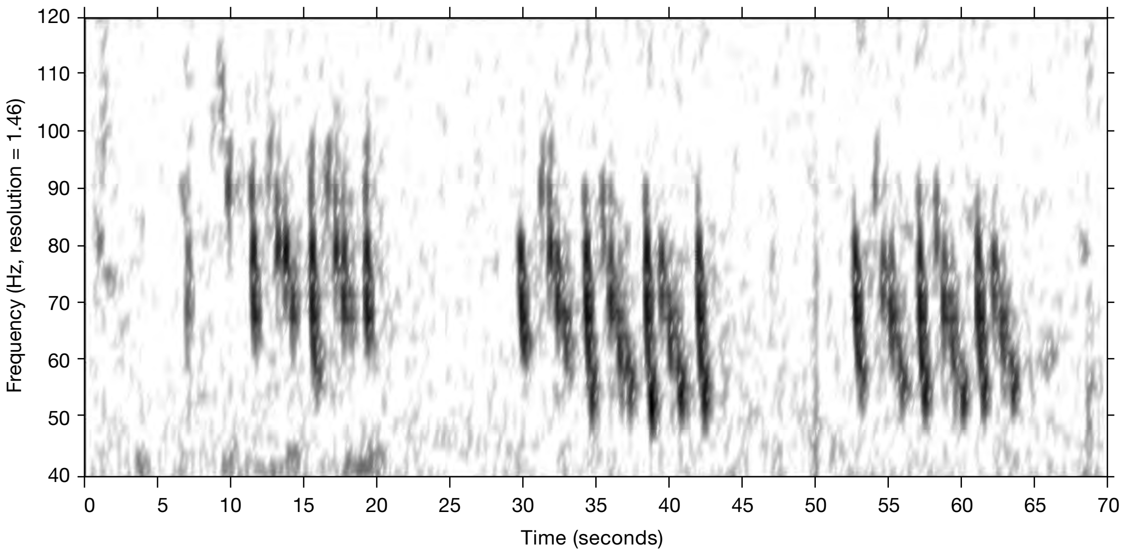

Figure 10-22: Repeated pattern of down-sweeps (presumably from a great whale) recorded by the Browse Basin noise logger at 1000 hours on 11 August 2007

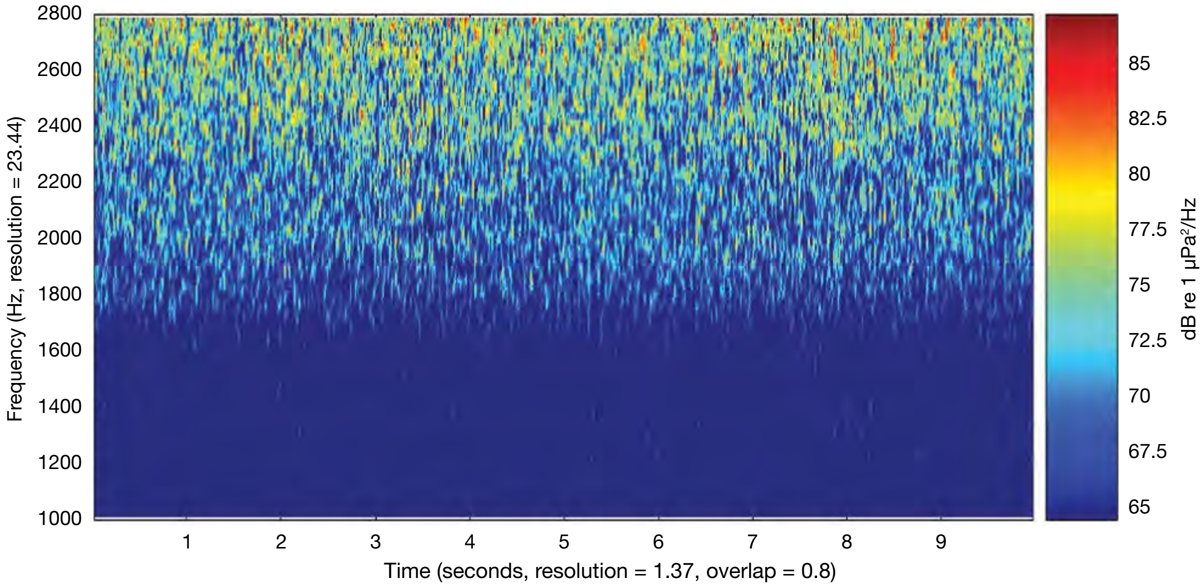

Figure 10-23: Spectrogram depicting a 10 s recording of a high-frequency noise signal at the Browse Basin site, received at 1930 hours on 21 September 2006. This noise was attributed to a fish chorus that was likely to have been produced by members of the lanternfish family Myctophidae

The chorus was very predictable in daily timing, which was related to ambient light levels and consequently the time of local sunset[7]. By zeroing each day's recording to the time of local sunset and then averaging each evening's chorus level in the 2 kHz ⅓ octave band[8] across the entire recording period, trends in chorus activity could be observed.

