



Natural values of Lord Howe Island Marine Park



Published by: NSW Marine Parks Authority, c/o PO Box 1967, Hurstville, NSW 1481.
Phone: 1300 361 967. Fax: (02) 9585 6544. Website: www.mpa.nsw.gov.au

Recommended citation: Marine Parks Authority 2010, *Natural values of Lord Howe Island Marine Park*

Available from: Lord Howe Island Marine Park or www.mpa.nsw.gov.au
Phone: (02) 6563 2359
Email: lord.howe@mpa.nsw.gov.au

As research into ecosystems, habitats and species in the marine park is ongoing, this document will be updated to incorporate new, relevant information. Future versions of this document will be clearly identified and made available to the public on CD.

© Copyright State of New South Wales and Marine Parks Authority 2010.

The NSW Marine Parks Authority is pleased to allow this material to be reproduced in whole or in part, provided the meaning is unchanged and its source, publisher and authorship are acknowledged.

Scientific and common names are used in this report to identify species. Where readers are likely to be more familiar with the common name of a species, only the common name is provided. Where the scientific name is more informative, or there is no common name, only the scientific name is provided. Where a combination of common names and scientific names will add value to the report, both are provided.

Cover photos top to bottom and left to right: Three-striped butterfly fish – G. Kelly, Lord Howe Island Marine Park – M. Legge-Wilkinson, Hawksbill turtle – J. Gilligan, McCullochs anemonefish – J. Gilligan. Photo on reverse of contents page: Erscotts Reef – S. Gudge.

Acknowledgements

This document was prepared by Aquenal Pty Ltd and the NSW Marine Parks Authority. The habitat maps were developed from data generated by Geoscience Australia, University of Wollongong and the Department of Environment, Climate Change and Water NSW. Bathymetric data was provided by Geoscience Australia and University of Wollongong.

DECCW 2010/207

ISBN 978 1 74232 595 8

April 2010

Printed on environmentally sustainable stock

Contents

Glossary

1 Introduction	1
1.1 About the marine park	1
1.2 Plants and animals	1
1.3 Purpose of this document	4
2 Physical environment	5
2.1 Climate	5
2.2 Ocean currents	5
2.3 Broad-scale bathymetry	7
2.4 Geology and geomorphology	8
3 Ecosystems and habitats	11
4 Ocean ecosystems	13
4.1 Subtidal reef habitat	13
4.1.1 Lagoon reefs	14
4.1.2 Open coastal fringing reefs (outside lagoons and inner shelf, 0–30 metres deep)	16
4.1.3 Mid–outer shelf reefs (30–100 metres deep)	20
4.1.4 Seamount slope (more than 100 metres deep)	22
4.2 Subtidal soft-sediment habitat	23
4.3 Intertidal reef habitat	25
4.4 Ocean and lagoon beaches	28
4.5 Seagrasses	30
5 Pelagic ecosystems	32
6 Estuarine ecosystems	34
7 Other marine species	36
7.1 Sharks and rays	36
7.2 Marine mammals	37
7.3 Marine reptiles	38
7.4 Birds	39
7.5 Threatened, protected, rare and endemic marine species	40
8 Further reading	43



Glossary

alluvium: sediment deposited by flowing water

ascidian: sea-squirt

amphipod: small crustacean with a compressed body and no protective shell-like covering over the upper body

annelid: segmented worm

assemblage: a group of species occupying a particular habitat or area

basalt: a hard, fine-grained, dark volcanic rock

bathymetry: depths of the seabed

bathypelagic: species living in open water at depths greater than 1000 metres

benthic: living on the seabed

biogeography: study of the geographic distribution of organisms

bioregion: relatively large area, often about 200 kilometres in extent, which is characterised by seascape-scale natural features

bivalve: mollusc with two shells, such as an oyster, mussel or clam

brachiopod: marine animal that has hard valves (shells) on its upper and lower surfaces. These valves are hinged at the rear end, while the front end can be opened for feeding or closed for protection

broadcast spawning: form of reproduction involving the release of sperm and eggs into the water column, where fertilisation takes place

brooding: form of reproduction where fertilisation of sperm and eggs, and development of the fertilised egg, takes place inside an organism

bryozoan: small aquatic animals that are usually grouped together in a mat or coral-like colony, such as sea mats and lace coral

calcarenite: rock formed through water passing through a mixture of calcareous matter and sand, causing them to stick together

calcareous: made up mostly of calcium carbonate

colluvium: a deposit of rock debris accumulated through the action of gravity at the base of a cliff or slope

consolidated habitat: seabed habitat consisting of solid material stuck together, most often rocky reef

coralline algae: algae with a coral-like, calcareous structure

crinoid: echinoderms such as sea lillies and feather stars that have a cup-shaped body and feathery radiating arms, and are attached to the seabed by a stalk or claw-like structure

decapod: crustacean such as a shrimp or crab with ten legs, each one joined to the central body

demersal: describes organisms that live on or feed near the seabed

diadromous: migrating between freshwater and marine environments

ecosystem: a dynamic combination of plants, animals and microorganic communities and their environment that interact as a functional unit

echinoderm: marine invertebrate, such as a starfish or sea urchin, with an internal calcareous skeleton, and often spines

elasmobranch: fish with a cartilaginous skeleton (skeleton made up entirely of cartilage), such as a shark, ray and skate

endemic: restricted to a particular geographic location

epibenthic: living on the surface of the seabed

foliose algae: leafy algae with fronds and a holdfast attached to the seabed

foraminifera: marine microorganisms with calcareous skeletons, often an important part of the fossil record

gastropod: a class of mollusc, including snails, that generally has a single shell and a muscular foot

gorgonian: coral-like seafan with a flexible, often branching, skeleton

habitat: a particular living space or environment in which an animal or plant lives

herbivorous: feeding on plants

holothurian: sea cucumber

hydroid: colonial, plant-like animal closely related to a jellyfish, with stinging cells

infauna: fauna living in the sediment

isopod: type of small crustacean with a flattened body and seven pairs of legs, such as sea lice

littorinid snails: species of mollusc characterised by thick-walled, turban-shaped shells, that mostly live in the high intertidal zone

meiofauna: very small animals (from 63 microns to 1 millimetre long) that are associated with the seabed, and often live in sand

mesopelagic species: species living in the open sea at depths of between 180 and 900 metres

octocorals: sedentary colonial animals with polyps and eight tentacles, including gorgonians

oligochaete worm: segmented worm with bristles

omnivorous: feeding on both plants and animals

pelagic: associated with the surface or middle depths of the open sea

plankton: mostly microscopic animals or plants that drift in the sea

planktivorous: feeding on microscopic animals and plants that drift in the sea

polychaete: segmented marine worms with bristles along the body

rheophilic: describes an area characterised by, or species found in, fast moving water

seamount: an underwater mountain rising from the ocean floor

scleractinian corals: hard or stony corals, such as brain coral

serpulids: worms commonly known as 'plume worms' due to a conspicuous frilly plume emerging from the opening of the tube

sessile: attached by the base, generally to the seabed

sipunculid: unsegmented marine worm

synchronous spawning: where species time reproduction to a particular cue and spawn at the same time

talus: coarse rock fragments, mixed with soil, at the foot of a cliff or natural slope

teleost: a group that includes most bony fishes

unconsolidated habitat: seabed habitat consisting primarily of soft sediments such as sand or mud

urchin barren: area where populations of sea urchins have overgrazed kelp beds

1 Introduction

1.1 About the marine park

Lord Howe Island Marine Park was declared on 26 February 1999 under the NSW *Marine Parks Act 1997*. The marine park encompasses Lord Howe Island and the Admiralty Islands (31°30'S, 159°00'E), as well as Balls Pyramid (31°46'S, 159°15'E) and South East Rock to the south-east, and extends three nautical miles out to sea from the mean high watermark (Figure 1). It covers an area of approximately 46,000 hectares of predominantly marine habitat, with additional small estuarine areas.

A zoning plan and an operational plan were produced for the marine park in late 2004. The zoning plan shows the location of each zone and explains which activities are permitted in each zone. The operational plan outlines ways in which the NSW Marine Parks Authority will sustainably manage Lord Howe Island Marine Park to be consistent with the objectives of the *Marine Parks Act 1997*.

The park caters for many different recreational and commercial activities including research, beach and reef walking, swimming, snorkelling and scuba diving, surfing, underwater photography, windsurfing, sea-kayaking, fishing, sightseeing cruises and eco tours, and other water sports and beach activities. Revenue generated from tourism activities is of critical economic importance to the small permanent local community of approximately 350 people on Lord Howe Island.

Immediately outside the Lord Howe Island Marine Park (State Waters) is the Lord Howe Island Marine Park (Commonwealth Waters), which falls within the East Marine Region for the purposes of commonwealth planning (Figure 1). The Commonwealth Park was proclaimed on 21 June 2000 under the *National Parks and Wildlife Conservation Act 1974* and is now managed under the commonwealth *Environment Protection and Biodiversity Conservation Act 1999*. The Commonwealth Park includes waters between 3 and 12 nautical miles from and around Lord Howe Island and Balls Pyramid, and covers an area of approximately 300,000 hectares. Its outer perimeter roughly corresponds to the 1,800-metre depth contour that follows the base of the seamounts that are beneath Lord Howe Island and Balls Pyramid (Environment Australia 2002).

A management plan for the Commonwealth Park came into effect in 2002. For the purposes of this document, 'the marine park' refers to the combined Lord Howe Island Marine Park (State Waters) and Lord Howe Island Marine Park (Commonwealth Waters). The marine park falls within the Lord Howe Province classified in the Integrated Marine and Coastal Regionalisation of Australia.

The combined area of the state and Commonwealth Lord Howe Island Marine Park lies within and encompasses most of the marine environs of the Lord Howe Island World Heritage Area, which was included in the UNESCO World Heritage List on 14 December 1982. It forms the largest marine protected area off the NSW coast.

1.2 Plants and animals

As a result of the alternating influences of warm and cool currents, the marine environment contains an unusual mixture of tropical, subtropical and temperate marine fauna and flora, as well as a high level of endemism. Tropical species tend to dominate in terms of total species counts, although temperate animals and plants dominate in terms of abundance and biomass (Allender and Kraft 1983, Aquenal 2008a, Hoggett and Rowe 1988). Lord Howe Island is the world's southernmost locality with a true coral reef community (Allen et al 1976), and also has the only fringing

coral reef lagoon in NSW (Lord Howe Island Board 1985). The island provides a rare example of the transition between coral and algal reefs and includes many species at their distributional limits, reflecting the extreme latitude of the Lord Howe Island coral reef ecosystems (Allen et al 1976, Harriott et al 1995, Harrison et al 1995, Millar and Kraft 1994a, Veron and Done 1979). Many tropical species in the marine park are common and widespread. The biogeographic significance of the area arises from the unique combination of tropical species at their southernmost limits of distribution and subtropical species which are rare or absent from tropical reefs (Harriott et al 1993).

The marine park contains a wide range of habitats including the fringing coral reef and associated sheltered lagoon (Figure 2), open coast and nearshore rocky reefs, sandy beaches, mid-shelf reefs, intertidal reefs, seagrass beds, mangroves, unconsolidated shelf habitats, deep seamount slope reefs and pelagic waters, all of which support distinct groups of plants and animals. As the park extends from the high tide mark to 1,800 metres deep and 22 kilometres offshore, there is considerable diversity in habitats and associated flora and fauna. This diversity is due to variations in oceanographic influences, depth, substrate and wave exposure, and the presence of offshore islands.

Figure 1.
Extent and zoning arrangement of Lord Howe Island Marine Park.

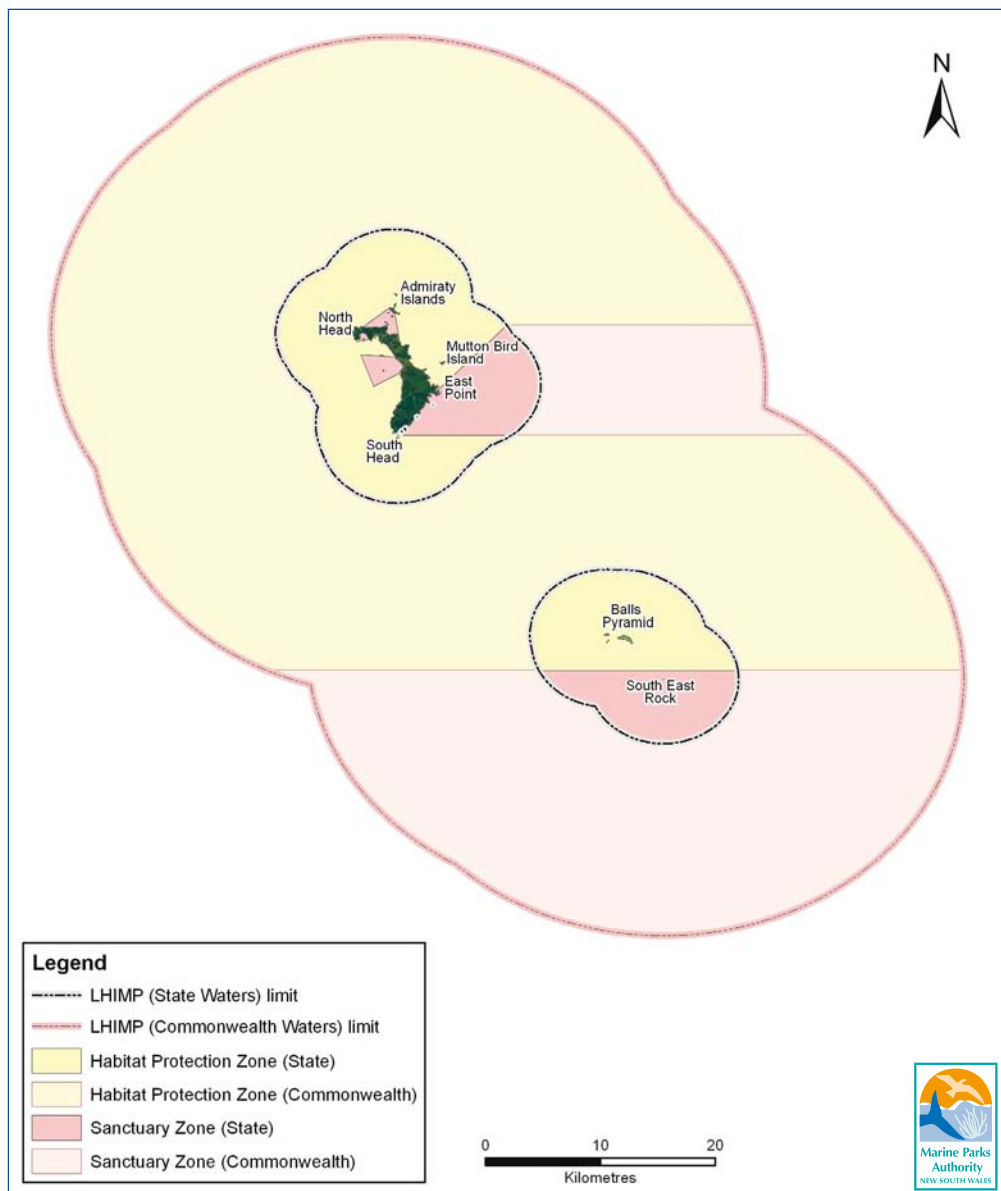




Figure 2.
View from Mt Eliza, Lord
Howe Island Marine Park.
Photo: M. Legge-Wilkinson

Reef habitats are particularly diverse and range from true coral reefs made of limestone in sheltered lagoonal habitats to complex rocky reefs in wave exposed habitats and mid and outer shelf and slope environments. A large fossil limestone 'relic' reef covered in Holocene coralline algae occurs on the Lord Howe Island shelf (Kennedy et al 2002).

Corals occur primarily in shallow protected and fringing reef environments, with 86 species of hard coral recorded (Bullard 2003, de Vantier and Deacon 1990, Harriott and Banks 2002, Harriott et al 1995, Harrison et al 1995, Veron and Done 1979). Coral species diversity is low compared with the Great Barrier Reef, but remarkably high considering the latitude of the park, the small size of the reef and the reef's isolation from other major coral communities (Harriott et al 1993). In addition, levels of coral cover in some areas are as high as those reported for the tropics (Bullard 2003, Harriott et al 1995, Harrison et al 1995). A few coral species tend to dominate, while a larger number of uncommon species have unstable populations and are likely to have resulted from sporadic chance recruitment (Harriott et al 1993, 1995; Harrison et al 1995).

The high abundance and diversity of macroalgal species is one striking feature of the marine habitat in the park. The close proximity of temperate macroalgal and tropical coral community species is considered to be unique globally (Aquenal 2008a). To date, 318 species of marine algae have been recorded at Lord Howe Island (Kraft 2000, Kraft and Abbott 2003, Millar 2004, Millar and Freshwater 2005, Millar and Kraft 1993, 1994a, 1994b), reflecting higher levels of diversity than those recorded for scleractinian (hard) or soft corals. There are 174 species of red algae, 68 species of brown algae and 76 species of green algae, which include at least 47 (15%) endemic species. The brown algal order Dictyotales achieves highest cover and possibly biomass from low intertidal habitats through to depths of at least 35 metres (Millar and Kraft 1994b).

This and several green algal genera have diversities as high as those recorded in the whole of southern Australia (Allender and Kraft 1983, Kraft 2000). Lord Howe Island is recognised as one of the richest localities for green macroalgae in Australia for its size, and is also important because it sits at the extreme latitudinal limit of many green algal species and genera (Millar and Kraft 1994a).

Benthic grazers such as sea urchins are abundant in shallow reef habitats (Aquenal 2008a, 2008b), while areas with high currents and deeper sections of the shelf are dominated by sessile filter feeding species including gorgonians and sea whips (octocorals) as well as sponges, basket stars, feather stars, hydroids, and colonial ascidians (Marine Parks Authority 2004, Speare et al 2004).

Mobile invertebrates are highly diverse, with more than 1,500 species of molluscs (snails and shellfish) likely to occur in the park (Parker 1993), in addition to at least 110 species of echinoderms (Hoggett and Rowe 1988), and 70 species of crustaceans (Coleman 2002). Levels of endemism are not well understood for most invertebrate groups, although estimates of 8% (Hoggett and Rowe 1988) and approximately 5% (Ponder et al 2000) have been indicated for echinoderms and molluscs, respectively. A lack of systematic surveys of many invertebrate groups, such as the crustaceans, means that the extent of their diversity is likely to be greatly underestimated.

More than 500 species of fishes have been recorded, with approximately 440 documented in coastal inshore habitats (Allen and Paxton 1974, Allen et al 1976, Aquenal 2008a, 2008b; Francis 1991, 1993; Francis and Randall 1993, Speare et al 2004). Of the inshore species, approximately 4% are endemic to the Lord Howe Island/Norfolk Island region, while new endemic and non-endemic fish continue to be described (e.g. Aquenal 2008a, 2008b; Hensley and Randall 1993, Kuitert 2003).