The mean chorus length with respect to local sunset for each of the Browse Basin recording sets is displayed in Figure 10-24, where the time-averaged spectra across each 200 s sample (after de-spiking) have been used to derive the 2 kHz ⅓ octave. In the figure, the sample time has been adjusted so that for each day the time of local sunset becomes time zero, the daily 2 kHz ⅓ octave level curve has been interpolated at a uniform time base about time zero each day, and the daily curves have then been averaged across the full recording period (i.e. with respect to local sunset). Based on the resulting data presented in the figure, the chorus is very predictable in timing, peaking approximately one hour after sunset each day.

Figure 10-25 displays the seasonal trends in the fish choruses recorded at the Browse Basin site between October 2006 and August 2008. To investigate seasonal shifts in the chorus timing, each evening's 2 kHz ⅓ octave intensity has been stacked across the full recording period (the top panel of the figure). There were long periods in the data set when the chorus either was not evident or occurred at a low level. Where the chorus was evident, the chorus timing over the 1–2 hours following sunset was stable. The integrated chorus level between 0.8 hours and 2 hours following sunset and the time of maximum levels reached are displayed in the middle and bottom panels of the figure. The chorus level began high and remained high until approximately 12 November when it dropped rapidly and then briefly oscillated at a low level until 23 January 2007 (with spikes caused by vessel noise) after which it essentially disappeared. The chorus did not resume again for 280 days, until 31 October 2007, when it resumed but remained sporadic and at comparatively low levels in comparison with those recorded in late 2006. This disappearance of the chorus for a large part of the recording period could have resulted from any one or more of several causes, including natural factors, or as a response to the increased vessel traffic in the area between late 2006 and late 2007.

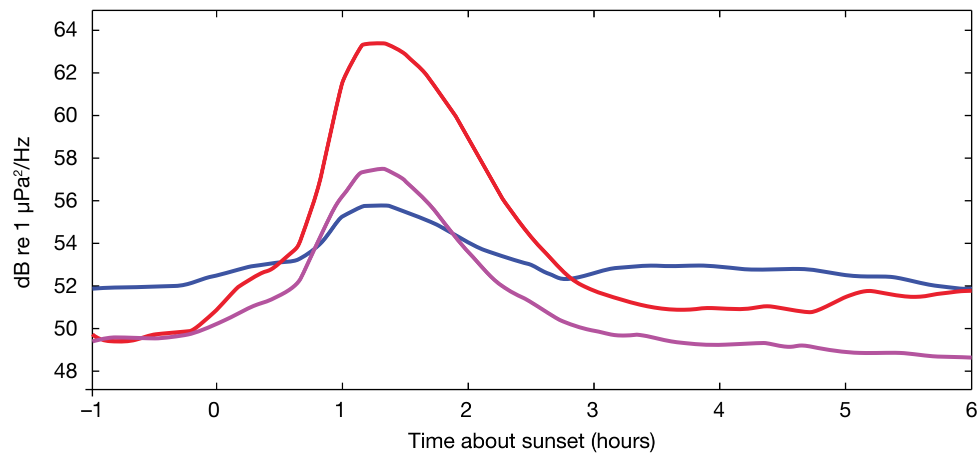

Figure 10-24: Time after sunset of the evening fish chorus at the Browse Basin site, from all three noise loggers. The red line represents logger 2721, the blue line represents logger 2755, and the magenta line represents logger 2798. Time was normalised for local sunset and the chorus level in the 2 kHz ⅓ octave range was averaged over each full recording period. Levels are mean spectral levels over the 2 kHz ⅓ octave band

[7] The time of local sunset was defined as the time when the sun's upper limb reached the horizon and was derived from astronomical tables for that latitude.

[8] The 2 kHz ⅓ octave band is essentially an integration of energy across the 1782 Hz to 2245 Hz frequency range, which is set by international standards.