High conservation value species include endemic taxa as well as protected and threatened species, while many other species are valued by fishers. Mammals, reptiles and birds also comprise a distinct part of the fauna, including permanent residents, seasonal visitors and migrants through the marine park. Lord Howe Island is well-known as a major seabird breeding site, with 14 species nesting in the region (Hutton 1991).

1.3 Purpose of this document

The purpose of this document is to consolidate information on the physical and ecological values of Lord Howe Island Marine Park, particularly new information acquired since the zoning plan was introduced in 2004. This publication is one of several documents that will be considered by the public during the review of the zoning plan. It provides information on the natural values of the marine park, so the public can consider these and contribute to discussions about current zoning arrangements. It complements a summary of the social, cultural and economic values of the marine park that has also been developed for reference during the review of zoning.

2 Physical environment

2.1 Climate

Lord Howe Island Marine Park is located approximately 600 kilometres east of the NSW north coast, and occurs on the western margin of the Lord Howe Rise. The climate is humid and subtropical, with average air temperatures ranging from 18.9°C in July–August to 25.6°C in February (Bureau of Meteorology 2009). The diurnal and seasonal temperature ranges are both approximately 7°C. Average rainfall for the area is 125 millimetres per month, with most rainfall occurring between March and July, while average annual rainfall is 1,505 millimetres, the average number of rainy days for the year is 150 (Bureau of Meteorology 2009) and humidity is moderate to high at approximately 70–77% (Environment Australia and Marine Parks Authority 2001).

Winds are predominantly easterly and north-easterly in the summer and south-westerly in the winter. Average wind speed ranges from 9–10 knots in January and March through to 13 knots in August (United Nations Environment Program 2008). Gales with wind speeds of more than 34 knots can be expected on an average of three days a month during winter. Other strong winds occur, on average, between four and seven days a month throughout the year (Lord Howe Island Board 1985).

The Lord Howe Island group and its surrounding waters are also subject to major storms and occasional cyclonic activity (Environment Australia and Marine Parks Authority 2001). Storms are frequent and can occur throughout the year (Woodroffe et al 2005). They can approach from the north during summer and autumn and from the west during autumn and spring.

2.2 Ocean currents

Lord Howe Island Marine Park is on a boundary between tropical (Coral Sea) and temperate (Tasman Sea) water masses, commonly referred to as the Tasman Front. This front forms where the eastward flow of the warm East Australian Current meets the waters of the southern temperate Tasman Current (Martinez 1994, Stanton 1981).

The East Australian Current dominates ocean circulation around the Lord Howe Island group (Boland and Church 1981, Kennedy et al 2002). This current first flows from the north along the eastern seaboard of the Australian continent and then swings offshore in pulses from about September to December before either returning north or dissipating after shedding warm core eddies (Nilsson and Cresswell 1980). The Tasman Front undulates in a north–south direction, with its latitudinal position varying from 30°S in winter to 34°S in summer (Stanton 1981). This contributes to alternating cooler and warmer waters in the marine park (Boland and Church 1981, Nilsson and Cresswell 1980), and explains why coral reefs occur further south on Lord Howe Island than on the Australian mainland (Martinez 1994, Woodroffe et al 2005).

The water circulation patterns associated with the Tasman Front can be explained in accordance with the major wind systems. Two important parallel zones of convergence occur:

- the northern tropical convergence zone lies between the eastward moving East Australian Current and the westward moving Trade Wind Drift
- the southern subtropical convergence lies between the southward moving subtropical water mass and the north-eastward moving West Wind Drift.

Lord Howe Island is primarily under the influence of the tropical convergence during summer but is nearer the much colder waters associated with the subtropical convergence during winter (Veron and Done 1979). The Lord Howe Island group and the shelves that surround it therefore represent a subtropical transition in the open ocean (Kennedy et al 2002).

Due to the alternating oceanographic influences of warm and cool currents, water temperatures at Lord Howe Island generally vary from 17°C in winter to 25°C in late summer (Hutton 1986), although temperatures of up to 27.5°C have been recorded in the lagoon (Allen et al 1976). On the basis of monthly maps of surface isotherms, the waters around Lord Howe Island vary from a summer average of 23°C to a winter average of 18–19°C (Allen et al 1976, Veron and Done 1979).

Currents and water circulation patterns vary considerably due to the range of depths, geomorphological structures and wave environments in the marine park. The coral fringing reef on the west side of Lord Howe Island has relatively sheltered conditions associated with the shallow lagoon (Dickson and Woodroffe 2005), with water exchange and hence current flow concentrated at four deeper water passages which are up to 6 metres deep (Allen et al 1976). Currents of 2.1 metres per second have been recorded in the centre of the lagoon, but would be significantly higher in areas where flow channels are constricted (Kennedy 2003).

A study of circulation in the lagoon is under way. This study will provide more detailed information on wave-driven and wind-driven circulation, including how both types of circulation affect larval dispersal and recruitment of marine organisms (Black et al 2008). The lagoon provides a protected environment where many sheltered-water species have established populations (Marine Parks Authority 2004).

In contrast to the lagoon, the vertical cliffs on the southern side of Lord Howe Island and the entire coastline of Balls Pyramid consist of open exposed habitats with strong wave action and high current velocities. Ocean swells approach Lord Howe Island from all directions following the predominant wind direction, but easterly swells dominate in summer and southerly swells dominate in winter (Kennedy et al 2002, Woodroffe et al 2005). The southern part of the island is most regularly exposed to strong wave action.

The deep water seamount slopes bordering the Lord Howe Island and Balls Pyramid shelves are exposed to highly variable currents and circulation patterns. The seamounts modify the large-scale dynamics of oceanic currents and the stratification of water column density. Geographic location, water depth and the intensity of the flow field near the seamount govern the interactions between seamounts and oceanic currents. The intensity of flows decreases with increasing water depth and distance from continental margins (Smith et al 1989). Seamounts generally experience enhanced currents which are temporally and spatially variable as a combined result of eddies, tides, and trapped waves (Smith et al 1989).

The perturbations created by seamounts in the flow field are believed to directly influence both pelagic and benthic communities. Enhanced mixing in the benthic boundary layer and associated eddies result in large numbers of small planktonic and pelagic organisms being swept into seamount habitats. These organisms are preyed on by corals and other suspension feeders or fish living on or near the seabed (Koslow and Gowlett-Holmes 1998, Koslow et al 1998). Water circulation patterns are therefore believed to enhance productivity, and seamounts are often regarded as hot spots of biodiversity and endemism.

The tidal range at Lord Howe Island is 1.5 metres at spring tides and 0.8 metres at neap tides, while mean significant wave heights of 2.3–2.5 metres have been documented (Kennedy et al 2002). Strong and variable currents are experienced between Lord Howe Island and the east Australian coast due to variations in the East Australian Current and its eddies. These currents have resulted in greater variance in mean sea level estimates than in nearby areas, such as at Norfolk Island (Hamon 1979).

2.3 Broad-scale bathymetry

The bathymetry of the nearshore environment at Lord Howe Island has previously been mapped by Veron and Done (1979), while Hydrographic Charts AUS213 and AUS610 include Lord Howe Island and its approaches respectively. The lagoon, which is approximately 6 kilometres by 1.5 kilometres at its widest point, has an average depth of just 2–3 metres, although its deeper holes can be up to 10 metres deep. The lagoon fringing reef is pierced by four principal passages: Erscotts Passage, South Passage and Erscotts Blind Passage to the south; and North Passage, the latter constituting the main entrance and being 4–6 metres deep (Allen et al 1976). On the seaward edge of the lagoon, the shoreline drops off steeply to depths of 15–20 metres and then gradually slopes to deeper water (Allen et al 1976). Around other parts of the island, the shorelines are steep, with rocky cliffs extending to the water's edge adjacent to water depths of 10–20 metres. Recent high resolution bathymetric mapping of the Lord Howe Island shelf has significantly increased understanding of the seabed structure (Figure 3).

Lord Howe Island lies near the centre of a broad rectangular shelf with a width from west to east of 24 kilometres, and a length from north to south of 36 kilometres. Its average depth is about 40–50 metres (Kennedy et al 2002, Woodroffe et al 2005). Balls Pyramid sits in the middle of a smaller shelf with a width from west to east of 15 kilometres and a length from north to south of 22 kilometres. Its average depth is 30–35 metres (McDougall et al 1981). The Lord Howe Island and Balls Pyramid shelves are separated by a trough that averages 600 metres deep. Both shelves are relatively flat with slopes of less than 1°, contrasting with the steep seamount slopes. They nevertheless also include more rugged sections with slopes of 15–20° near the outer shelf. A distinct shelf break occurs at a depth of 70–100 metres (Kennedy et al 2002), while a steep drop-off falls away quickly at 200 metres to depths of more than 2,000 metres (Environment Australian and Marine Parks Authority 2001).

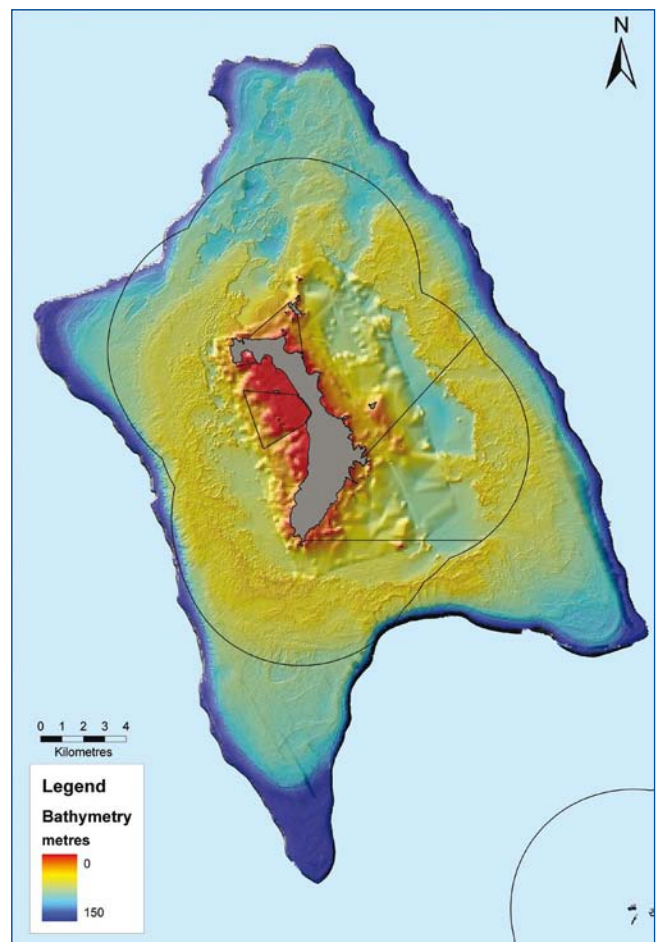


Figure 3. Bathymetric image of the seabed on the Lord Howe Island shelf. Source: University of Wollongong and Geoscience Australia.

2.4 Geology and geomorphology

Lord Howe Island is a crescent-shaped island approximately 11 kilometres long and up to 2.5 kilometres wide, and with 24 kilometres of coastline. Several small rocky islets occur around its periphery, most notably the Admiralty Group of seven islets, which are located 1.5 kilometres off the north-east tip of Lord Howe Island (Figure 4). Mutton Bird Island and Gower Island lie within 2 kilometres of the main island, while Blackburn (or Rabbit) Island is located in the western lagoon. Balls Pyramid is a monolithic spire located 25 kilometres south-east of the main island (Figure 5). Balls Pyramid has a few satellite islets, with Observatory Rock and Wheatsheaf Islet both located within 1 kilometre of the pyramid, while Southeast Rock is a pinnacle located about 3.5 kilometres to the south-east.

Lord Howe Island, Balls Pyramid and the associated offshore islands are of volcanic origin and occur at the southern end of a chain of nine seamounts extending for 1,000 km along the Lord Howe Rise (Hayes and Ringis 1973). The seamount system marks the successive movements of the Australian tectonic plate over a hot spot in the upper mantle of the earth's crust (Hayes and Ringis 1973, McDougall et al 1981). Lord Howe Island occurs at the southernmost limit of coral-reef formation, on a transition from tropical to subtropical open-ocean carbonate environments, but is gradually moving into reef-forming seas due to the northward migration of the Australian plate, which is moving 5–6 centimetres a year (McDougall et al 1981, Woodroffe et al 2005).

Lord Howe Island and Balls Pyramid are the eroded remnants of a much larger basaltic shield volcano which erupted from the sea floor intermittently for about 500,000 years in the late Miocene between 6.9 and 6.4 million years ago (McDougall et al 1981). As separate peaks of one major volcano (Woodroffe et al 2006), they now form the terrestrial component of a large volcanic seamount some 65 kilometres long by 24 kilometres wide which rises from a depth of over 2,000 metres. The main structure of the seamount is contained within the 12 nautical mile limit of the marine park (Pichon 1995). Erosion has removed 90% of the volume of the volcano, so the present islands occupy about one-fortieth of its original area (World Heritage Nomination 1981).

Figure 4.
Admiralty Islands, Lord
Howe Island Marine Park.
Photo: M. Legge-Wilkinson



The wide submerged shelves which surround Lord Howe Island and Balls Pyramid are many times the area of the present islands and were probably cut by wave action during the change of sea level associated with the last Pleistocene glaciation around 110,000–10,000 years ago (McDougall et al 1981). Balls Pyramid – the youngest of the islands within the seamount chain – is formed from gently-dipping lava flows and a plug associated with a former volcanic vent (Woodroffe et al 2006), and represents the nearly final stage in the destruction of a volcanic island (World Heritage Nomination 1981).



Figure 5. Balls Pyramid, Lord Howe Island Marine Park. Photo: M. Legge-Wilkinson

Most of Lord Howe Island is composed of basalt and other volcanic rocks, with two spectacular sheer-sided mountains dominating the south of the island (Figure 2). However, the lowland part of the island includes more recent sedimentary deposits of Pleistocene and Holocene age (Brooke et al 2003a, McDougall et al 1981). A white sedimentary rock called calcarenite (formed through the cementing of calcareous algal and coral fragments and sand) is locally important and makes up central and northern parts of the island to below sea level in several places. Dating indicates that calcarenite was deposited in the past 350,000 years during the Pleistocene (Brooke et al 2003a, 2003b). Other sedimentary deposits include a single sand dune, alluvium, talus, colluvium, unconsolidated lagoonal sands and possibly guano (Davey 1986). Balls Pyramid and the offshore islands are all basaltic and surrounded by cliffs.

A fringing coral reef on the western side of Lord Howe Island extends for about six kilometres and is the result of rapid growth and lagoonal infill during the Middle Holocene at least 5,000 years ago (Kennedy and Woodroffe 2000). While the modern reef supports coral communities (Harriott et al 1995, Veron and Done 1979), coring and dating of lagoonal sediments suggest that reef growth has slowed since the Middle Holocene. This may be due to climatic conditions becoming less favourable, but is a more likely consequence of intrinsic changes in depositional environments leading to reduced suitable habitat for coral growth (Kennedy and Woodroffe 2000, Woodroffe et al 2005).

The beach and shallow-water calcarenites indicate a sea level around 2–3 metres above the present level during the last interglacial period (Pleistocene – around 130,000–70,000 years ago). Little direct evidence of the reefs present during this time is preserved, and they may have occurred in locations similar to those of modern reefs and been largely destroyed during emergence when the sea level fell (Woodroffe et al 2005). The fringing coral reef on the western coastline of Lord Howe Island markedly attenuates wave energy and acts as a breakwater preventing storm waves from eroding the low-lying central region of Lord Howe Island (Dickson and Woodroffe 2005). The sheltered lagoon in the lee of the reef contains a number of different habitats, dominated by sand (65% of the lagoonal area), as well as lagoonal corals, gravel sheets, algal flats and patch reefs (Kennedy 2003). Sedimentological studies indicate that sand and gravel are continually being reworked by waves and tides, while sediments are dominated by medium–coarse sands and include smaller portions of coral, foraminifera and molluscs (Kennedy 2003).

In contrast with the lagoonal coastline, the exposed coastline of Balls Pyramid and southern Lord Howe Island has been eroded into precipitous plunging cliffs and cliffs with basal shore platforms (Dickson and Woodroffe 2005). Shore platforms on exposed shores are significantly wider than those in the sheltered lagoon, with wave erosion resulting in localised wave-quarrying of sea caves, arches, blowholes and gulches (Dickson and Woodroffe 2005).

A massive fossil limestone relic reef covered in Holocene coralline algae occurs on the Lord Howe Island shelf (Kennedy et al 2002). It has a discontinuous drowned ridge on the mid-shelf, with a base around 40–50 metres deep, and rises to water depths of around 30 metres. Sampling indicates the upper surface of the fossil reef is composed of a thin covering of Holocene growth that accreted during postglacial increases in sea level. Beneath this material is believed to be an older feature which likely developed in the Late Quaternary (in the past one million years), though the entire history of its formation requires further investigation (Linklater 2009). The relic reef is significantly larger than the Holocene fringing reef on the western shoreline, being 2–3 kilometres wide in places. This indicates that periods of prolific coral growth occurred before and during the Holocene epoch, which is significant due to the position of the island shelf at the latitudinal limits of reef growth. The relic reef lies between 1.5 and 8 kilometres from the shore, on the western, southern and eastern sides of Lord Howe Island. It is generally used to delineate the inner and outer zones of the Lord Howe Island shelf (Kennedy et al 2002).

The Balls Pyramid shelf was believed to be devoid of any similar fossil reef (Kennedy et al 2002, Woodroffe et al 2005, 2006), although recent surveys indicate that there are features similar to those on the Lord Howe Island shelf. Further mapping is needed to confirm the nature of these geological structures (Woodroffe and Brooke 2008).

The deeper seamount habitats offshore from the shelves include highly variable slopes that face in all directions, thus maximizing exposure to ocean currents (Pichon 1995). Surveys have indicated a high degree of seafloor complexity, with downslope flow structures (probably old lava flows or coarse sediment debris flows), canyons and numerous volcanic cones and pinnacles, many 150–300 metres high (Hill et al 2000a). Over 20 ‘parasitic’ cones were also found (cone-shaped accumulations of volcanic material created by eruptions from fractures other than the central vent of a volcano), with a cluster of several cones located in the deep channel between Lord Howe Island and Balls Pyramid. The slopes appear to be mostly rocky volcanic outcrops with thin patches of sediment, while the shallow channel between the two islands contains some very coarse sediment (Hill et al 2000a). The complex substrate in deeper sections of the marine park is indicative of diverse ecosystems (Hill et al 2000b).