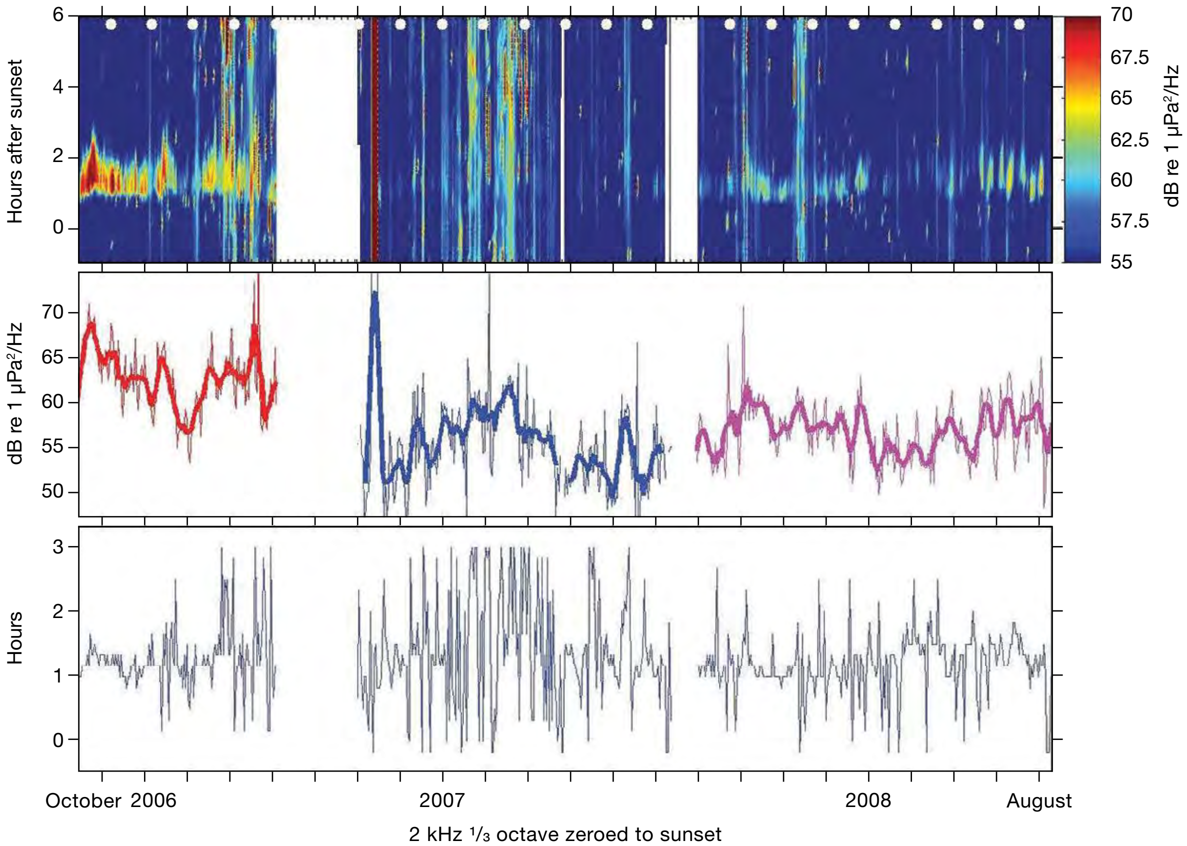

Figure 10-25: Depiction of the seasonal trends in the fish chorus recorded by the Browse Basin loggers. The top panel depicts the intensity of the 2 kHz ⅓ octave each evening over the Browse Basin sea noise data sets, where 0 hours (y-axis) is the time of local sunset. The middle panel represents the integrated 2 kHz intensity over 0.8 to 2 hours after sunset, with the light bars representing the chorus trend and the heavy curves a 3-day running average. The red line represents logger 2721, the blue line represents logger 2755, and the magenta line represents logger 2798. The bottom panel represents the time of maximum energy in the 2 kHz ⅓ octave each evening, with reference to the time of local sunset. The open circles along the top of the top panel represent each month's full-moon phase

Signals recorded within the 200 Hz band

Signals consistent with fish choruses were recorded daily within the 200 Hz frequency band until 30 March 2007. These choruses consisted of many short distinct calls, peaking about 30 minutes after sunset and lasting for approximately one hour (see Figure 10-26 for an example of this trend). The chorus activity was summarised based on energy present in the 2 kHz ⅓ octave (with a bandwidth of 177–223 Hz) across the full recording period. However, noise logger 2798 developed a fault on 6 March 2008, which gradually reduced its sensitivity across this frequency band until the 200 Hz chorus met the system noise floor in May 2008.

Figure 10-27 depicts the 200 Hz ⅓ octave spectra over the whole survey period, with the time of local sunset as zero hours. From this figure, periods of intense noise across this frequency band, attributed to vessel and seismic survey activity, are evident between late 2006 and August 2007. From the 5-day stacked sea noise spectra for loggers 2721 and 2755, the chorus was evident for several weeks after the vessel and seismic noise began, but then disappeared, not returning until September 2007.

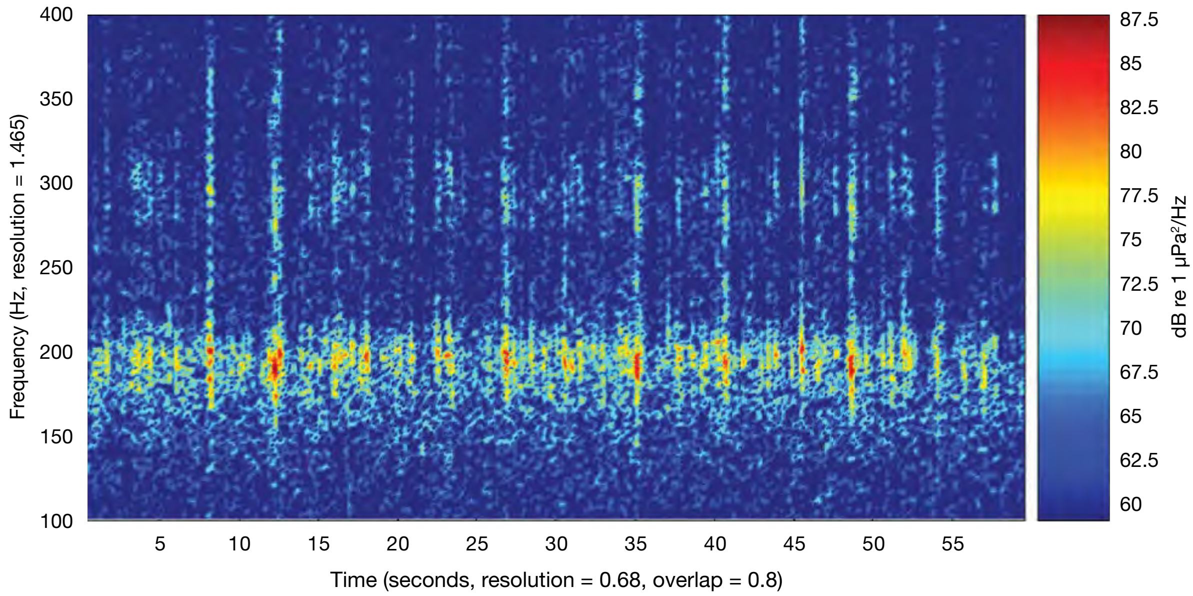

Figure 10-26: Spectrogram of the 200 Hz fish-chorus signals recorded at the Browse Basin site at 1845 hours on 31 October 2006

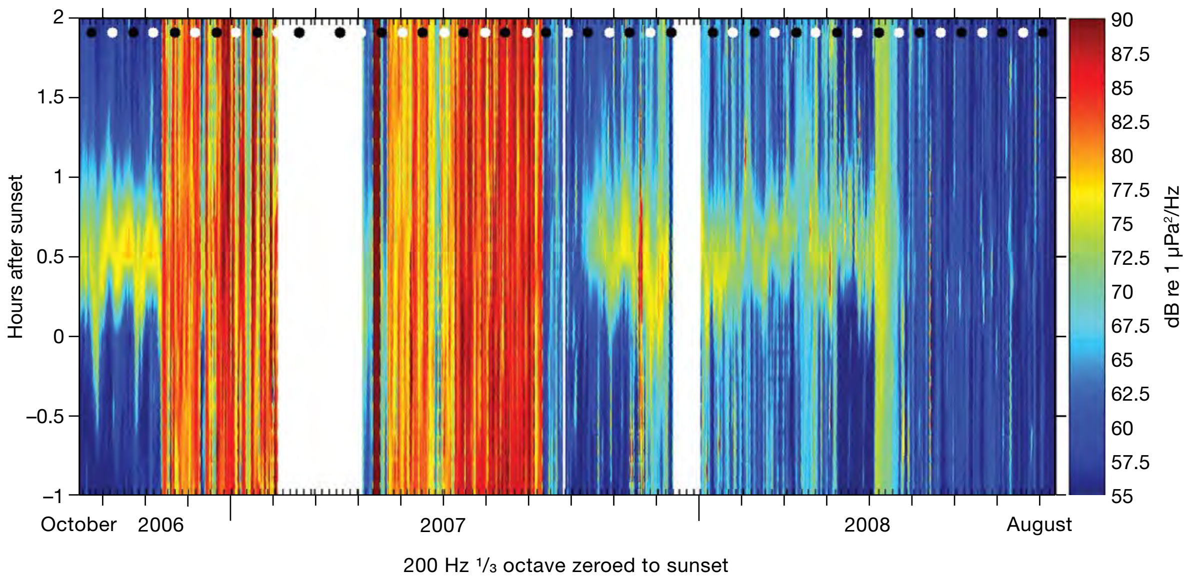

Figure 10-27: The evening 200 Hz ⅓ octave level for the Browse Basin site, with time zeroed to that of local sunset, as indicative of a fish chorus, centred around 200 Hz and beginning each evening approximately 0.5 h after sunset. The timing of the recordings also appears to oscillate in step with the lunar phase. Intense noise periods are depicted on this spectrogram by the full red and green bars. The white circles and black circles along the top of the panel represent the full-moon phase and new-moon phase respectively

Maret Islands fish choruses

A wide diversity of signals, thought to be fish call types, were recorded by the noise loggers at the Maret Islands site. Only the dominant calls were identified because of the diversity of the call types. Of particular interest were the patterns of the two most dominant calls, one produced by nocturnal planktivorous fishes on a year-round basis and the other produced seasonally by fishes of the family Terapontidae (grunters); the habits of these fish are discussed in McCauley (2001). Each chorus displayed strong linking to a half-lunar cycle. Figure 10-28 depicts both of these choruses, with the chorus produced by the planktivorous fish evident in the late evening and that of the terapontid fish in the early morning.