The Lord Howe Island group is regarded as having high geological, geomorphological and geodiversity values (Biosis Research 1998). Some of these values are primarily evident in terrestrial environments, but many also extend into the habitats of the marine park. The area contains a diverse range of ongoing geological processes, and provides the only accessible outcrop of a wide range of oceanic volcanic rocks in the Tasman Sea. It is considered an excellent example of the evolution of a volcanic island formed on an oceanic ridge, while also providing a unique demonstration of the reef building process at the latitudinal limits of reef formation. The region additionally contains important palaeontological data within the calcarenite formations, including a fossil site for the large horned turtle (*Meiolania platyceps*), which probably became extinct over 20,000 years ago when sea levels were low (Gaffney 1991).

3 Ecosystems and habitats

Biological diversity can be described and classified on a number of levels, and information about the spatial distribution of biodiversity is mostly very limited. The Integrated Marine and Coastal Regionalisation of Australia (IMCRA v4.0) is a spatial framework for classifying Australia's marine environment into bioregions that are ecologically based and are at a scale useful for regional planning (Commonwealth of Australia 2006). The framework is based on collated data and inferred patterns across a variety of spatial scales, enables ecosystem boundaries to be defined and provides a framework for subsequent finer levels of planning and management. This framework builds on the inshore regionalisation (IMCRA v3.3) which defines bioregions using a range of biological and physical information (ANZECC TFMPA 1998a). This hierarchical classification has been used by all governments in Australia to develop a National Representative System of Marine Protected Areas (ANZECC TFMPA 1998b).

Further classification of estuarine and ocean environments can be applied at the following levels:

- ecosystem – a dynamic combination of plant and animal communities and their environment interacting as a functional unit
- habitat – a specific type of environment inhabited permanently or temporarily by organisms, and based on factors such as substrate type and tidal exposure
- community – a number of species occupying a particular habitat or area
- estimated distributions and abundances of species and populations.

Ocean currents, climate, bathymetry and coastal geomorphology result in the formation of many types of marine ecosystems, which support a variety of habitats, communities and populations of animals and plants. These ecosystems are interconnected as species move between them and currents pass in and out of the marine park, transporting larvae, sediments and nutrients. The ecosystems can be broadly split into oceanic and estuarine ecosystems, which are further divided into smaller units based primarily on the dominant geomorphology, aquatic vegetation, benthic communities or depth.

The most distinct separation of species occurs between consolidated and unconsolidated habitats:

- consolidated habitats consist of rocky or coral reef; their distribution and structure can vary widely, due to differences in patchiness, rock type (e.g. basalt, granite), rock size (e.g. large and small boulders) and complexity (e.g. gutters, walls, pinnacles)
- unconsolidated habitats are made up of soft sediment that consists mostly of sand; their distribution and structure can vary due to the presence or absence of vegetation cover (e.g. seagrass), sediment size and composition, the dominant seagrass species and their spatial structure.

As detailed spatial information on the distribution of many species is limited in the marine park, ecosystems and habitats are used as 'surrogates' for species diversity in the planning process. Surrogates are components shown or assumed to be related to biological diversity that are more easily measured or more capable of being mapped than species diversity itself. The distribution and measures of biodiversity are inferred from the distribution and measures of surrogates.

There is evidence that the use of habitats as surrogates for species diversity is effective, provided they are validated (Ward et al 1999) and all representative habitats are included (Roff et al 2003). However, the effectiveness of habitat classification as a surrogate for biodiversity will depend, to some extent, on how well it represents patterns of biodiversity (Gladstone 2005, Lindsay et al 2008). To improve the likelihood that habitats are represented in appropriate marine park zones, and to facilitate discussion of possible locations based on the inclusion of other planning criteria, seabed habitat maps have been developed from several sources.

Firstly, island boundaries were based on the Australian Maritime Boundaries Information System provided by Geoscience Australia. Shallow inshore reefs were then digitised from aerial photographs. Information on the distribution of subtidal seabed habitats in the marine park has recently been collected using multibeam swath acoustics that provide high resolution bathymetric and backscatter mosaics of the seafloor (Linklater 2009, Woodroffe and Brooke 2008, Brooke et al 2010).

Figure 6.

Ballina angelfish
(*Chaetodontoplus ballinae*)
Photo: J. Gilligan



4 Ocean ecosystems

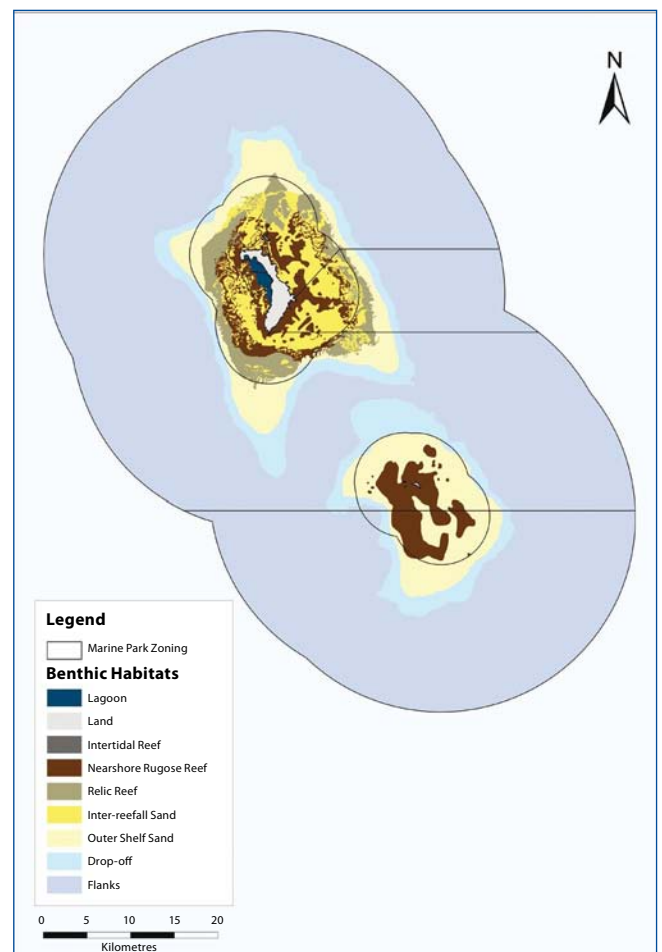
4.1 Subtidal reef habitat

Subtidal reef habitats dominate the coastline of Lord Howe Island, Balls Pyramid and associated smaller islands and islets (Figure 6). Reef habitats also extend into shelf and slope environments of the marine park. The inshore reef systems include true coral reefs (indicated by limestone accumulation) in the protected environments of the lagoon on the western side of Lord Howe Island, and rocky reefs in other parts of the park that include a shallow cover of coral growth but no limestone coral reef build-up (Harriott et al 1995, Veron and Done 1979). There are also large areas of relic reef that extend around much of the island on the mid-shelf. Overall, the reefs are characterised by high levels of biodiversity because the region represents a biogeographic overlap between tropical, subtropical and temperate species (Harriott et al 1993). In addition, the marine park represents one of the few reef systems where macroalgal and coral habitats coexist at close proximity (Harriott et al 1993).

Based on geomorphological studies (e.g. Kennedy and Woodroffe 2000, Kennedy et al 2002, McDougall et al 1981), and surveys of fish and benthic communities (e.g. Aquenal 2008a, 2008b; Bullard 2003, Lindsay 2004, Harriott et al 1993, 1995; Harrison and Carroll 2002, Harrison et al 1995, Speare et al 2004, Veron and Done 1979), reefs in the marine park can be separated into several main groups based on structure, depth and dominant benthic communities (Figures 7, 8). These are:

- lagoon reefs (around or less than 10 metres deep) – reefs located in the lagoon on the western side of Lord Howe Island, including the back slope of the fringing reef, lagoonal hole reefs and other reefs located between the lagoon and the shoreline on the leeward side of the lagoon
- open coastal reefs extending to a depth of 30 metres (the approximate maximum depth of the inner shelf around Lord Howe Island and the approximate average depth of the Balls Pyramid shelf (McDougall et al 1981) – reefs located on other sections of the Lord Howe Island coastline (i.e. outside the lagoon), including the foreslope of the fringing reef, Balls Pyramid, the Admiralty Islands and additional smaller islands and islets
- mid-shelf reefs around 30–50 metres deep on the Lord Howe Island and Balls Pyramid shelves, with the 30-metre demarcation representing the upper depth limit of a ridge interpreted as a relic reef that divides the inner and outer parts of the shelf (Kennedy et al 2002)
- seamount slope – reefs more than 100 metres to 1,800 metres deep (a depth of 100 metres represents the approximate depth of the shelf 'break' and the minimum depth of the seamount slope environment (Heagney et al 2007, Kennedy et al 2002, O'Hara 2008, Speare et al 2004).

Figure 7. Map of known seabed habitats on the Lord Howe Island and Balls Pyramid shelves. Source: Linklater 2009, Brooke et al 2010 and DECCW unpublished data



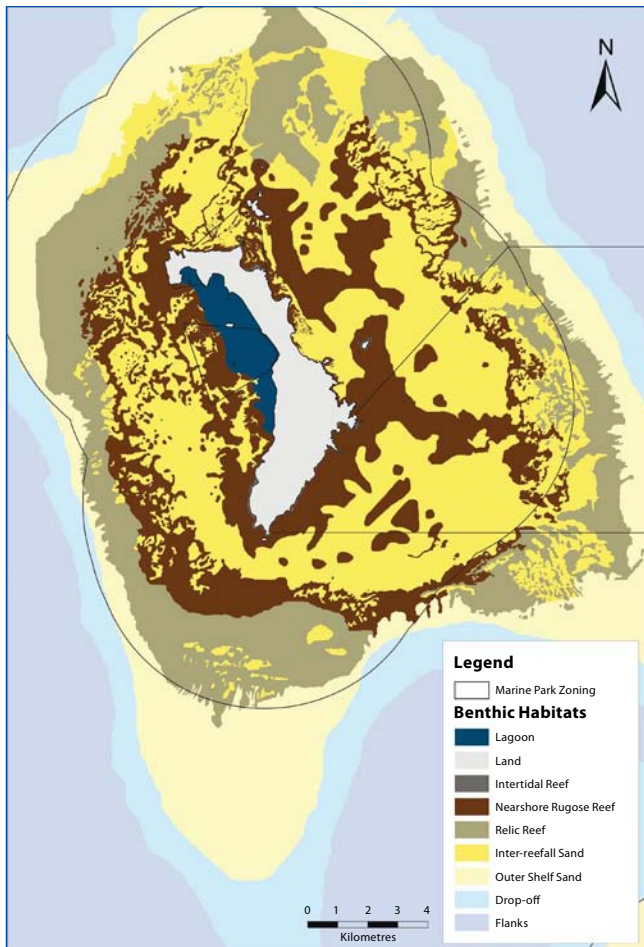


Figure 8. Map of known seabed habitats in the marine park. Source: Linklater 2009, Brooke et al 2010 and DECCW unpublished data.

These classifications are based on information current as at December 2009, and may be refined over time as further mapping and video surveys are conducted. Further video and sediment ground-truthing surveys in the marine park will allow maps of reef habitats to be based more on ecological characteristics. Such maps will improve understanding of the spatial distribution of benthic and other faunal assemblages in the deeper shelf and slope habitats.

4.1.1 Lagoon reefs

Lagoon reefs at Lord Howe Island are situated along the island's western margin where a six-kilometre-long discontinuous fringing reef encloses a shallow lagoon that is up to 1.5 kilometres wide (Kennedy and Woodroffe 2000) (Figure 2). The living structure of the fringing reef protects the reefs and associated biota within the lagoon from ocean waves. The structure and extent of the lagoon reefs are variable and include shallow reef platforms, cemented rubble zones associated with the reef crest, gravel sheets, deep trenches and isolated depressions ('lagoon holes' which are up to 10 metres deep), and scattered patch reefs in the lagoon (Kennedy 2003). There are also numerous channels and passages through the crest of the fringing reef that allow

ocean waves to partially penetrate the lagoon (Kennedy and Woodroffe 2000, Veron and Done 1979).

Sparse reef habitats occur intermixed with the sandy substrate on the far leeward side of the lagoon and gradually increase in extent and biotic cover towards the crest of the fringing reef and areas where tidal currents are focused within channels (Kennedy and Woodroffe 2002, Kennedy 2003). Reef habitats in the lagoon can be broadly divided into coral and macroalgal dominated habitats, and display some marked differences to those found on the wave exposed coastlines of the park (Figure 8). On the east coast of Australia, Lord Howe Island provides the only example of significant coral reef accretion south of the Great Barrier Reef (Harriott and Banks 2002).

The protected reefs in the lagoon, and in particular those around the edges of the deeper lagoon holes (e.g. Comets Hole and Erscotts Hole) and back-reef slopes, constitute the only 'true coral reefs' in the marine park, where the corals exhibit reef accretion and grow on a built-up skeleton of limestone (Allen and Paxton 1974, Harriott and Banks 2002, Veron and Done 1979).

Coral habitat is best represented in the lagoon holes, where growth of scleractinian (hard) corals can exceed 60% cover (Bullard 2003, Harriott et al 1995) and forms a typical tropical reef with high structural diversity (Allen et al 1976). Common corals in the lagoon include the columnar species *Porites lichen* and *P. heronensis*; the staghorn species *Acropora palifera*, *A. yongei* and *A. lovelli*; and *Pocillopora damicornis* (Bullard 2003, Harriott et al 1993, 1995; Harrison and Carroll 2002, Harrison et al 1995, Veron and Done 1979), with some growing at rates comparable to those on tropical reefs (Harriott 1999). The protected lagoonal reefs have a higher abundance of delicate plate or branching *Acropora* species than reefs in areas of the open coast (Harrison et al 1995).

Soft corals such as *Xenia elongata* are also present on most lagoonal reef sites, although generally in sparse amounts save for in a few of the lagoon holes (Bullard 2003, Harrison et al 1995, Hutton and Harrison 2004, Kaplan 1997). Some of the lagoon holes have freshwater springs which seep into reefs after heavy rainfall has recharged the water table (Harrison et al 1995), further contributing to the unique conditions in this protected environment.

Corals that produce larvae through brooding are particularly successful, as this reproductive strategy facilitates self-seeding and sustainability of local populations in the isolated environs of the park (Harriott 1992, 1995; Harriott et al 1993, Miller and Ayre 2004). Those with broadcast spawning rely on a mixture of self-seeding, replenishment of larvae from reefs further to the north (Bullard 2003, Harriott et al 1993, 1995; Harrison et al 1995), and possibly natural fragmentation and cloning (Highsmith 1982). Synchronous multi-species coral spawning and development of coral spawn slicks have been observed along the shoreline and in the lagoon, usually associated with periods of calm weather in summer months (Harrison 2008). The combination of synchronous spawning and calm weather increases the potential for some locally produced planktonic larvae to be retained and settle on reefs in the park. In addition to dispersal and recruitment processes, the other factors that limit coral species distribution and diversity patterns primarily relate to water currents, water temperature and physiological tolerances (Harriott and Banks 2002).

Some lagoonal reefs are dominated by macroalgae (Harriott et al 1993, 1995) such as the 'algal holes' at the southern end of the lagoon. These reefs primarily display temperate characteristics with common genera including the brown algae *Dictyota*, *Sargassum*, and *Labophora*; green algae *Caulerpa*, *Ulva*, *Codium*, and *Chlorodesmis*; and a range of upright red algal taxa (Allender and Kraft 1983, Harriott et al 1993, 1995) (Figure 9). Encrusting coralline algae such as *Lithothamnium* are important in reef structure and dominate in some habitats such as the algal pavement and cemented rubble zones near the reef crest (Kennedy 2003). In areas of highest coral cover, such as Escott's Hole, algal cover is relatively low, but still contains a diverse range of species (Bullard 2003). The macroalgal reefs are dominated by warm temperate fish species, particularly herbivorous species, and warm temperate urchin species (Aqueal 2008a).

There are various sheltered reef habitats and communities in the lagoon. Recent surveys of 13 lagoon reef sites identified 148 fish species, 43 mobile macrofauna species, and a wide range of sessile fauna and flora (Aqueal 2008a, 2008b). Abundant and widespread fish species include the cardinalfish *Ostorhinchus norfolcensis*, damselfishes *Neoglyphidodon polyacanthus* and *Stegastes gascoynei*, and wrasse *Pseudolabrus luculentus*, while the urchins *Heliocidaris tuberculata* and *Centrostephanus rodgersii* are common amongst macrofauna communities (Aqueal 2008a, 2008b; Patterson et al 2007). Common and conspicuous molluscs on shallow reefs include the turban shell *Turbo cepoides*, cartrut shell *Dicathais orbita*, clam *Tridacna maxima* and cowries, strombs, moon snails, mulberry shells, nudibranchs, sea hares, mussels and octopuses (Hutton and Harrison 2004). A range of crabs and hermit crabs, shrimps, sea cucumbers, seastars, feather stars and additional urchin species also occur on the lagoon's reefs.



Figure 9.
Algal reef *Caulerpa racemosa*, Lord Howe Island Marine Park.
Photo: S. Gudge



Figure 10.
McCullochs anemonefish
Amphiprion mccullochi,
Lord Howe Island Marine
Park. Photo: G. Edgar,
Aquenal

Some species appear to thrive in the shallow waters of the lagoon and occur at lower densities on the open coast, including McCullochs anemonefish *Amphiprion mccullochi* (Figure 10), three-striped butterflyfish *Chaetodon tricinctus*, multi-spine damselfish *Neoglyphidodon polyacanthus*, Norfolk cardinalfish *Ostorhinchus norfolcensis*, sawtail *Prionurus maculatus* and urchin *Heliocidaris tuberculata* (Aquenal 2008a, 2008b; Hobbs et al unpublished, Lindsay 2004). The lagoon shelters many juvenile fish, such as those of the doubleheader wrasse *Coris bulbifrons*, an insular and locally important fish species (Lindsay 2004)

(Figure 11). Another important fish species, the bluefish *Girella cyanea* (Figure 13), is closely associated with algal habitats and has been recorded in high numbers in the southern part of the lagoon (Aquenal 2008a, 2008b). The sheltered habitats also provide important foraging grounds for species such as squid and cuttlefish (Hutton and Harrison 2004), and are likely to provide nursery areas for a range of fish and invertebrate reef species.