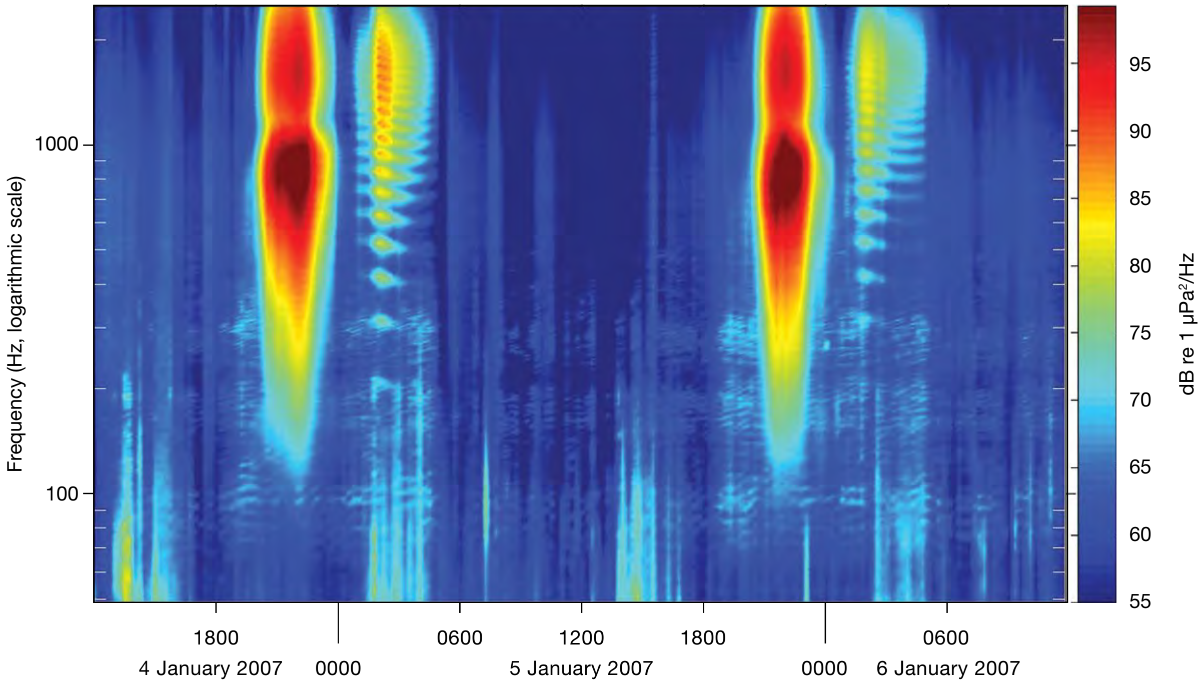

Figure 10-28: Stacked time-averaged marine noise spectra, highlighting two fish choruses between 1200 hours on 4 January and 1200 hours on 6 January 2007 at the Maret Islands site. Another signal, which was strongest between 50 Hz and 300 Hz and which was also thought to be a fish chorus, is evident

Planktivorous fish chorus

The character and behaviour of both the calls and the chorus recorded late each evening at the Maret Islands site and centred around 800 Hz have been ascribed to nocturnally active planktivorous fishes (primarily of the families Holocentridae, Priacanthidae and Apogonidae) based on previous studies by McCauley (2001) and McCauley and Cato (2000). The chorus is thought to be related to feeding activity. Using the same analytical approach as described for the Browse Basin fish choruses, that is, of zeroing each day's recordings to the time of local sunset and calculating averages or statistics of a ⅓ octave indicative of the chorus, the chorus's average daily pattern has been depicted in Figure 10-29 using the 800 Hz ⅓ octave[9]. This chorus peaked each evening several hours after sunset and displayed a strong cyclic pattern, repeating in a 14.8-day cycle in phase with a half-lunar cycle and correlating with spring tides. The chorus is very intense compared with other fish choruses (R.D. McCauley, unpublished data), suggesting a high level of nocturnal feeding activity in the vicinity of the logger.

The 800 Hz chorus also displayed seasonal variation, with its highest intensity occurring between October and November each year.

The overlaid seasonal cycles from all of the Maret Islands loggers are depicted in Figure 10-30 using seasonal bounds of 1 July to 30 June to overlay different years. The period of peak chorus activity across two seasons was sampled for the 2006–2007 and 2007–2008 summers, which are shown overlaid in the figure. From this analysis there appeared to be a drop in chorus activity over the beginning of the 2007–2008 summer (September 2007 to December 2007).

Terapontid fish chorus

Terapontid fish choruses have previously been recorded from inshore waters from the Kimberley region of Western Australia across northern Australia and south along the east Australian coast to Fraser Island (McCauley 2001). In northern Queensland and in the Gulf of Carpentaria this chorus has been specifically attributed to the largescale grunter *Terapon theraps,* although it is possible that closely related species may produce the chorus at other locations.

The chorus timing was difficult to discern as the energy from the much more intense nocturnal planktivorous fish chorus at around 800 Hz often spilled into the 1200 Hz ⅓ octave; this had the effect of making the technique of following the ⅓ octave level over the course of an evening problematical. Figure 10-31 depicts the 1200 Hz ⅓ octave over the full recording period, where the terapontid chorus is evident 5–10 hours after sunset between November and February each year.

[9] For this analysis, the chorus was actually centred at 793.7 Hz and had a bandwidth of 707–891 Hz. For convenience, however, the chorus has been referred to in this report as being 800 Hz.

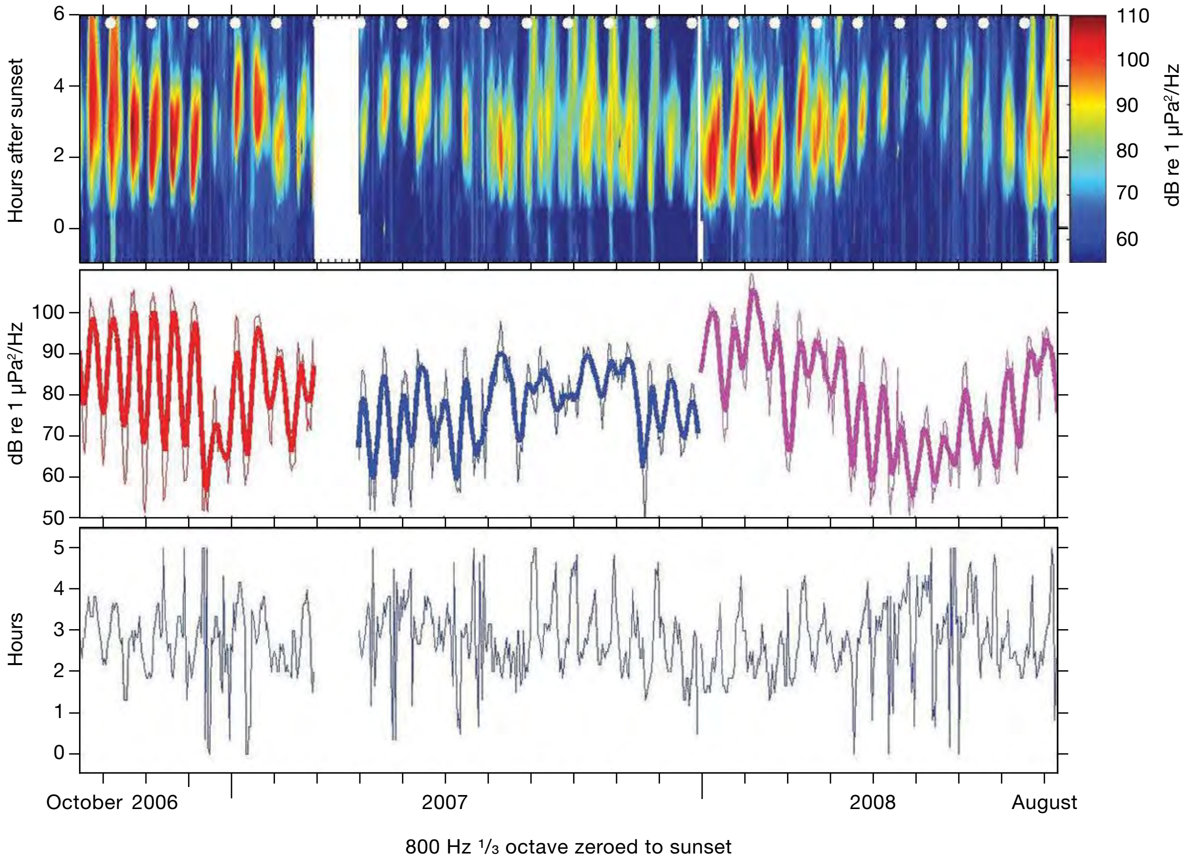

Figure 10-29: Depiction of the 800 Hz fish chorus recorded by the Maret Islands noise loggers. The top panel depicts the intensity of the 800 Hz ⅓ octave each evening over the Maret Islands sea noise data sets, where 0 hours (y-axis) is the time of local sunset. The middle panel represents the integrated 800 Hz intensity over 1 to 4 hours after sunset each evening, with the light bars representing the chorus trend and the heavy curves a 3-day running average. The red line represents logger 2722, the blue line represents logger 2756, and the magenta line represents logger 2797. The bottom panel represents the time of maximum energy in the 800 Hz ⅓ octave each evening, with reference to the time of local sunset. The open circles at the top of the top panel represent each month's full-moon phase

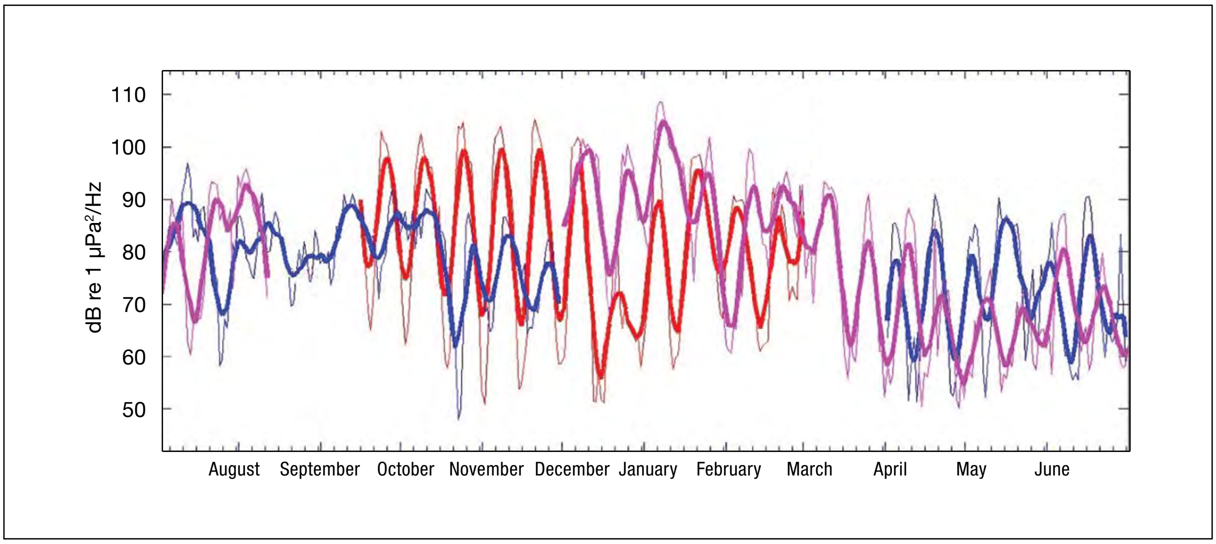

Figure 10-30: Seasonal changes in the fish chorus level recorded at the Maret Islands site. The 800 Hz ⅓ octave band was averaged over 2 to 4 hours after sunset each evening. The thin bars indicate the daily maximum intensities, and the heavy bars indicate the 3-day running averages. The red line represents logger 2722, the blue line represents logger 2756, and the magenta line represents logger 2797. Months are displayed along the x-axis, with 5-day increments