Figure 11.
Doubleheader wrasse
Coris bulbifrons,
Erscotts Reef, Lord Howe
Island Marine Park.
Photo: S. Gudge

Monitoring of benthic reef communities over the past nearly 20 years has revealed some changes in the lagoon, most noticeably at North Bay where staghorn coral *Acropora* coverage has been greatly reduced since the earlier surveys of Veron and Done (1979). There have been smaller declines and changes in dominance of hard coral species in several lagoon holes, generally associated with an increase in cover of the green alga *Caulerpa racemosa* and other algal species (Harriott et al 1993, 1995; Harrison et al 1995, Harrison and Carroll 2002). There have also been localised impacts associated with coral bleaching and sedimentation following

storms (Harrison and Carroll 2002, Kaplan 1997). Monitoring to date has indicated that the coral populations are mostly in good condition and have been minimally affected by coral bleaching (Aquenal 2008a, Bullard 2003, Harriott et al 1993, 1995; Harrison and Carroll 2002, Harrison et al 1995). However, some coral species, particularly in the lagoon area, exhibited signs of significant bleaching during the first few months of 2010 (Harrison et al unpublished) due to the presence of warmer than normal water around the island, a high number of warm cloudless days and minimal ocean mixing, particularly within the lagoon. Moderate to severe bleaching was recorded at two sites (Sylphs Hole and Comets Hole) and mild to moderate bleaching in other shallower parts of the lagoon reef (Harrison et al unpublished).

4.1.2 Open coastal fringing reefs (outside lagoons and inner shelf, 0–30 metres deep)

Open coastal reefs in the marine park include the foreslope of the fringing reef on the western side of Lord Howe Island, as well as the nearshore reefs surrounding the remainder of the island, the Admiralty Islands, Balls Pyramid and other smaller islands and islets (Figure 8). The reefs also extend in places up to eight kilometres offshore into depths of around 30 metres. The nearshore reefs are generally exposed to high levels of wave action and therefore contrast with the sheltered reef environments in

the lagoon. The open coast and nearshore reefs also differ in that they appear to be actively erosional or consist of a relatively thin cover of living coral communities on rock (Veron and Done 1979). There are few areas of significant reef accretion, and reefs are generally classified as rocky rather than true coral reefs because the corals grow directly onto the rocky substratum rather than on an accumulated limestone skeleton (Bullard 2003, Harriott and Banks 2002, Harriott et al 1995).

The open coastal reefs extending across the inner shelf region are interspersed with accumulation of sand. In the outer bounds of the inner shelf region, large areas of inter-reef sands are prominent, and reef morphology becomes increasingly patchy and discontinuous. Most of the open coastline is composed of rugged, steeply-sloping volcanic rock exposed to strong wave action, although there are a number of promontories on the north-east coast which give partial protection from ocean swells (Veron and Done 1979). This area, including the Admiralty Islands, consists of unusual rheophilic reefs (i.e. reefs characterised by strong currents) on both calcareous and basalt substrates, and gulches containing unconsolidated boulder stacks adjacent to vertical rock walls (Allender and Kraft 1983, Marine Parks Authority 2004). The foreslope of the western fringing reef slopes gradually to a depth of 20 metres or more over approximately 800 metres, and includes deeply grooved and smooth slope habitats.

Reefs on the east coast of Lord Howe Island have many similarities to the lagoon reef foreslope, but have morphologies more limited by storm surge, and are steeper, thus extending over a narrower band of seabed (Environment Australia and Marine Parks Authority 2001, Harriott 1992). This area includes a mixture of calcarenite and basalt rocky substrata, with the abrupt vertical and undercut edges of calcarenite platforms adjacent to Neds Beach and Middle Beach perforated by numerous caves which provide structurally complex habitats. Boulder stacks derived from basalt rock falls occur in the south-west extremity of Lord Howe Island, while the entire coastline of Balls Pyramid as well as much of the southern coast of Lord Howe Island are characterised by vertical basalt cliffs plunging to a base where water is between 10 and 20 metres deep (Environment Australia and Marine Parks Authority 2001, Marine Parks Authority 2004).

The fringing reefs of Lord Howe Island extend from the shallow sublittoral fringe into depths frequently ranging from 15 to 20 metres, where they are replaced to some extent by soft-sediment substrata at depths of up to 30 metres (Environment Australia and Marine Parks Authority 2001, Marine Parks Authority 2004). This denotes the upper depth limit of a discontinuous drowned ridge on the Lord Howe Island shelf which represents a relic reef that accreted (possibly in part) during the Holocene and delineates the inner and outer portions of the shelf (Woodroffe and Brooke 2000). In the inner shelf areas, the reef becomes increasingly patchy and contains sand. The 30-metre boundary also represents the average depth of the Balls Pyramid shelf (McDougall et al 1981) and the lower depth of scientific diving, and hence the limit of many biological studies.

Algae are dominant on many open coastal and nearshore reefs and include encrusting, foliose and fleshy green, brown and red algal species which occur on both calcarenite and basalt substrata (Allender and Kraft 1983, Aquenal 2008a, 2008b; Harriott et al 1993, 1995; Harrison et al 1995, Veron and Done 1979). While there is little evidence of significant coral reef accretion on the open coast of the marine park (Veron and Done 1979), cover of scleractinian corals is still very high and diverse in some areas. While reefs in the sheltered lagoonal holes generally have the highest coral cover (Aquenal 2008a), some studies have recorded areas of even higher cover and coral diversity at semi-exposed sites in open coastal environments on the eastern

side of the island (e.g. Harrison et al 1995). There is also considerable variation in the communities of corals and other sessile species on the open coast, depending on currents, levels of wave exposure and substratum type (Harrison et al 1995). The foreslope of the fringing reef includes some areas dissected by deep grooves which are dominated by plate corals, while the open face of the slope is colonised by a range of coral forms and leafy green and brown algae, with coral cover decreasing with depth (Harriott et al 1993, Veron and Done 1979).

On the north-east coast of Lord Howe Island, the combined attenuation of wave surge and strong currents have favoured the development of distinctive coral communities with more delicate and complex morphology than elsewhere outside the lagoon. This area is characterised by large foliose and vase-shaped hard corals (particularly *Turbinaria* species) and includes a high diversity of filter feeding organisms such as octocorals (gorgonians and sea whips), basket stars, feather stars, hydroids, colonial ascidians and many others that are uncommon elsewhere but have an ability to withstand the strong currents of the area (Environment Australia and Marine Parks Authority 2001, Marine Parks Authority 2004).

In contrast, communities at sites exposed to high wave action are dominated by robust corals with massive, sub-massive or encrusting forms able to withstand increased surge, with dominant species including *Acropora palifera* and *Porites* species (Harrison et al 1995). The basalt cliff-base shores of the most exposed sites support a diversity of algae, massive corals, and other sessile species adapted to strong wave action, including a number of unusual brown, green and red foliose algae (Marine Parks Authority 2004). Monitoring over the past 20 years (e.g. Bullard 2003, Harrison and Carroll 2002, Harriott et al 1993, 1995; Harrison et al 1995) has found that the benthic community composition of open coastal communities has changed little since the earlier surveys of Veron and Done (1979).

The crown-of-thorns starfish *Acanthaster planci*, a species that preys on corals and has caused major reductions in coral cover on many tropical reefs, has been recorded in the marine park since 1975. This species is limited primarily to the open coastal and offshore fringing reefs (de Vantier and Andrews 1987, de Vantier and Deacon 1990, Harriott 1995), with the most recent surveys identifying it in depths of 8–26 metres, but with the highest numbers recorded at depths of 14–19 metres (Taylor 2003). This reflects a shallower depth range than recorded in earlier surveys, although colonisation has still not occurred in the lagoon. Damage to reefs is evident from feeding scars and localised declines in coral cover (de Vantier and Deacon 1990, Taylor 2003), although populations have remained relatively small and the probability of a major starfish outbreak has been categorised as low (Harriott 1995). If an outbreak were to occur at Lord Howe Island, recovery of the reefs would most likely be slow because rates of coral growth and larval replenishment have been generally reduced compared with tropical reefs (Harriott 1995).

Overall, while there is some overlap of community composition between reefs in the sheltered lagoon and open coastal reefs, most of the latter comprise a distinctive community containing a predominance of warm temperate fish species, a very high abundance and richness of macroinvertebrate species, and high densities of soft corals, planktivorous fishes and the urchin *Centrostephanus rodgersii*, which forms small barrens in some areas (Aquenal 2008a). Certain algal species are also mostly associated with open coast environments (e.g. the red alga *Dasya pilosa*). Fish species with warm temperate affinities tend to dominate the nearshore reef sites, contrasting with the tropical-dominated communities of the sheltered lagoonal reefs. The nearshore reefs also support a higher biomass of insular fish species than sheltered lagoonal

habitats (Aquenal 2008a). Such insular fish species are predominantly found at Lord Howe Island and associated islands, but with vagrant individuals on the NSW coast and in northern New Zealand.

The urchins *Tripneustes gratilla*, *Echinostrephus aciculatus* and *Heliocidaris tuberculata* are highly abundant. The lamington urchin *T. gratilla* has recently recorded a large increase in abundance, primarily in the Admiralty Islands group, leading to changes in benthic community structure including a localised reduction in foliose brown and red algae and an increase in abundance of crustose coralline algae and mobile invertebrates (Aquenal 2008b) (Figure 12). Additional species that are more common on the exposed coast include the feather stars *Cenolia glebosus* and *Amphimetra tessellata*, the snail *Coriocella nigra*, and the spiny lobster *Panulirus longipes* (Aquenal 2008a, b), while a range of nudibranchs and other gastropod and bivalve molluscs, crabs and hermit crabs, shrimps, feather duster worms, sea cucumbers, flatworms, feather stars and additional urchins also occur.

In addition to levels of wave exposure, depth is important in species composition. For example, the urchin *Centrostephanus rodgersii* occurs mostly in water more than eight metres deep, while the total number of macroinvertebrate species also increases significantly with depth (Aquenal 2008a, b). The doubleheader wrasse *Coris bulbifrons* (Figure 11) and bluefish *Girella cyanea* (Figure 13) occur on the open coast and nearshore reefs. The uncommon Ballina angelfish *Chaetodontoplus ballinae* (Figure 6) also occurs in deeper sections of the open coastal and nearshore reefs, for example at a depth of 25 metres near Balls Pyramid (Parker 1994), but most records for this species indicate that it occurs at greater depths further offshore (Marine Parks Authority unpublished, Speare et al 2004). Certain fish species usually limited to deeper waters of the shelf, such as the yellowtail kingfish *Seriola lalandi*, occur in fringing habitats where they are attracted by fish feeding activities conducted for tourists, for example, at Neds Beach.

Recent biological surveys conducted at 25 shallow open coastal sites around Lord Howe Island and Balls Pyramid recorded 167 fish species, 48 mobile macrofauna species, and additional sessile fauna and flora, with variation in wave exposure explaining much of the community variation amongst the habitats sampled (Aquenal 2008a, 2008b). Characteristic fish species included the demoiselle *Chromis hypsilepis*, butterflyfish *Amphichaetodon howensis* and hawkfish *Cirrhites splendens*, while additional abundant species included the wrasse *Pseudolabrus luculentus*, damselfishes *Stegastes fasciolatus* and *Stegastes gascoynei*, demoiselle *Chrysiptera notialis*, scalyfin *Parma polylepis* and cardinalfish *Ostorhinchus norfolcensis*. Characteristic invertebrate species included the seastar *Ophidiaster confertus*, ascidian *Herdmania grandis*, coral *Montastrea curta* and various encrusting sponges and hydroids.



Figure 12.
Tripneustes gratilla urchin aggregation, Keyholes, Lord Howe Island Marine Park. Photo: J. Valentine, Aquenal



Figure 13.
Bluefish *Girella cyanea*, Lord Howe Island Marine Park. Photo: G. Kelly

4.1.3 Mid-outer shelf reefs (30–100 metres deep)

A broad area of relic reef is evident on the mid-shelf of much of the Lord Howe Island shelf, mostly between depths of 30–70 metres (Figure 8), and has previously been detected in the form of a discontinuous drowned ridge (Kennedy et al 2002). The relic reef is 2–3 kilometres wide in places on the western, southern and eastern sides of Lord Howe Island, and is narrower on the northern edge of the shelf. The relic reef is covered in Holocene coralline algae (Kennedy et al 2002), with recent high resolution seabed mapping revealing variations in the complexity of the bathymetry, with some areas relatively flat compared to adjacent areas (Linklater 2009). Surveys of shelf habitats have revealed an often dense cover of benthic organisms where consolidated substrate is present (Speare et al 2004, Woodroffe et al 2005) (Figure 14). There is also evidence of considerable variability in the cover of consolidated habitat within this large area of reef, and large areas of unconsolidated habitat are also present within a complex mosaic of reef and sand.



Figure 14.
Mid-shelf reef adjacent to
Lord Howe Island.
Photo: Marine Parks
Authority

Benthic communities of the mid-shelf include solitary hard corals, soft corals, sponges, ascidians, encrusting bryozoans and foraminifers, hydroids, starfish, sea urchins, molluscs, crustaceans and a dense cover of algae including foliose and nodular coralline species (Marine Parks Authority 2004, Ponder et al 2000, Speare et al 2004, Woodroffe et al 2005). The deeper waters of the mid-shelf also support communities dominated by gorgonians where rubble, stone or bedrock is exposed (Speare et al 2004). Coralline algae frequently form multiple

sheets over the reef surface and are associated with calcareous green macroalgae such as *Halimeda* (Woodroffe et al 2005). Hard corals include some solitary species that are not found in shallower waters of the park (Marine Parks Authority 2004). They do not form the dense cover recorded in studies of inshore habitats, but are prevalent in some areas, such as on the shelf east of Lord Howe Island and south of Balls Pyramid. It may be that these areas have higher biological diversity than other areas of the shelves due to greater topographic complexity and vertical relief (Speare et al 2004).

Museum databases include 545 species of invertebrates recorded in depths of 40 metres and more around Lord Howe Island and the adjacent NSW coast (Australian Museum Business Services 1998), although these are likely to include some non-reef and deeper water species. Marine invertebrates recorded for the marine park's shelf habitats consist of approximately 200 mollusc species as well as small numbers of

annelids, echinoderms, brachiopods, crustaceans, sipunculids and bryozoans (Ponder et al 2000). Pencil urchins *Phyllacanthus* sp. have been recorded in highest numbers on the north-east shelf of Lord Howe Island (Speare et al 2004), while the urchins *Pseudoboletia indiana* and *Prionocidaris callista* (Figure 15) are also noted as being common on the shelf (Ponder et al 2000).

Figure 15.
Beautiful sea urchin
Prionocidaris callista,
Lord Howe Island Marine
Park. Photo: Marine Parks
Authority



At least 9.4% of the molluscs and 12.5% of the non-mollusc taxa are known only from the shelves, reflecting a potentially high level of endemism. While endemism in all habitats is not yet fully understood, levels may be even higher on the shelves than in the shallower inshore reefs (Ponder et al 2000).

Biological communities of shelf habitats also include a large number of reef-associated fish and sharks (Marine Parks Authority 2010, Speare et al 2004). Baited video surveys deployed in depths of around 35–65 metres recorded a wide range of teleost and elasmobranch fish, as well as crab and squid species, with 43 species recorded in shelf reef habitats (Speare et al 2004). The silver trevally *Pseudocaranx dentex* (Figure 16), black-spot pigfish *Bodianus unimaculatus*, and comb wrasse *Coris picta* tend to characterise the consolidated algal-dominated habitats (Speare et al 2004). A more recent baited video survey in depths of 30–50 metres recorded 77 species of sharks, rays, and fishes on the Lord Howe Island and Balls Pyramid shelf (Marine Parks Authority 2010). Fish assemblages were numerically dominated by Galapagos sharks *Carcharhinus galapagensis* (Figure 17), wrasses (Labridae) and damselfish (Pomacentridae). White spot chromis *Chromis hypsilepsis* and painted ladies *Paracaesio xanthura* were locally abundant in large schools.

In deeper waters of the mid-shelf, a small range of fish species typically characterise reef habitats, including the silver trevally *Pseudocaranx dentex* (Figure 16), black-spot pigfish *Bodianus unimaculatus*, and comb wrasse *Coris picta* (Speare et al 2004). The shelf community includes some fish species of high conservation value, such as the rare Ballina angelfish *Chaetodontoplus ballinae* (Figure 6), which has been recorded off both Lord Howe Island and Balls Pyramid in depths of 25–200 metres (Clarke et al 2003, Marine Parks Authority 2010, Parker 1994, Speare et al 2004).

A very high abundance of sharks and a mix of tropical and temperate families distinguish the fish communities from those on the exposed coasts of south-eastern mainland Australia (Speare et al 2004). The species recorded in recent shelf surveys are likely to reflect only a portion of the resident and transient fish communities, since museum databases include 1,064 fish species from depths of more than 40 metres around Lord Howe Island and the adjacent areas of the NSW coast (Australian Museum Business Services 1998), although data for the latter area includes additional non-reef and deeper water species. The absence of commercial trawling or other major industrial activity on the shelves around Lord Howe Island and Balls Pyramid suggest that they are relatively pristine areas compared with many other shelf habitats around Australia. This fact, combined with a relatively high level of faunal endemism (Ponder et al 2000) suggests the mid–outer slopes of the park have a high conservation value.



Figure 16. Silver trevally *Pseudocaranx dentex*, Lord Howe Island Marine Park. Photo: G. Kelly



Figure 17. *Carcharhinus galapagensis* Galapagos whaler shark, Lord Howe Island Marine Park. Photo: S. Lindfield

4.1.4 Seamount slope (more than 100 metres deep)

Habitats to depths of approximately 200 metres near the steep shelf drop-off at Lord Howe Island and Balls Pyramid are topographically complex and provide more outcrops, walls and overhangs than seen on the shelf. They support a diverse and abundant fauna of filter-feeding invertebrates and large numbers of reef fish (Speare et al 2004). Benthic communities are dominated by octocorals such as gorgonians and sea whips, with prolific gorgonian gardens found in some areas and a mix of algae and low–medium density gorgonians in other areas. Filter-feeding crinoids, sponges, ascidians and pencil urchins, *Phyllacanthus* sp., also occur in large numbers. The latter are more common than on the shelf and are particularly abundant on the bedrock of the northern margin of Balls Pyramid. Smaller numbers of anemones, bryozoans, holothurians, hydroids, sea pens, starfish and solitary corals have also been recorded on the seamount slopes to a depth of 200 metres (Speare et al 2004).

Seamount slopes comprise a unique deep-sea environment, characterised by substantially enhanced currents, high species diversity and a fauna dominated by suspension feeders (de Forges et al 2000, Environment Australia and Marine Parks Authority 2001, Koslow et al 1998). High levels of endemism have been reported, with studies identifying a large number of species and genera that are new to science and, in some cases, are confined to particular seamounts (Clarke et al 2003). Seamounts are also believed to act as refugia for deep sea ‘archaic’ fauna, representing relic species that have survived through long periods of geological time (Pichon 1995). Age and growth studies have shown that these complex yet fragile communities are dominated by long-lived species, some attaining ages of well over 100 years.

The 100–200-metre depth zone supports larger numbers of fish than the shelf, most notably yellowtail kingfish *Seriola lalandi* (Figure 18), redfish *Centroberyx* sp., rosy jobfish *Pristipomoides multidens*, and large unidentified groupers (Family: Epinephelinae). The uncommon Ballina angelfish *Chaetodontoplus ballinae* (Figure 6) has been recorded in gorgonian gardens to depths of at least 200 metres (Speare et al 2004), although it may extend into even deeper waters. Further information is provided by fisheries catches, with about ten species of demersal fish regularly taken from depths of 100–150 metres (Environment Australia and Marine Parks Authority 2001). In addition to the above species, predatory fish collected include long finned perch, nannygai, pigfish, deep sea perch, emperor fish, fusilier fish, silver trevally, snapper, bigeye, yellowfin tuna and wahoo (Environment Australia and Marine Parks Authority 2001, Pichon 1995.). The prevalence of large predatory fishes in the darkness of the steep Lord Howe slopes is possibly associated with the diurnal migrations of ommastrephid squid and slimy mackerel (Speare et al 2004).

Figure 18.
Yellowtail kingfish *Seriola lalandi*, Lord Howe Island Marine Park. Photo: G. Kelly



Depths exceeding 200 metres are frequently reported as being the most species-rich seamount habitats. These areas have been targeted in several studies of the Lord Howe Rise and neighbouring seamount systems in the Tasman and Coral seas. While many survey sites fall outside the marine park and some extend into waters deeper than those contained in the park’s limits (i.e. at depths of more than 1,800 metres), they provide indicative data on the seamount assemblages.

One remote sampling program on the Norfolk Ridge and Lord Howe Rise identified at least 590 fish species and 1,300 invertebrate species (Clarke et al 2003). Of the fish species, the dogfish *Deania cf. calcea*, slickhead *Rouleina attrita*, and boarfish *Pseudopentaceros richardsoni* were the major species found, whilst the basketwork eel *Diastobranchus capensis* was the most widespread species. Additional frequently caught species included the brown slickhead *Alepocephalus australis*, viperfish *Chauliodus sloani*, rat tail *Gadomus aoteanus* and common mora *Mora moro*. A total of 222 invertebrate families were recorded, including sponges, corals, molluscs, seastars, urchins, crabs and prawns, with smaller numbers of other groups also being recorded. Crustaceans, especially a number of prawn families, were very widespread. Many of the fish and invertebrates identified were either new records for the Tasman Sea area, New Zealand or Australia, or completely new species to science (Clarke et al 2003).

In a separate study, community analysis revealed that benthic fish and invertebrate fauna of the Lord Howe Rise seamounts have little affinity with those of the nearby Norfolk Ridge or more distant southern Tasman Sea (de Forges et al 2000). This low species overlap suggests that the seamounts in clusters or along ridge systems function as 'island groups' or 'chains' leading to highly localised species distributions and apparent speciation between groups or ridge systems (de Forges et al 2000). A total of 108 species were recorded on the Lord Howe Rise, 31% of which were new to science and considered potential endemic species. Four new genera were recorded from the Lord Howe Rise, some appearing to be relics of groups earlier believed to have disappeared in the Mesozoic (225–65 million years ago). The lack of affinity between Lord Howe Rise and Norfolk Ridge seamount communities is considered remarkable, particularly given their similar habitat type, latitude and depth, and limited geographical separation (about 1,000 kilometres apart), and also given the strong affinity displayed by continental slope fauna in south-eastern Australia (Poore et al 1994).

However, certain groups such as the brittle stars, which represent a numerically abundant group amongst invertebrate assemblages, do not demonstrate strong differentiation between Lord Howe Island and Norfolk Island seamount communities (O'Hara 2008). This may either be because they have better overall dispersal abilities than the wide range of invertebrates included in the de Forges et al (2000) study, or discrepancies may be due to the potential for sampling artefacts in the species-rich environments of the seamount slopes (O'Hara 2008). While certain taxa may demonstrate equally high levels of diversity and endemism in neighbouring species-rich areas of the mainland Australian continental slope, the biogeographic and ecological importance of the deep seamount habitats is consistently recognised. The limited fixed habitat, extreme longevity of many species, potentially limited recruitment between seamounts, and localised distribution of some benthic seamount species have important implications for their conservation and management.

4.2 Subtidal soft-sediment habitat

Unconsolidated habitats are extensive throughout the lagoon, shelf and deeper seamount slope areas of the marine park. Much of the seabed of the lagoon consists of bare sand, although this includes numerous scattered areas of coral, macroalgae and seagrass (Environment Australia and Marine Parks Authority 2001, Kennedy 2003).

Within the lagoon, sand and gravel are continually being reworked by waves and tides, and are relatively mobile despite protection from wave action from the adjacent fringing reef. Sediments are dominated by medium–coarse sands, with smaller portions of coral, foraminifera and molluscs (Kennedy 2003), and overlay finer muddier sediments (Environment Australia and Marine Parks Authority 2001). Deep holes occur in nine locations in the lagoon, which also have sandy seafloors.

The sandy sediments of the Lord Howe Island lagoon are occupied by many specialised organisms including burrowing bivalves, urchins, seastars and eels, as well as sea slugs, sand anemones and various crustaceans and fish. Small clumps of a few species of coral, such as *Pocillopora damicornis* and *Acropora* species, algae and small sponges are scattered widely over the sand (Environment Australia and Marine Parks Authority 2001, Kennedy 2003). When cooler currents flow around Lord Howe Island, squid are present in large numbers and often come into the lagoon to feed at night. Similarly, cuttlefish inhabit the bottom of shallow seabeds where they feed on fish and invertebrates (Hutton and Harrison 2004). Sandy seafloors in the lagoon's deep holes provide habitats for species requiring a high level of protection from wave action.

Some conspicuous soft-sediment macrofauna species in the lagoon include the heart urchin *Breynia australasiae*, seastar *Luidia australiae*, blue swimmer crab *Portunus pelagicus* and orange spanner crab *Ranina ranina* (Hutton and Harrison 2004). The less conspicuous communities of burrowing species consist primarily of amphipods, isopods, decapods and other crustaceans, as well as polychaete worms and gastropod and bivalve molluscs, with smaller numbers of oligochaete worms, nematodes (roundworms) and nemertean (ribbon worms) (Aquenal 2006). A survey of 13 soft-sediment lagoon sites recorded 68 species, including 31 species of polychaetes, 16 species each of molluscs and crustaceans, and smaller numbers of other taxa. Amongst the most common and widespread species were the bivalve molluscs *Codakia paytenorum* and *Solemya* sp., the polychaete worms *Nephtys* sp. and *Malacoceros* sp., an isopod and a mantis shrimp (Aquenal 2006). Undoubtedly, more intensive sampling of the lagoon's soft sediments would reveal a larger range of species.

Unconsolidated habitats of the fringing reef foreslope include areas of deep sand with sparse algae and coral, while sand and rubble patches on the lower part of the slope beyond depths of 15 metres are heavily colonised by leafy brown algae (Environment Australia and Marine Parks Authority 2001). Several species of coral that are uncommon elsewhere occur in sparse colonies. Inshore areas of the open coast include patches of calcareous sand and coral/algal rubble between the reef-colonised hard substrates (Environment Australia and Marine Parks Authority 2001). The outer reef slopes give way to larger areas of sand and rubble which form a transition into the sandy habitats of the shelf. Limited sampling of the subtidal benthic infauna on the open coast near Neds Beach has recorded a range of polychaete and crustacean species (Aquenal 2006). Most of the species recorded are also found in the lagoon, although several polychaete species were unique to Neds Beach. This suggests subtle differences in community composition, most likely as a result of contrasting levels of wave exposure and associated variables such as sediment particle size.

Preliminary analysis of benthic samples suggests that the seafloor of the inner shelf of Lord Howe Island (i.e. inshore of the relic reef located in a depth of 30–50 metres) is composed primarily of lagoonal sands, remnants of the period of lower sea level when a very large lagoon surrounded much of Lord Howe Island (Woodroffe and Brooke 2008, Brooke et al 2010). The deeper parts of the shelf (60–100 metres), located between the relic reef and the shelf break, also consist predominantly of

unconsolidated sandy seafloors. This area is characterised by low profile sand waves, with sparse rubble contained in the troughs or low spots (Speare et al 2004).

The sandy areas of shelf habitats surrounding Lord Howe Island and Balls Pyramid are typically devoid of benthic structure and contain sparse populations of epibenthic species (Speare et al 2004). Fauna include urchins, seastars, solitary corals, sponges, bryozoans, molluscs and sea pens, while flora communities are dominated by leafy and nodular calcareous algae (Environment Australia and Marine Parks Authority 2001, Speare et al 2004). The pencil urchin *Phyllacanthus* sp. is particularly common. While this species also occurs on reef habitats, it occurs predominantly on the sandy seafloor on some areas of the shelf (Speare et al 2004).

Benthic infauna in shelf sediments may support higher levels of diversity than revealed by the epibenthic communities, as suggested by results of early dredging studies. Very high diversities of benthic molluscs have been recorded in samples taken from a mixture of calcareous *Lithothamnion* (calcareous algae) nodules and coral sand on the Lord Howe Island and Balls Pyramid shelves (Ponder et al 2000). While samples may contain a mixture of soft-sediment and low profile reef species, the sampling methodology and substrata notes suggest that a significant portion of species recorded are likely to be burrowing species. In addition to molluscs, other taxa, including annelids, echinoderms, brachiopods, crustaceans, and sipunculids (Ponder et al 2000), include soft-sediment dwelling species.

Fish communities associated with open, sandy seafloors on the shelf contrast with those of reef habitats, and are characterised by a species assemblage including the Galapagos whaler shark *Carcharhinus galapagensis*, large stingrays (smooth *Dasyatis brevicaudata*, black *D. thetidis* and blotched fantail *Taeniura meyeni*), and silver toadfish *Lagocephalus sceleratus*. Species diversity of fish on the shelves is generally reduced in sandy areas compared with reef habitats (Speare et al 2004). Ten fish species are believed to be limited to the sandy, open seafloor and absent from reef substrata, although increased sampling intensity may reveal this number to be higher.

Sampling of unconsolidated habitats in deeper seamount slope sections of the park has been limited to date, although surveys of adjacent areas of the Lord Howe Rise and neighbouring seamount systems have revealed very high diversities of fish and invertebrates (Clarke et al 2003, de Forges et al 2000). A wide range of sessile and mobile invertebrates, such as sponges, corals, molluscs, starfish, urchins, crabs and prawns, occur on the slopes. Surveys in these deep environments are logistically difficult, and methods used tend to be those that survey large areas of the seabed. These factors, combined with potentially patchy habitats, can make it difficult to differentiate between sandy sediment and low profile reef species. However, the nature of the sampling techniques most commonly applied indicates that a significant portion of the highly diverse communities recorded are associated with soft-sediment habitats.

4.3 Intertidal reef habitat

Intertidal rocky shores occupy a zone of transition between marine and terrestrial environments, and include the intertidal zone and the adjacent wave surge zone. These habitats are characterised by local variations in the distribution of organisms determined by factors such as levels of tidal exposure, wave action, biological interactions and geomorphic structure (Underwood and Chapman 1995).

A number of rocky shore types have been described at Lord Howe Island (Environment Australia and Marine Parks Authority 2001, Marine Parks Authority 2004), including:

- open coast boulder shores – there are basalt boulder beaches terminating in small gulches on the north and south-east coasts, and sections of boulder beaches at the northern end of Neds Beach and southern extremity of the lagoon shore
- open coast calcarenite rock platforms – these extensive platforms occur on the north-east coast of Lord Howe Island, at Neds Beach and Middle Beach, and a smaller platform is located off the centre of Blinky Beach; the total area of these platforms is estimated to be 10 hectares
- sheltered calcarenite rock platforms – these sheltered platforms occur in the lagoon where they occupy approximately 1.5 kilometres of the shoreline (Figure 19)
- sheltered basalt rocky shores – these are formed from boulder scree at the bottom of hill slopes within the lagoon, where they comprise approximately 1.5 kilometres of the shoreline
- drying rubble banks and other coral rubble shores – these consist of approximately ten groyne or banks of broken coral and calcareous algae, which are exposed on most low tides, and are formed by storm waves on the reef crest in the lagoon. Together, these drying banks cover an area of about 400 hectares. Rubble also dominates the shore on reefs at the northern and southern ends of the lagoon: at North Reef rubble piles over a basalt platform, while South Reef borders the deep trenches known as the ‘pot holes’ and an aggregation of coral rubble cemented together by coralline algae.

These rocky shore types provide a range of habitats such as rock pools, channels and crevices. Increases in the structural complexity of rocky shores are generally associated with an increase in species diversity (Smith and James 1999, Smith 2005). This complexity is largely lacking from Balls Pyramid, where the presence of sheer cliffs around the entire coastline generates an intertidal zone consisting of a fairly uniform band of exposed vertical rock wall.

The exposed calcarenite platforms on Lord Howe Island are highly dissected by crevices, channels, moats and pools providing a huge variety of microhabitats.

Figure 19.
Calcarenite platform in the lagoon, Lord Howe Island Marine Park. Photo: G. Kelly



Sponges, corals, crabs, shrimps, bryozoans, gastropod and bivalve molluscs, seastars, brittle stars, sea urchins, sea cucumbers and polychaete worms are all abundant (Aquenal 2006, 2008a, 2008b; Hutton and Harrison 2004) (Figure 20). A diverse range of algae are also abundant, including the common green algae sea grapes *Caulerpa racemosa* and sea lettuce *Ulva ranunculata*, and growing in deeper pools, the green turtle weed *Chlorodesmis major* (Hutton and Harrison 2004). Differences in species abundance and dominance have been noted between platforms; for example, the white urchin *Tripneustes gratilla* is considerably more common on the Middle Beach platform than the Neds Beach platform (Hutton and Harrison 2004).

The sheltered calcarenite platforms in the lagoon are smaller in size and support an assemblage different to that on the exposed platforms. The sheltered areas are covered with diminutive algae, which are grazed on by a variety of gastropods, urchins, crabs and fish (Environment Australia and Marine Parks Authority 2001). Many additional sessile and mobile fauna shelter among crevices. Rock pools are frequently occupied by schools of juvenile bluefish *Girella cyanea*, and may be an important nursery area for this species.

The lagoon basalt shores support a community of algae which is distinct from those found on calcarenite. While many species of animals occupy both substrata, some species of molluscs and crabs appear to be largely restricted to the basalt. The drying rubble banks in the lagoon provide a different habitat again, and are heavily colonised by a wide range of algae, corals, anemones, sponges, ascidians, crustaceans, starfish, molluscs, and many other groups. Large numbers of herbivorous and omnivorous fish occupy the banks with the rising tide. The coral rubble habitats of North and South reefs support many species found on the rocky shores of the island, but some unusual animals are additionally present. At South Reef, the close proximity to deep water results in unusual occurrences of nudibranchs such as the Spanish dancer *Hexabranthus sanguineus* (Figure 21), while North Reef is home to some rare animals including the endemic seastar *Patiriella oliveri* (Hutton and Harrison 2004). The exposed basalt boulder shores outside the lagoon have comparatively few biological communities due to re-sorting of the boulders during heavy weather, although a few species of crabs such as the variegated shore crab *Leptograpus variegated* are numerous among the boulders (Environment Australia and Marine Parks Authority 2001).

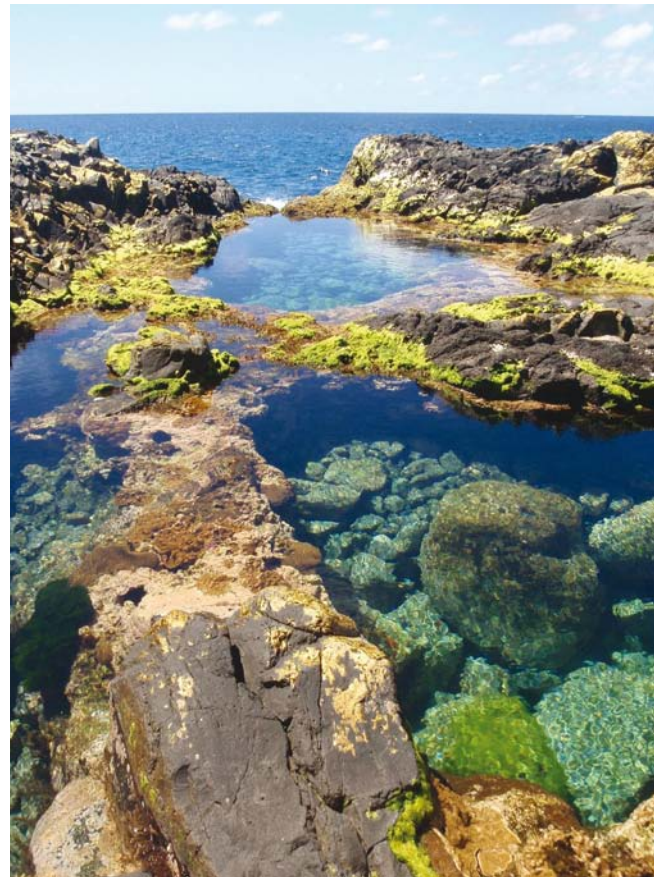


Figure 20. Reef platform, Old Gulch, Lord Howe Island Marine Park. Photo: S. Gudge



Figure 21. Spanish dancer *Hexabranthus sanguineus* with eggs, Lord Howe Island Marine Park. Photo: J. Gilligan

Reef surveys have reported lower species numbers but a higher number of endemic species on rocky intertidal habitats compared with subtidal reefs (Aquenal 2008a), including the limpet *Cellana howensis* (Ponder 1981). The intertidal species are mainly warm temperate rather than tropical, being similar to species found along the central NSW coast (Aquenal 2008a, Ponder 1981). The tropical Indo-West Pacific elements are mostly inconspicuous and often limited to the lower shore or sublittoral zone. The biota consists of two major community types, one present near the high water mark, and another extending from the mid to low littoral zone (Aquenal 2008a). Little variation around the island is evident in the high intertidal community; however, the mid- to low-tidal community varies from site to site. While the high intertidal area supports a low number of species, dominated by a few mollusc taxa, species richness increases rapidly downshore from the mid intertidal zone (Aquenal 2008a). The number of mobile macroinvertebrate species is highest midway between medium tide and the high water mark, while the number of sessile invertebrate and macroalgal species is highest near the low water mark (Aquenal 2008a). Quantitative surveys have found that on average, gastropod molluscs are the most abundant animals in the rocky intertidal zone, with the black nerite *Nerita melanotragus* the most common species (Aquenal 2008a). This species is commonly described as *N. atramentosa*, but Spencer et al (2007) showed this to be a misidentification.