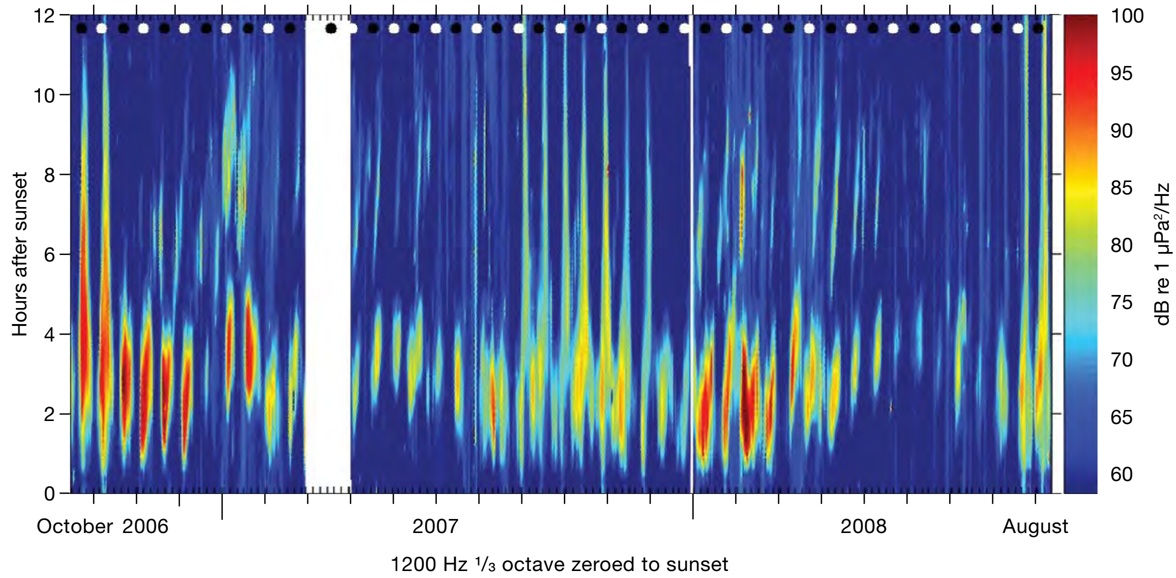

Figure 10-31: Depiction of the sound energy intensity in the 1200 Hz ⅓ octave each evening across the full Maret Islands recording period. The terapontid chorus occurred between 5 and 10 hours after sunset from November to February each year. Note that the energy between 0 (sunset) and the following 5 hours each evening was from the 800 Hz chorus

DISCUSSION

A broad range of biological marine noise sources was detected at the Browse Basin and Maret Islands sites throughout the course of the study (Table 10-2). Both locations are believed to be biologically rich, having a wide diversity of vocalising animals, including fish choruses and visiting great whales. However, more diverse and louder fish choruses were recorded at the shallower Maret Islands site than at the Browse Basin site.

Several of the biological sources present in the area have been discussed and their contribution to ambient noise across selected frequency bands highlighted. The presence of whales may greatly elevate background noise levels, while fish choruses were found to be predictable in raising daily ambient noise levels for several hours at a time across selected sections of the frequency spectra. At the Maret Islands site, daily evening fish choruses were shown to raise ambient levels by almost 60 dB at 1 kHz for upwards of an hour.

Some of the noise sources detected at the Browse Basin were obscured by interference from what has been deduced to be vessel noise associated with petroleum exploration activities in the Browse Basin. These signals dominated the Browse Basin recordings over most of the two years of deployment.

At the Browse Basin site, at least five different great whale call types were catalogued; these included signals from pygmy blue, humpback and dwarf minke whales as well as signals that were possibly attributable to Antarctic minke and Bryde's whales, together with at least one other unknown source. At the Maret Islands site only two great whale signal types were identified: these were for humpback whales and (presumed) Bryde's whales.

The pygmy blue whale calls were recorded only by the Browse Basin loggers and occurred only in small numbers; this meant that seasonality could not be ascertained. The humpback whales were recorded regularly at both sites between July and September each year. The Antarctic and dwarf minke whales were recorded at both sites in September each year. The unknown signal that was attributed to Bryde's whales was recorded at both sites and was persistent throughout the study period.

Fish choruses were common at both sites and this, based on the diversity, regularity and intensity of the signals, suggests that the offshore site is at least reasonably productive while the inshore site is highly productive. The fish choruses displayed daily, lunar, and possibly seasonal trends.

The two dominant fish choruses heard at the Browse Basin and Maret Islands sites were associated with different complements of nocturnally active, planktivorous foraging fishes. At the Browse Basin site, a chorus believed to be associated with foraging fish of the lanternfish family Myctophidae was recorded from the deep scattering layer, while at the Maret Islands site, fishes of the families Priacanthidae (bigeyes), Holocentridae (squirrelfishes) and Apogonidae (cardinalfishes) were recorded.