While the major community differentiation occurs between the high and mid–low littoral zones, dominant and common species can be summarised for a broader range of intertidal zones at Lord Howe Island (Allen and Paxton 1974, Aquenal 2008a, 2008b; Hutton and Harrison 2004), as outlined below:

- the high shore is dominated by small littorinid snails such as *Nodolittorina unifasciata*
- the upper–mid shore is dominated by grazing snails, including the littorinid *Bembicium flavescens*, the black nerite *Nerita melanotragus*, and the clusterwink *Hinea brasiliana*
- the mid shore includes species such as the limpet *Cellana howensis*, carnivorous *Morula* gastropods, the rock oyster *Saccostrea cucullata* and the rock barnacle *Tesseropora wireni*
- the low shore is occupied by serpulid worms, the urchins *Heliocidaris tuberculata* and *Echiometra mathaei*, *Calcinus* hermit crabs, the turban shell *Turbo cepoides*, encrusting sponges and ascidians, hard and soft corals, and algae. The green alga *Caulerpa racemosa*, brown algae *Padina* spp. and calcareous red alga *Lithothamnion* sp. are amongst the most widespread forms.

The intertidal reefs of Lord Howe Island are also the only known habitats of a range of endemic species belonging to groups such as the molluscs, echinoderms and algae (Hedley and Hull 1912, Hutton and Harrison 2004, Kraft 2000, Ponder 1981). Coastal rocky and coral rubble shores are important roosting and feeding habitat for many birds, such as noddies, terns and other protected seabird species that live on Lord Howe Island or visit seasonally.

4.4 Ocean and lagoon beaches

Sandy beaches on Lord Howe Island are found along the western lagoon shore and in three limited sections along the eastern side of the island (Allen et al 1976). The lagoon beaches are protected from the ocean swell by the fringing reef about one kilometre offshore (Hutton and Harrison 2004). Old Settlement Beach and North Beach at the northern end of the lagoon comprise the most sheltered beach environments, since they are also protected by headlands. Lagoon Beach extends along much of the central and southern coastline of the lagoon over approximately three kilometres (Figure 22). The east coast ocean beaches are subject to stronger wave action,



Figure 22.
Lagoon Beach, Lord Howe
Island Marine Park.
Photo: J. Gilligan

although Neds Beach and Middle Beach are partially protected by headlands and calcarenite platforms with fringing reefs immediately offshore (Environment Australia and Marine Parks Authority 2001). Blinky Beach is the beach which is most exposed to wave action because of a lower level of reef development and minimal protection from headlands.

The beaches in the lagoon are composed almost entirely of carbonate sand, with some basalt-derived 'black' sand at the southern end of the lagoon (Environment Australia and Marine Parks Authority 2001). Seagrass beds (see section 4.5) form narrow crescents off the lagoon beaches and provide a contrasting soft-sediment intertidal habitat. While most beach environments in the lagoon have essentially retained their natural structure, Lagoon Beach is intersected near its southern end by an artificial rock wall created during airstrip construction. The sandy beaches on the east coast of the island are calcareous, with the adjacent calcarenite platforms at Neds Beach and Middle Beach being extensions of the geological structures on land. Balls Pyramid is composed of basalt cliffs around its entire coastline, and therefore does not provide any beach habitats.

Sandy beaches are naturally dynamic, changing seasonally as winter storms remove sand from the beach, and summer weather returns sand to the beach. Assemblages are likely to be most dynamic on beaches with high wave activity and swell. The intertidal sandy beach habitats are continuous with, and ecologically linked to, subtidal soft substrate habitats where they occur immediately offshore. Different beach types and environments support characteristic assemblages, determined to a large extent by the size of particles making up the sediment (Marine Parks Authority 2008).

A diverse range of invertebrate species often occur beneath the surface of the sand, the most obvious being the macrofauna which are dominated by crustaceans, polychaetes and molluscs (Environment Australia and Marine Parks Authority 2001, Jones and Short 1995). Very small animals living in the sand are called meiofauna (animals ranging in size from over 63 microns to 1 millimetre), and these assemblages are generally highly variable at spatial scales that range from tens of centimetres to kilometres, and are also highly variable through time (Bell 2005).

Between the mid-tide level and low water on the lagoon beaches, the sand is occupied by various burrowing species. Burrowing echinoderms, such as the heart urchin *Breyenia australasiae* and large seastar *Luidia australiae*, occur on the edge of the lagoon beaches. The lagoon is home to various crabs, such as the blue swimmer crab *Portunus pelagicus* and large orange spanner crab *Ranina ranina* that are sometimes seen walking on the beach at low tide, but generally burrow in sand at greater depths. Along the tide line of the beaches are numerous holes that are burrows of the stalk-eyed ghost crab *Ocypode ceratophthalma*. Much higher up on the shore, and up to 30 metres inland, are the burrows of another species of ghost crab, *Ocypode cordimana* (Hutton and Harrison 2004). A variety of amphipods (beach fleas) and other small invertebrates inhabit wave-thrown algae and seagrass along the beach strand line.

The calcareous sandy beaches on the east coast that are partially protected by headlands and reef platforms superficially appear to support a similar fauna to that described for the lagoon beaches, although some animals that live in sand off the sheltered lagoon beaches are not found on the east coast. This is presumably due to dissimilar wave climate, slope, compaction and grain size (Hutton and Harrison 2004).

Sandy beach shallows are important nursery and feeding areas for fish and invertebrate species. For example, squid feed in the shallows in the lagoon during winter months and are frequently stranded on Lagoon Beach (Hutton and Harrison 2004). Beaches are also key feeding and roosting sites for seabirds and migratory wading birds.

While there are no seal breeding sites or well-utilised haul-out sites, seals are occasional visitors to the lagoon beaches. Species such as the Australian fur seal *Arctocephalus pusillus* and New Zealand fur seal *A. forsteri* are mostly seen during winter, while the leopard seal *Hydurga leptonyx* is also an occasional visitor (Hutton and Harrison 2004). The occasional fairy penguin *Eudyptula minor*, usually in poor condition or deceased, has been found on the eastern beaches of the island.

4.5 Seagrasses

Seagrasses are flowering plants that are adapted for life submerged in the marine environment. They often form extensive beds described as 'meadows', or can occur in smaller isolated patches. Like terrestrial grasses, they are anchored to the substrate by roots or rhizomes, have leaves with veins, reproduce using flowers and seeds, and require sunlight to grow. Seagrasses are important in maintaining sediment stability and also play a role in improving water quality through uptake of nutrients. They comprise highly productive ecosystems that provide foraging habitats and nursery grounds for marine animals. Various algae are also associated with the seagrass beds, often growing epiphytically on seagrass leaves, and further contribute to productivity and food resources for resident and migratory animal species. Seagrasses occupy sheltered intertidal and shallow subtidal areas of the Lord Howe Island lagoon, and occur on the exposed eastern side of the island at Neds Beach, Middle Beach and in random patches offshore from Blinkys Beach. They are not common on wave exposed sections of the coast outside the lagoon.

Two species of seagrass occur at Lord Howe Island: eelgrass *Zostera muelleri* subsp. *capricorni* (previously named *Zostera capricorni* but re-classified by Jacobs et al 2006) and paddleweed *Halophila ovalis* (Figure 23). The most extensive seagrass beds occur in Hunter and North bays at the northern end of the lagoon, where there is greatest protection from wave action. Here, mixed stands of the two species form narrow crescents off sections of the beaches and occupy a combined area of four hectares of intertidal habitats through to one-metre depths at low tides (Allender and Kraft 1983, Picard 1983). These areas of high seagrass density are characterised by fine sands, while reduced density has been reported in areas of coarser sediment (Pollard and Burchmore 1985). Seagrass is found in smaller patches over the entire length of the lagoon, occurring on sandy sediments in protected pools and other habitats to depths of at least five metres (Kuitert 2003, Picard 1983). While the two species are regularly mixed, *Zostera* is regarded as the dominant species close to shore in North and Hunter bays, while *Halophila* tends to be dominant at the bottom of the lagoonal holes (Environment Australia and Marine Parks Authority 2001, Picard 1983). Temporal variation in seagrass density has been observed and may be associated with winter dieback or other environmental factors (Picard 1983, Pollard and Burchmore 1985).

Seagrass beds provide important habitat for a range of invertebrate species such as bivalve and gastropod molluscs, crabs, shrimps and polychaete worms (Environment Australia and Marine Parks Authority 2001). One large animal living in the seagrass beds is the prickly razor clam *Pinna muricata*, while two other large bivalves – the strawberry cockle *Fragum unedo* and Payten's codakia *Codakia paytenorum* – are abundant on or just below the sand (Hutton and Harrison 2004). The seagrass beds are important nursery areas for juvenile fish, and also provide foraging habitat for green turtles (*Chelonia mydas*) which occur in the lagoon (Environment Australia and Marine Parks Authority 2001). The eastern sea garfish (*Hypohampus australis*), a locally important recreational fish species, utilises seagrass beds for breeding. The endemic pygmy seahorse *Hippocampus colemani* has only been recorded in sparse seagrass patches in Erscotts Hole (Kuitert 2003).

The intertidal seagrass flats at the northern end of the lagoon are important foraging grounds for migratory shorebirds. These birds forage during low tide and include northern hemisphere species such as whimbrels, bar-tailed godwits (Figure 30), ruddy turnstones, Pacific golden plovers and tattlers during summer, and New Zealand double-banded plovers during winter (Hutton and Harrison 2004).



Figure 23.
Halophila ovalis seagrass,
Lord Howe Island Marine
Park. Photo: G. Kelly

5 Pelagic ecosystems

Ocean currents are a major influence on open ocean habitats in the marine park. The East Australian Current dominates ocean circulation around the Lord Howe group (Boland and Church 1981). The north–south undulation of its convergence with cooler waters of the southern temperate Tasman Current results in alternating cooler and warmer waters (Nilsson and Cresswell 1980, Stanton 1981). As with other habitats in the park, this results in a mix of temperate and tropical species in the pelagic environment. In addition, the seamounts crowned by Lord Howe Island and Balls Pyramid modify the large-scale dynamics of the oceanic currents and result in enhanced and highly variable currents, as well as modified circulation patterns (Smith et al 1989). These variations have a major influence on the pelagic environment and biological assemblages in different areas of the park.

The open ocean habitats are inhabited by a wide diversity of marine organisms including whales and dolphins, large pelagic fish, jellyfish and smaller invertebrates (Hutton and Harrison 2004). Microscopic plants known as phytoplankton are the foundation of the food chain, providing food resources for the zooplankton, which consist of a host of microscopic animals and also include the larval phases of many macroscopic marine species. One tiny crustacean, the krill *Thysanoessa gregaria*, is a conspicuous part of the zooplankton fauna in the marine park, forming swarms in spring months (Hutton and Harrison 2004). Species such as this provide prey for larger animal species and so the marine food chain extends upwards, ending with toothed whales such as the sperm whale and large predatory fish species such as sharks.

A close association exists between species in open oceans and other marine habitats. Bottom-dwelling fish species rely on pelagic bait species, linking pelagic food chains with those of seafloor communities (Smale 1992). Biological communities of the shelf habitats of the park, for example, include a broad mix of reef-associated fish and sharks, as well as numerous pelagic species (Environment Australia and Marine Parks Authority 2001). Deep water pelagic fishes reported through fisheries activities include marlin (blue and striped), sharks (Galapagos whaler, tiger, white and mako), sailfish, dolphin fish, yellowfin tuna, wahoo, trevally, bonito, yellowtail kingfish (Figure 8) and spangled emperor fish (Edgecombe 1987).

More recently, additional information on species in pelagic shelf environments has been provided using remote underwater video techniques (Heagney et al 2007). Of the environmental variables measured, current speed had the greatest influence on the species composition of pelagic fish assemblages, while differences in communities were detectable on a scale of tens of kilometres. Of eleven pelagic fish species recorded, seven were abundant and widespread, with the Galapagos whaler shark *Carcharhinus galapagensis* (Figure 17) being most numerous, and yellowtail kingfish, highfin amberjack, silver trevally, Sydney drummer, southern fusilier, and slimy mackerel also common. Some pelagic species exhibited behavioural associations with *C. galapagensis*, perhaps to enhance camouflage or gain a feeding advantage via the superior detection and hunting skills of this species (Heagney et al 2007).

The yellowtail kingfish *Seriola lalandi* is a particularly highly-valued pelagic fisheries species, and some adult kingfish are resident in the park (Patterson and Swearer 2008). This could be due to aggregation of fish at the seamounts for breeding, or alternatively reflect some degree of site fidelity, emphasising the importance of spatially explicit management of this species.

Information on mesopelagic species (species living at depths of between 180 and 900 metres) and bathypelagic species (species living below 1,000 metres) is limited, although some deep water surveys of the Lord Howe Rise and adjacent seamount chains have revealed diverse communities of fish and invertebrates (Clarke et al 2003, de Forges et al 2000). Species living in these deep water environments often have special morphological traits that have allowed them to adapt to high water pressures and dark conditions. For example, fish species have greatly reduced bone and musculature to help them maintain neutral buoyancy, as well as reduced metabolisms associated with a lack of ambient light (Koslow 1997). Species at these depths also tend to be long-lived and slow-growing, and have only sporadically successful recruitment.

Larger megafauna such as whales and dolphins are regularly seen in the park, with the manta ray *Manta birostris* and whale shark *Rhincodon typus* occasionally seen by divers and marine tour operators. The most recent sighting of both species occurred during the summer of 2007–08 (S. Gudge pers comm).

Figure 24.
Diver and fan coral.
Photo: J. Gilligan



6 Estuarine ecosystems

Estuaries are places where freshwater creeks and rivers meet the sea. In their natural state, they are productive systems supporting high levels of floral and faunal diversity, and providing important nursery grounds for fish and invertebrate species. Three small estuaries exist on the western side of Lord Howe Island, all bordering the lagoon. They are intermittently closed to the sea and have small catchment areas. Soldiers Creek is the largest creek and is frequently flushed by tidal inundation (Pollard and Burchmore 1985), but has been observed to be closed to the sea during summer (Aquenal 2006). Cobbys Creek and Old Settlement Creek are small creeks that are infrequently open to incursions of marine water, as little as once a year, and hence remain almost permanently brackish. The frequency and extent of opening of estuaries depends in part on coastal drift processes, which affect the way that sand is eroded or deposited near the estuary mouths. These creeks are mechanically opened intermittently by the Lord Howe Island Board during high rainfall and high tide to reduce household flooding (I. Kerr pers comm).

The estuarine creeks create an aquatic environment characterised by lower average salinity than the neighbouring lagoon, as well as lower dissolved oxygen concentration and pH, and elevated turbidity (Aquenal 2006). When closed to the sea, they may form a trap for organically enriched terrestrial sediments, which results in depleted oxygen concentrations in the sediments and bottom waters, reflected by black colouration of the sediments (Aquenal 2006). While estuarine sediments are frequently rich in invertebrate life, regular closure to the sea and build-up of fine land-based material inhibits the establishment of estuarine assemblages. Therefore, the invertebrate populations in the Lord Howe Island estuaries are comprised of brackish and freshwater invertebrates for much of the year, with true marine species only likely to establish transient populations during periodic tidal exposure. The large mud crab *Scylla* sp. is tolerant of brackish conditions and occurs in the creek environments (Aquenal unpublished data).

The availability of invertebrate food, and its temporal variability associated with salinity and other environmental fluctuations, influences the composition of the estuarine fish assemblage. Limited sampling near the entrance of Soldiers Creek identified two mullet species, Broussonnet's mullet *Mugil broussonnetii* and the sand mullet *Myxus elongatus* (Aquenal 2006), which are typically found near estuary mouths. *Myxus elongatus* spends at least part of its life cycle in freshwater, and the remainder in marine waters. Many estuarine fish species divide their lives between these habitats, and are described as being diadromous. Long-finned eels, which spawn in the Coral Sea but live in fresh water as adults, are reportedly present in Soldiers Creek (Pollard and Burchmore 1985).

Estuaries are also key habitats for migratory and other protected bird species, although the absence of major mudflats at the mouths of the small Lord Howe Island estuaries limit available habitat for birds. Soldiers Creek provides habitat for waterfowl such as introduced mallard ducks, but does not provide feeding grounds for wading shorebirds. These feeding areas are instead provided by the mudflats outside the estuaries, at the northern end of the lagoon.

There are small stands of saltmarsh on the fringes of estuaries at limited sites. The areas of saltmarsh primarily consist of grasses, rushes and reeds such as the saltwater couch *Sporobolus virginicus* and *Triglochin striatum*, the reed *Phragmites australis* and the beardgrass *Polypogon monspeliensis* (Pollard and Burchmore 1985), as well as the herbaceous plant *Sacocornia quinqueflora*, all of which can tolerate inundation by marine tides.

Coastal saltmarsh in the NSW North Coast, Sydney Basin and South East Corner bioregions is listed as an endangered ecological community under the NSW *Threatened Species Conservation Act 1995*. Lord Howe Island forms part of the NSW North Coast Bioregion.

Mangroves comprise the estuarine vegetation community of primary importance at Lord Howe Island. Two species of mangrove occur, the grey mangrove *Avicennia marina* and river mangrove *Aegiceras corniculatum* (Figure 25) (Pollard and Burchmore 1985). Both species occur along the banks of the Soldiers, Old Settlement, and Cobbys creeks (Environment Australia and Marine Parks Authority 2001). *Avicennia marina* is the rarer of the two species, comprising a highly restricted plant community (Picard 1983), while *A. corniculatum* forms larger stands in the creek environments. Soldiers Creek has two main branches which are lined by *A. corniculatum* mangroves, while Cobbys Creek is lined with larger mangroves of this species just upstream of its mouth (Pollard and Burchmore 1985). Mangroves populate the banks of Old Settlement Creek as well as several neighbouring areas (Environment Australia and Marine Parks Authority 2001). Mangroves provide shelter as well as breeding and foraging habitat for fish and invertebrates, and are also considered important for filtering pollutants and stabilising sediments.

A number of species that require an estuarine environment during their early life stages have been found at Lord Howe Island, and the very limited mangrove areas are likely to be important for their continuing survival (Environment Australia and Marine Parks Authority 2001). Species such as the mud crab *Scylla* sp., for example, are typically associated with mangrove-lined estuarine habitats. Clearing and grazing around the remaining stands are considered risks to the sustainability of mangrove communities (Picard 1983).

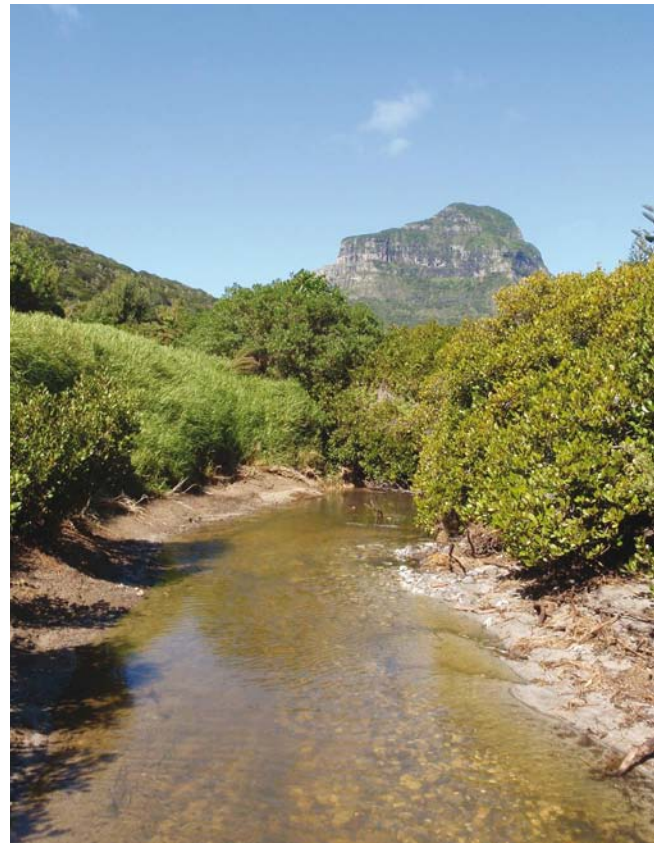


Figure 25.
River mangrove *Aegiceras corniculatum*, Cobbys Creek, Lord Howe Island.
Photo: S. Gudge

7 Other marine species

7.1 Sharks and rays

At least 12 species of sharks and rays are known from shallow inshore and shelf waters of the park. Of these, the Galapagos whaler shark *Carcharhinus galapagensis* is by far the most abundant. It is ubiquitous across lagoonal, fringing reef, shelf and deeper pelagic environments (Allen et al 1976, Aquenal 2008a, 2008b; Heagney et al 2007, Speare et al 2004). In baited video surveys of Lord Howe Island shelf waters, Speare et al (2004) and Marine Parks Authority unpublished (2010) noted a high abundance of Galapagos whaler sharks. Numerous juveniles occur on the shelf, indicating that this area could be an important nursery for the sharks (Heagney et al 2007). At inshore locations, this species tends to be common outside the lagoon, as well as in the lagoon at night (Allen et al 1976). The Galapagos whaler shark has a patchy distribution worldwide, but in Australia is limited to the waters of Lord Howe Island and Balls Pyramid, and Elizabeth and Middleton reefs to the north. A genetic study has shown that the Lord Howe Island population represents a separate stock to the northern reefs, implying that it should be managed as a separate resource as it cannot be replenished from nearby areas (van Herwerden et al 2008).

Additional shark species observed in lower numbers around Lord Howe Island include dogfish sharks such as the cookie cutter shark *Isistius brasiliensis*; hammerheads such as the smooth hammerhead shark *Sphyrna zygaena*; and whaler sharks including the tiger shark *Galeocerdo cuvier*, grey whaler shark *Carcharhinus amblyrhynchos* and blue shark *Prionace glauca* (Allen et al 1976, Heagney et al 2007, Speare et al 2004). Two mackerel sharks, the mako shark *Isurus oxyrinchus* and the threatened great white shark *Carcharodon carcharias*, have also been recorded (Edgecombe 1987, Parker 1994). Whale sharks *Rhincodon typus* were sighted and photographed in the trench between the Island and Balls Pyramid during the summer of 2007–2008. Diver operators have records of additional sightings of whale sharks, although the occurrence is uncommon.

Stingrays are most abundant in sandy habitats where they are often observed partially buried. At least five species have been observed in the park, with the ribbontail stingray *Taeniura brocki* observed in the lagoon (Allen et al 1976), the smooth short-tailed stingray *Dasyatis brevicaudata* recorded from the shelf (Speare et al 2004), and the black stingray *Dasyatis thetidis* and blotched fantail ray *Taeniura meyeni* ubiquitous across shallow inshore and shelf habitats (Figure 26) (Aquenal 2008a, 2008b; Francis and Randall 1993, Speare et al 2004). The manta ray *Manta birostris* has been recorded off Malabar (by diver operators in 2007 and 2009) and has been seen occasionally in the lagoon (S. Gudge pers comm).

Figure 26.
Fantail ray *Taeniura meyeni*,
Lord Howe Island Marine
Park. Photo: J. Gilligan



The shark and ray fauna in Australia is particularly rich, and it is likely that ongoing surveying will continue to identify additional species in the marine park. A survey of deeper seamount habitats on the Lord Howe Rise and Norfolk Ridge identified a high diversity of sharks and rays, with 55 species documented (Clarke et al 2003). These included 28 species of dogfish sharks (Squaliformes), 14 species of ground sharks (Carchariniformes), 11 species of true rays and skates (Rajiformes), one species of cow shark (Hexanchiformes), and one species of electric ray (Torpediniformes). The most widespread species

were dogfish sharks, including the birdbeak dogfish *Deania cf calcea*, and lantern sharks *Etmopterus lucifer* and *Etmopterus* sp. (Clarke et al 2003).

7.2 Marine mammals

Marine mammals occurring in the park consist of cetaceans (whales and dolphins) and pinnipeds (seals and sea lions). Individual seals and sea lions occasionally haul up on Lord Howe Island beaches; however, this is an infrequent occurrence and no breeding occurs (Environment Australia and Marine Parks Authority 2001). Visits occur mostly during winter, when species such as the Australian fur seal *Arctocephalus pusillus doriferus* and New Zealand fur seal *A. forsteri* are observed. The fur seals may stay around the island for some days and are sometimes seen on rocky shores, including Blackburn Island in the lagoon. On rare occasions, the large leopard seal *Hydurga leptonyx* has been seen on local beaches (Hutton and Harrison 2004).

Dolphins live in the waters around Lord Howe Island, with the bottlenose dolphin *Tursiops truncatus* most frequently sighted (Figure 27). An additional species recorded is the common dolphin *Delphinus delphis*, while migratory dolphins such as the spinner dolphin *Stenella longirostris*, the dusky dolphin *Lagenorhynchus obscurus* and pantropical spotted dolphin *Stenella attenuata* are also likely to pass through the park's waters (Environment Australia and Marine Parks Authority 2001). Dolphins sometimes enter the lagoon, or can be seen at other popular fishing spots around the island, and are commonly sighted in the deeper water trench between Lord Howe Island and Balls Pyramid. They feed on fishes, squid and crustaceans.

The marine park is in the migratory pathways of species such as the humpback whale *Megaptera novaeangliae*. The humpback is the most regularly observed whale species, with numbers of sightings apparently increasing in recent times. Humpback whales are sighted on both northern and southern migrations, particularly from August to October or November when mothers and calves return to Antarctic waters from their northern breeding grounds in the Coral Sea (Hutton and Harrison 2004). Other whale species recorded around Lord Howe Island include the sperm whale *Physeter macrocephalus*, pilot whales *Globicephala* sp. and the dense-beaked whale *Mesoplodon densirostris* (Environment Australia and Marine Parks Authority 2001, Hutton and Harrison 2004).

A database search of nationally significant species revealed a wide range of additional cetaceans, with 31 species listed as potentially occurring in the park's waters. Marine mammals are protected in Commonwealth and State waters as threatened, migratory or marine species, and are categorised as having national significance. Of particular interest are those categorised as threatened or subject to international and national agreements (Environment Australia and Marine Parks Authority 2001).



Figure 27. Offshore bottlenose dolphin *Tursiops truncatus*, Lord Howe Island Marine Park. Photo: S. Gudge

7.3 Marine reptiles

Marine reptiles in the park consist of turtles and sea snakes. At least four species of turtle reside in or periodically migrate through the park's waters, with sightings generally more common in summer than winter months (Pollard and Burchmore 1985):

- the green turtle *Chelonia mydas* is the most frequent species observed (Figure 28); it occurs from the sheltered habitats of the lagoon through to the offshore fringing reefs and deeper shelf waters of the park (Aqueenal 2008a, Environment Australia and Marine Parks Authority 2001, Hutton and Harrison 2004), and feeds predominantly on seagrass and algae
- the hawksbill turtle *Eretmochelys imbricata*, previously recorded on the Lord Howe Island shelf (Environment Australia and Marine Parks Authority 2001) is also observed in the lagoon; it feeds primarily on sponges but also consumes seagrasses, algae, soft corals and shellfish
- the leatherback turtle *Dermochelys coriacea* has been sighted very occasionally and is likely to migrate periodically through the park's waters; it has a carnivorous diet consisting of jellyfish and other soft-bodied invertebrates
- the loggerhead turtle *Caretta caretta* is a visitor in the park during trans-Pacific migrations; it feeds mostly on shellfish, crabs, sea urchins and jellyfish.

Populations of turtle species possess high conservation value. There are no recent records of turtles nesting on the islands of the park, although some historical records imply that turtles were caught on beaches and may have been nesting on Lord Howe Island during early human settlement in the eighteenth century (Pollard and Burchmore 1985). Lord Howe Island is famous for its extinct horned turtle *Meiolania*. Important fossil sites for this species are located between Neds Beach and the lagoon at the north end of the island (Biosis Research 1998). Occasionally post-hatchling sea turtles wash up on the island's beaches, both on the lagoon beaches and the more exposed eastern coast.

The most conspicuous sea snake at Lord Howe Island is the yellow-bellied sea snake *Pelamis platurus*, which regularly washes up on the lagoon beaches where it may survive out of the water for some time (Hutton and Harrison 2004). This species is pelagic and is found over a wide area of the Pacific and Indian oceans. Numerous other sea snakes are likely to occur in the park's waters, with at least 11 species known in neighbouring NSW waters (Marine Parks Authority 2008). Sea snakes are highly venomous and feed on a variety of small reef fish such as gobies, or on fish eggs (Hutton and Harrison 2004).

Figure 28.
Green turtle *Chelonia mydas*, Lord Howe Island Marine Park.
Photo: J. Gilligan



7.4 Birds

At least 168 bird species have been recorded in the Lord Howe Island group since settlement, with over 70% of these being only occasional visitors or vagrants, and the remainder having a stable and permanent association with the island (Hutton 1991, United Nations Environment Program 2008). While some unique endemic species are limited to terrestrial habitats, the primary wealth of birdlife on the island in terms of numbers and diversity is the seabird population (Hutton 1991). Birds that utilise marine habitats in the park consist primarily of the 'true' seabirds, as well as waders and other shorebirds, while waterfowl species such as ducks feed in the limited available estuarine habitats.



Figure 29.
Sooty tern. Photo: G. Kelly

The Lord Howe Island Group is considered to be one of the major seabird breeding sites in the south-west Pacific (Biosis Research 1998, Hutton 1991). There are remarkably few islands in the Tasman Sea; consequently, seabirds come to roost and breed on Lord Howe Island in the hundreds of thousands. In all, 14 breeding species are present. There is an interesting mix of tropical and temperate species, with the largest numbers of seabirds present in spring and summer, but there is sustained activity all year round (Hutton 1991). Breeding sites are located above the littoral zone, although many species rely on rocky shores and intertidal flats for roosting, resting, and feeding, as well as on the open ocean waters for capturing food.

Seabirds breeding on the islands of the marine park include the masked booby, grey ternlet, sooty tern (Figure 29), common noddy, black noddy, white tern, red-tailed tropicbird, wedge-tailed shearwater, flesh-footed shearwater, black-winged petrel, white-bellied storm petrel, kermadec petrel, providence petrel and little shearwater (Hutton 1991). Lord Howe Island (and probably Balls Pyramid) is one of only two known breeding grounds for the providence petrel, the other one being Phillip Island near Norfolk Island (Hutton 1991). Balls Pyramid is the only known location in Australia where the kermadec petrel breeds (Hutton 1991). An estimated half of the world's population of fleshy-footed shearwaters breeds on the island, while the red-tailed tropic bird breeds at Lord Howe Island in greater concentrations than probably anywhere else in the world. The island also has the most southerly breeding colony for the masked booby (Hutton 1991), one of the most southerly breeding locations for both the sooty tern (Figure 29) and the common noddy, and one of only two known breeding locations in Australian waters for the grey ternlet (Hutton 1991).

White-bellied storm petrels and kermadec petrels bred on the precipitous cliffs of Mt Gower and Lidgbird until the accidental introduction of the ship rat *Rattus rattus* to the main island in 1918. They are now confined to breeding on rat-free offshore islands and Balls Pyramid, respectively.

Seabird activity is closely linked to the food supply of the oceans. Generally, the smaller the seabird, the smaller the marine prey it requires for food. Consequently, there is a tendency for the smaller seabirds to breed earlier, feeding on smaller organisms at the lower end of the food chain (Hutton 1991). The primary food sources for seabirds are crustaceans, fish and squid of varying sizes. Some seabirds depend on the action of large pelagic fish that force smaller fish to the surface within reach of birds (Environment Australia and Marine Parks Authority 2001).



Figure 30.
Bar tailed godwit.
Photo: G. Kelly

Other bird species regularly visit the island to forage rather than breed. In particular, shorebirds that breed in the northern hemisphere migrate to foraging grounds at Lord Howe Island and other Australian sites during the southern hemisphere summer. Four such species coming regularly to Lord Howe in reasonable numbers include the whimbrel, Pacific golden plover, ruddy turnstone and bar-tailed godwit (Figure 30) (Hutton 1991). A fifth regular visitor is the double-banded plover, a summer breeding bird from New Zealand that crosses the Tasman Sea to Australia each year. Additional migratory species seen in smaller numbers at Lord Howe Island include the red-necked stint, greenshank, eastern curlew, Mongolian sand dotterel, greater sand-plover, lesser sand-

plover, black-tailed godwit, wandering tattler and grey-tailed tattler (Biosis Research 1998, Hutton 1991). Primary foraging sites for these migratory species include swampy areas and tidal mudflats, with the protected shores of North Bay comprising a feeding hot spot.

A large proportion of the seabirds that breed on the islands, as well as a smaller number of species that are occasional visitors, are listed as threatened in NSW. In addition, many of the migratory species that utilise Lord Howe for foraging are protected under Commonwealth legislation and international agreements (Table 1 on page 42, and section 7.5 below).

7.5 Threatened, protected, rare and endemic marine species

Threatened fish species in NSW are listed in the *Fisheries Management Act 1994*, while additional species listed as 'protected' from fishing activities are also listed in this Act. The black cod *Epinephelus daemeli* and great white shark *Carcharodon carcharias* are listed as vulnerable, while three other fish species and all members of the Family Syngnathidae are listed as protected (see Table 1). Members of the Syngnathiformes, as well as the Order Squamata (sea snakes) are classified as listed marine species in the Commonwealth *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). Syngnathids, such as pipehorses, seahorses and pipefishes, have been recorded in the park from the shallows of the lagoon through to the deep waters of the seamount slope (Clarke et al 2003, Kuitert 2003). The protected elegant wrasse *Anampses elegans* occurs on shallow reefs in the lagoon.

Two additional species not included in Table 1 are the doubleheader wrasse *Coris bulbifrons* (Figure 11) and the lionfish *Pterois volitans* but they are not listed as totally protected species in NSW. There is a ban on spearfishing of all species in the State Waters of the park. Note that while the bluefish *Girella cyanea* (Figure 13) is totally protected from fishing in other NSW waters, limited fishing of this species is allowed at Lord Howe Island.

Threatened seabirds and marine mammals and reptiles are listed in the NSW *Threatened Species Conservation Act 1995*. Several threatened species may be found in the marine park at different times of the year, often passing through on their yearly migration along the east coast. The green turtle *Chelonia mydas* (Figure 28) is often seen in the lagoon, particularly around Sylphs Hole in Hunter Bay, and in various other locations. The hawksbill turtle *Eretmochelys imbricata* also occurs in the lagoon and offshore reef locations.

Turtles are listed in state legislation and the Commonwealth EPBC Act as threatened, and a national recovery plan for all species of sea turtles has been prepared by the Australian Government. Similarly, national recovery plans have been developed for whale species listed as threatened under both state and Commonwealth legislation, including those that are likely to occur in the marine park (Table 1). Whale sharks *Rhincodon typus* are listed as vulnerable, though they are rarely seen in the marine park. The seal species classified as vulnerable in NSW are included as listed marine species in the EPBC Act. Migratory dolphins that are likely to occur in the park (e.g. the dusky dolphin *Lagenorhynchus obscurus*) are not listed as threatened but are included as listed marine species in the EPBC Act.

Of the 14 seabird species that breed in the park, 11 are listed as vulnerable in NSW (Table 1). A number of these species are also classified as threatened, migratory or listed marine species in the Commonwealth EPBC Act. An additional four species listed as vulnerable in NSW forage in intertidal habitats and are occasional visitors to the park (Biosis Research 1998; Table 1). These are migratory species that breed in the northern hemisphere, with the exception of the pied oystercatcher *Haematopus longirostris*, which is a resident species. Four albatross species that occur in the vicinity of the park are also listed as threatened in both state and Commonwealth legislation, and a national recovery plan has been prepared that includes these species. Wading shorebirds that visit from the northern hemisphere to forage at Lord Howe Island, including both threatened and non-threatened species, are listed as migratory species in the EPBC Act, and international agreements have been implemented for their protection (e.g. the Japan–Australia Migratory Birds Agreement (JAMBA)).

A relatively high number of endemic marine plants and animals live on Lord Howe Island, with an equivalent group of species restricted to the broader region of Lord Howe Island, Norfolk Island, and Elizabeth and Middleton reefs. The endemic biota in shallow reef habitats comprises approximately 4% of total fish (Allen et al 1976, Francis 1991, 1993), 8% of echinoderms (Hoggett and Rowe 1988), 15% of macroalgal species (Kraft 2000, Millar and Kraft 1993, 1994a, 1994b) and an estimated 5% of molluscs (Ponder et al 2000). No endemic coral species have been identified (Harriott et al 1993, Veron and Done 1979), although few islands worldwide exceed the levels of endemism indicated above for other fauna and flora groups. Levels of endemism in deeper shelf and slope habitats of the park are still poorly understood, but initial assessments indicate they may exceed 10% for some taxa (Ponder et al 2000).

The recent description of an endemic Lord Howe Island seahorse (Kuitert 2003), indicates the high likelihood that future studies will identify additional endemic species (Aquenal 2008a). Nevertheless, some endemic species may also be found to be more widely distributed than currently recognised (Hoggett and Rowe 1988), so the proportion of island endemic species will probably not change greatly in the medium term (Aquenal 2008a).

Table 1.

Endangered, vulnerable and protected marine species (including seabirds) under NSW and Commonwealth legislation that occur, or are likely to occur, in the marine park.