The 2 kHz ⅓ octave at the Browse Basin site and the 800 Hz ⅓ octave at the Maret Islands site were used to define the fish-chorus activity of the different groups. At the Browse Basin site the chorus was intense in late 2006, decreased in early 2007 and remained low until late 2007, then returned at low to modest levels to carry into 2008. At the Maret Islands site the chorus remained year-round but showed summer peaks. The chorus activity for the two sites has been plotted on the same time-scale in Figure 10-32. The period during which the 2 kHz chorus disappeared from the Browse Basin site corresponded with vessel activity in the area, suggesting that the vessels may have played some part in the displacement of the fish responsible for the chorus. But, on examination of the trends for the 800 Hz chorus at the Maret site, which did not disappear like the Browse Basin chorus but did show reduced chorus activity over the same time frame (i.e. September 2007 to January 2008), vessel noise was not detected by the Maret Islands loggers. Therefore it is possible that the drop in chorus activity at the Browse Basin site was not related to vessel noise, but to some other factor such as a large-scale environmental change.

Assuming that the trend in each chorus reflects the feeding activity of the different fish groups and thus the secondary productivity of the area, both sites displayed a similar drop in productivity during this period. While this phenomenon has not been further analysed, it is probable that the fish responsible for the chorus at the Browse Basin site follow the plankton plumes over large extents and were displaced because of a drop in plankton density in the vicinity of the site.

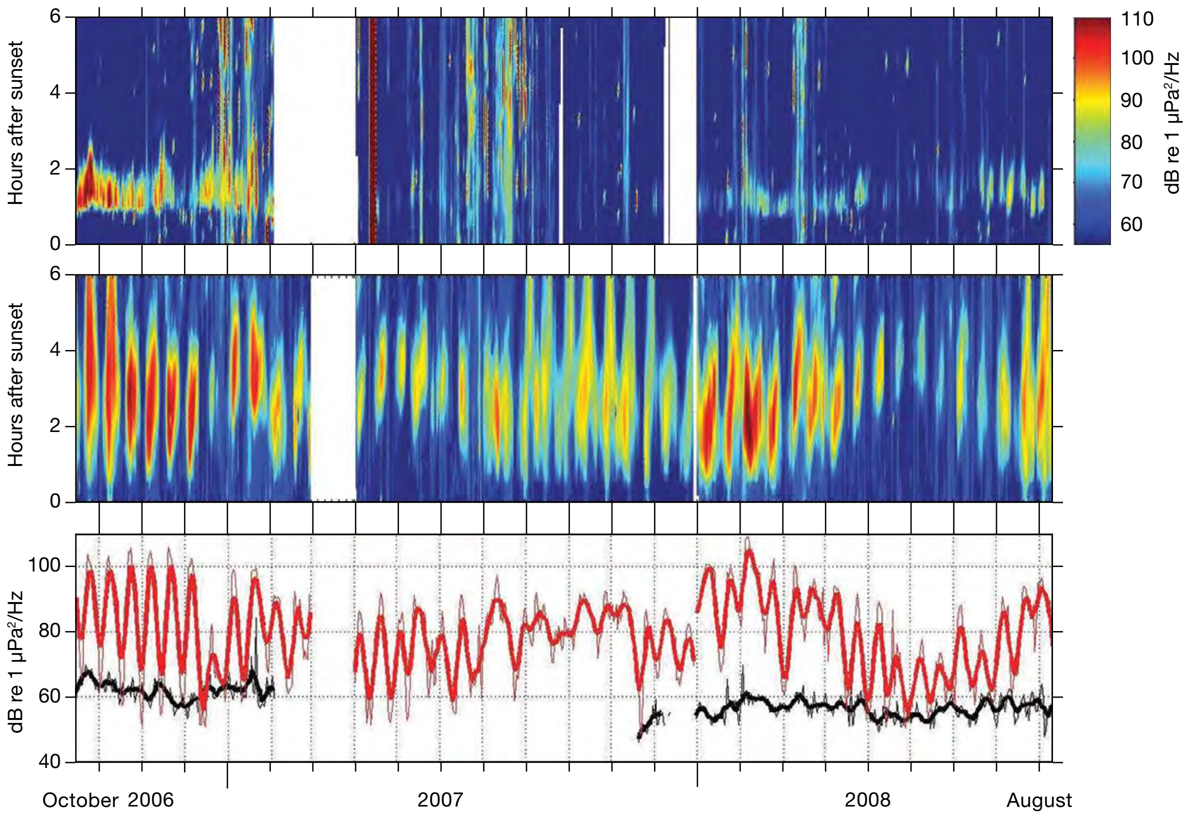

Figure 10-32: The top panel represents the daily chorus activity after sunset at the Browse Basin site within the 2 kHz ⅓ octave band. The middle panel represents the daily chorus activity after sunset at the Maret Islands within the 800 Hz ⅓ octave band. The bottom panel represents the time-integrated curves of chorus levels for the Browse Basin and Maret Islands sites. The black curve represents the Browse Basin data integrated over 0.5 hours to 2 hours after sunset. The red curve represents the Maret Islands data integrated over 1.5 hours to 4 hours after sunset. The period during which the Browse Basin chorus was not heard has been excluded

The seasonal trends of great whales recorded by the noise loggers tie in well with larger-scale regional trends deduced by collating similar data from along the Western Australian coast. This analysis has been carried out to some degree using these data but has not been presented because of the proprietary nature of many of the studies and the complexities surrounding the obtaining of the necessary permissions.

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