COMMON NAME	SCIENTIFIC NAME	STATUS
Blue whale	<i>Balaenoptera musculus</i>	Endangered
Loggerhead turtle	<i>Caretta caretta</i>	Endangered
Wandering albatross	<i>Diomedea exulans</i>	Endangered ^v
Black cod	<i>Epinephelus daemeli</i>	Vulnerable
Great white shark	<i>Carcharodon carcharias</i>	Vulnerable
Green turtle	<i>Chelonia mydas</i>	Vulnerable
Leatherback turtle	<i>Dermochelys coriacea</i>	Vulnerable
Humpback whale	<i>Megaptera novaeangliae</i>	Vulnerable
Southern right whale	<i>Eubalaena australis</i>	Vulnerable
Sperm whale	<i>Physeter macrocephalus</i>	Vulnerable
Whale shark	<i>Rhincodon typus</i>	Vulnerable
New Zealand fur seal	<i>Arctocephalus forsteri</i>	Vulnerable
Australian fur seal	<i>Arctocephalus pusillus doriferus</i>	Vulnerable
Masked booby	<i>Sula dactylatra</i>	Vulnerable ^b
Grey ternlet	<i>Procelsterna cerulea</i>	Vulnerable ^b
Sooty tern	<i>Sterna fuscata</i>	Vulnerable ^b
White tern	<i>Gygis alba</i>	Vulnerable ^b
Black-winged petrel	<i>Pterodroma nigripennis</i>	Vulnerable ^b
Kermadec petrel	<i>Pterodroma neglecta</i>	Vulnerable ^b
Providence petrel	<i>Pterodroma solandri</i>	Vulnerable ^b
White-bellied storm petrel	<i>Fregetta grallaria</i>	Vulnerable ^b
Little shearwater	<i>Puffinus assimilis</i>	Vulnerable ^b
Flesh-footed shearwater	<i>Puffinus carneipes</i>	Vulnerable ^b
Red-tailed tropicbird	<i>Phaethon rubricauda</i>	Vulnerable ^b
Pied oystercatcher	<i>Haematopus longirostris</i>	Vulnerable ^r
Greater sand-plover	<i>Charadrius leschenaultii</i>	Vulnerable ^r
Lesser sand-plover	<i>Charadrius mongolus</i>	Vulnerable ^r
Black-tailed godwit	<i>Limosa limosa</i>	Vulnerable ^r
Shy albatross	<i>Thalassarche cauta</i>	Vulnerable ^v
Antipodean albatross	<i>Diomedea antipodensis</i>	Vulnerable ^v
Gibson's albatross	<i>Diomedea gibsoni</i>	Vulnerable ^v
Ballina angelfish	<i>Chaetodontoplus ballinae</i>	Protected
Elegant wrasse	<i>Anampses elegans</i>	Protected
All Syngnathids	Syngnathidae	Protected
Bluefish	<i>Girella cyanea</i>	Protected [*]

b = seabird: breeding population/s present in the park.

r = seabird: occasional visitor, rarely observed.

v = seabird: likely to occur in the vicinity of the park.

* = The taking of bluefish is allowed at Lord Howe Island; bag limits apply and sale is prohibited.

8 Further reading

- Allen GR, Hoese DF, Paxton JR, Randall JE, Russell BC, Starck WA, Talbot FH and Whitley GP 1976, 'Annotated checklist of the fishes of Lord Howe Island', *Records of the Australian Museum* 30, pp 365–454.
- Allen GR and Paxton JR 1974, 'A tropical outpost in the Pacific', *Australian Natural History* 18, pp 50–55.
- Allender BM and Kraft GT 1983, 'The marine algae of Lord Howe Island (New South Wales): the Dictyotales and Cutleriales (Phaeophyta)', *Brunonia* 6, pp 73–130.
- ANZECC TFMPA 1998a, *Strategic plan of action for establishing the national representative system of marine protected areas*, Environment Australia, Canberra.
- ANZECC TFMPA 1998b, *Interim marine and coastal regionalisation for Australia. An ecosystem based classification for marine and coastal environments*, Environment Australia, Canberra.
- Aquenal 2006, *Exotic marine pests survey, Lord Howe Island, New South Wales*, report prepared by Aquenal Pty Ltd for the NSW Marine Parks Authority.
- Aquenal 2008a, *Baseline surveys of marine flora and fauna at Lord Howe Island Marine Park, New South Wales, February 2006*, report prepared by Aquenal Pty Ltd for the NSW Marine Parks Authority.
- Aquenal 2008b, *Monitoring of biotic changes at Lord Howe Island Marine Park, New South Wales February 2008*, report prepared by Aquenal Pty Ltd for the NSW Marine Parks Authority.
- Auster PJ, Malatesta RJ and LaRosa SC 1995, 'Patterns of microhabitat utilization by mobile megafauna on the southern New England (USA) continental shelf and slope', *Marine Ecology Progress Series* 127, pp 77–85.
- Australian Museum 2007, *Description of key species groups in the East Marine Region*, Australian Museum, Sydney.
- Australian Museum Business Services 1998, *Proposed Lord Howe Island Marine Park marine fish and invertebrate data investigation*, report by Australian Museum Business Services for Environment Australia, Canberra.
- Bell TA 2005, 'The impact of four wheel drive vehicles on, and the natural variation of, sandy beach meiofauna', MSc thesis, University of New England, Armidale.
- Biosis Research 1998, *World Heritage values and other values of the Lord Howe Island Group – update*, report prepared by Biosis Research.
- Black K, Swearer S and Symonds G 2008, *Understanding larval dispersal and the interconnected wave and wind-driven circulation at Lord Howe Island: numerical modelling, empirical observations and model validation*, preliminary report prepared by ASR Marine Consulting and Research for the NSW National Parks and Wildlife Service.
- Boland FM and Church JA 1981, 'The East Australian Current 1978', *Deep Sea Research* 28, pp 937–957.
- Brooke B, Woodroffe C, Linklater M, McArthur M, Nichol S, Jones B, Kennedy D, Buchanan C, Spinoccia M, Mleczo R, Cortese A, Atkinson I and Sexton M 2010, *Geomorphology of the Lord Howe Island shelf and submarine volcano, SS06–2008 post-survey report*, Geoscience Australia, record 2010/XX.
- Brooke BP, Murray-Wallace CV, Woodroffe CD and Heijnis H 2003a, 'Quaternary calcarenite stratigraphy on Lord Howe Island, south-western Pacific Ocean and the record of coastal carbonate deposition', *Quaternary Science Reviews* 22, pp 859–880.
- Brooke BP, Woodroffe CD, Murray-Wallace CV, Heijnis H and Jones BG 2003b, 'Quaternary aminostratigraphy of eolianite on Lord Howe Island, south-west Pacific Ocean', *Quaternary Science Reviews* 22, pp 213–232.
- Brown I 1979, 'Birds of Ball's Pyramid, Lord Howe Island', *Australian Birds* 13, pp 41–42.
- Bullard JM 2003, 'Assessing the status of the marine benthic communities at Lord Howe Island using video transects', Honours thesis, Southern Cross University.
- Bureau of Meteorology 2009, *Climate statistics for Australian locations: summary statistics Lord Howe Island Aero*, Bureau of Meteorology, Commonwealth of Australia, available at: www.bom.gov.au/climate/averages/tables/cw_200839.shtml.
- Clarke M, Roberts C, Williams A and Last P 2003, *Voyage report of a biodiversity survey of seamounts and slopes of the Norfolk Ridge and Lord Howe Rise (NORFANZ), May-June 2003*, CSIRO, Hobart.

- Coleman N 2002, *Lord Howe Island Marine Park: sea shore to sea floor. World Heritage Wildlife Guide*, Neville Coleman's Underwater Geographic Pty Ltd.
- Commonwealth of Australia 2006, *A guide to the integrated marine and coastal regionalisation of Australia version 4.0*, Department of the Environment and Heritage, Canberra.
- Davey A 1986, *Plan of management: Lord Howe Island Permanent Park Preserve*, NSW National Parks and Wildlife Service, Sydney.
- de Forges BR, Koslow JA and Poore GCB 2000, 'Diversity and endemism of the benthic seamount fauna in the southwest Pacific', *Nature* 405, pp 944–947.
- de Vantier LM and Andrews GJ 1987, *Report on surveys of the distribution, abundance and impact of Acanthaster planci on the fringing reefs of Lord Howe Island and the Solitary Islands*, Australian Institute of Marine Science, Townsville.
- de Vantier LM and Deacon G 1990, 'Distribution of *Acanthaster planci* at Lord Howe Island, the southernmost Indo-Pacific reef', *Coral Reefs* 9, pp 145–148.
- Department of Environment, Water, Heritage and the Arts 2009, *The East Marine Bioregional Plan – bioregional profile*, Department of Environment, Water, Heritage and the Arts, Canberra.
- Dickson ME, Kennedy DM and CD Woodroffe 2004, 'The influence of rock resistance on coastal morphology around Lord Howe Island, south-west Pacific', *Earth Surface Processes and Landforms* 29, pp 629–643.
- Dickson ME and Woodroffe CD 2005, 'Rock coast morphology in relation to lithology and wave exposure, Lord Howe Island, south-west Pacific', *Annals of Geomorphology* 49, pp 239–251.
- Edgar GJ, Davey A, Kelly G, Mawbey R, and Parsons K (in press) 'Biogeographical and ecological context for managing threats to coral and rocky reef communities in the Lord Howe Island Marine Park, south-western Pacific', *Aquatic Conservation: Marine and Freshwater Ecosystems*.
- Edgecombe J 1977, 'Saving Lord Howe Island', *Habitat* 5, pp 10–19.
- Edgecombe J 1987, *Lord Howe Island World Heritage Area*, Australian Environmental Publications, NSW.
- Environment Australia 2002, *Lord Howe Island Marine Park (Commonwealth Waters) Management Plan, 2002*, Environment Australia, Canberra.
- Environment Australia and Marine Parks Authority 2001, *Lord Howe Island Marine Park issues paper. A planning issues paper for the Lord Howe Island Marine Park (State and Commonwealth waters)*, Environment Australia, Canberra, and NSW Marine Parks Authority.
- Environmental Water Monitoring 2000, *Lord Howe Island groundwater quality: study and assessment of groundwater quality*, report prepared by Environmental Water Monitoring for the Lord Howe Island Board.
- Ferrell DJ 2005, *Biological information for appropriate management of endemic fish species at Lord Howe Island*, NSW Department of Primary Industries, Cronulla.
- Francis MP 1991, 'Additions to the fish faunas of Lord Howe, Norfolk, and Kermadec islands, south-west Pacific Ocean', *Pacific Science* 45, pp 204–220.
- Francis MP 1993, 'Checklist of the coastal fishes of Lord Howe, Norfolk, and Kermadec islands, south-west Pacific Ocean', *Pacific Science* 47, pp 136–170.
- Francis MP and Randall JE 1993, 'Further additions to the fish faunas of Lord Howe and Norfolk islands, south-west Pacific Ocean', *Pacific Science* 47, pp 118–135.
- Gaffney ES 1991, 'The fossil turtles of Australia, chapter 19' in P Vickers-Rich, JM Monaghan, RF Baird and TH Rich (eds), *Vertebrate Palaeontology of Australasia*, pp 704–720, Pioneer Design Studio, Melbourne.
- Gillanders BM, Ferrell DJ and Andrews NL 2001, 'Estimates of movements and life-history parameters of yellowtail kingfish (*Seriola lalandi*): how useful are data from a cooperative tagging programme?', *Marine and Freshwater Research* 52, pp 179–192.
- Gladstone W 2005, 'Requirements for marine protected areas to conserve the biodiversity of rocky reef fishes', *Aquatic Conservation: Marine and Freshwater Ecosystems*, 15.
- Hamon BV 1979, *Mean sea level at Norfolk Island and Lord Howe Island*, CSIRO Division of Fisheries and Oceanography, Cronulla.

- Harriott VJ 1992, 'Recruitment patterns of scleractinian corals in an isolated sub-tropical reef system', *Coral Reefs* 11, pp 215–219.
- Harriott VJ 1995, 'Is the crown-of-thorns starfish a threat to the reefs of Lord Howe Island?', *Aquatic Conservation: Marine and Freshwater Ecosystems* 5, pp 179–190.
- Harriott VJ 1999, 'Coral growth in subtropical eastern Australia', *Coral Reefs* 18, pp 281–291.
- Harriott VJ and Banks SA 2002, 'Latitudinal variation in coral communities in eastern Australia: a qualitative biophysical model of factors regulating coral reefs', *Coral Reefs* 21, pp 83–94.
- Harriott VJ, Harrison PL and Banks SA 1993, *The marine benthic communities of Lord Howe Island*, report prepared by the Centre for Coastal Management, University of New England, for the Australian National Parks and Wildlife Service.
- Harriott VJ, Harrison PL and Banks SA 1995, 'The coral communities of Lord Howe Island', *Marine and Freshwater Research* 46, pp 457–465.
- Harrison PL 2008, 'Coral spawn slicks at Lord Howe Island, Tasman Sea, Australia; the world's most southerly coral reef', *Coral Reefs* 27, p 35.
- Harrison PL and Carroll AG 2002, *Monitoring of coral reef communities at Lord Howe Island, northern NSW*, Coastcare Grant Report, School of Environmental Science and Management, Southern Cross University, NSW.
- Harrison PL, Harriott VJ and Banks SA 1995, *Status of coral reef benthic communities of Lord Howe Island*, report prepared by the Centre for Coastal Management, Southern Cross University, for the Australian Nature Conservation Agency.
- Hayes DE and Ringis J 1973, 'Seafloor spreading in the Tasman Sea', *Nature* 243, pp 454–458.
- Heagney E, Lynch TP, Babcock RC and Suthers I 2007, 'Pelagic fish assemblages assessed using mid-water baited video: standardising fish counts using bait plume size', *Marine Ecology Progress Series* 350, pp 255–266.
- Heagney E, Lynch TP, Babcock RC and Suthers I in press, 'Pelagic fish assemblages on the Lord Howe Island continental shelf assessed using mid-water baited video: accounting for current speed', *Marine Ecology Progress Series*.
- Hedley C and Hull AFB 1912, 'The polyplacophora of Lord Howe Island and Norfolk Islands', *Proceedings of the Linnean Society of New South Wales* 37, pp 271–281.
- Hensley DA and Randall JE 1993, 'Description of a new flatfish of the Indo-Pacific genus *Crossorhombus* (Teleostei: Bothidae), with comments on congeners', *Copeia* 4, pp 1119–1126.
- Highsmith RC 1982, 'Reproduction by fragmentation in corals', *Marine Ecology Progress Series* 7, pp 207–226.
- Hill PJ, Rollet N, Rowland D, Calver CR and Bathgate J 2000a, *Swath-mapping and geophysical survey of Australia's south-east marine zone: AUSTREA-1 research cruise using L'Atalante*, Australian Geological Survey Organisation, Record 2000/4.
- Hill PJ, Rollet N, Rowland D, Calver CR and Bathgate J 2000b, *Seafloor mapping of the south-east region and adjacent waters. AUSTREA-1 cruise report: Lord Howe Island, south-east Australian margin and central Great Australian Bight*, Australian Geological Survey Organisation/National Oceans Office, Canberra.
- Hoggett AK and Rowe FWE 1988, 'Zoogeography of echinoderms on the world's most southern coral reefs', in Burke RD, Mladenov PV, Lampert P and Parsley RL (eds) *Echinoderm Biology*, pp 379–387, proceedings of the Sixth International Echinoderm Conference, Victoria, 23–28 August 1987, Rotterdam, Balkema.
- Hutchins JB, Pearce AF and Walker DI 1991, 'Dispersal of tropical fishes to temperate seas in the southern hemisphere', *Royal Society of Western Australia* 74, pp 79–84.
- Hutton I 1986, *Discovering Australia's World Heritage: Lord Howe Island*, Conservation Press, Canberra.
- Hutton I 1991, *Birds of Lord Howe Island, past and present*, Ian Hutton, Coffs Harbour.
- Hutton I 2002, *A field guide to the birds of Lord Howe Island*, Ian Hutton, Lord Howe Island.
- Hutton I and Harrison P 2004, *A field guide to the marine life of Lord Howe Island*, Ian Hutton, Lord Howe Island.
- Jacobs SWL, Les DH and Moody ML 2006, 'New combinations in Australasian *Zostera* (Zosteraceae)', *Telopea* 11, pp 127–128.
- Jones AR and Short AD 1995, 'Sandy beaches', in Underwood AJ and Chapman MG (eds), *Coastal marine ecology of temperate Australia*, pp 136–151.

- Kaplan G 1997, 'Effects of major storm events on coral reef communities, with reference to Lord Howe Island', integrated project for Bachelor of Applied Science, Southern Cross University.
- Kennedy DM 2003, 'Surface lagoonal sediments on Lord Howe Island, Tasman Sea', *Journal of Coastal Research* 19, pp 57–63.
- Kennedy DM and Woodroffe CD 2000, 'Holocene lagoonal sedimentation at the latitudinal limits of reef growth, Lord Howe Island, Tasman Sea', *Marine Geology* 169, pp 287–304.
- Kennedy DM, Woodroffe CD, Jones BG, Dickson ME and Phipps CVG 2002, 'Carbonate sedimentation on subtropical shelves around Lord Howe Island and Balls Pyramid, south-west Pacific', *Marine Geology* 188, pp 333–349.
- Koslow JA 1997, 'Seamounts and the ecology of deep-sea fisheries', *American Scientist* 85, pp 168–176.
- Koslow JA and Gowlett-Holmes K 1998, *The seamount fauna off southern Tasmania: benthic communities, their conservation and impacts of trawling*, final report to Environment Australia and the Fisheries Research and Development Corporation, Canberra.
- Koslow JA, Gunn J and Rintoul SR 1998, *Deep-water ecosystem structure and the management of a proposed deep-water marine park south of Tasmania*, report to Environment Australia, Canberra.
- Kraft GT 2000, 'Marine and estuarine benthic green algae (Chlorophyta) of Lord Howe Island, south-western Pacific', *Australian Systematic Botany* 13, pp 509–648.
- Kraft GT and Abbott IA 2003, '*Hydroclathrus* (Scytosiphonaceae, Phaeophyceae): conspectus of the genus and proposal of new species from Australia and Hawaii', *Phycological Research* 51, pp 244–258.
- Kuiter RH 2001, 'Revision of the Australian seahorses of the genus *Hippocampus* (Syngnathiformes: Syngnathidae) with descriptions of nine new species', *Records of the Australian Museum* 53, pp 293–340.
- Kuiter RH 2003, 'A new pygmy seahorse (Pisces: Syngnathidae: *Hippocampus*) from Lord Howe Island', *Records of the Australian Museum* 55, pp 113–116.
- Linklater M 2009, 'An assessment of the geomorphology and benthic environments of the Lord Howe Island shelf, south-west Pacific Ocean, and implications for Quaternary sea level', unpublished environmental science report, University of Wollongong, 145 pp.
- Lindsay M 2004, 'How the lack of ecological information effects the siting of marine reserves: a case study of the Lord Howe Island Marine Park', Honours thesis, University of Melbourne.
- Lindsay MJ, Patterson HM and Swearer SE 2008, 'Habitat as a surrogate measure of reef fish diversity in the zoning of the Lord Howe Island Marine Park, Australia', *Marine Ecology Progress Series* 353, pp 265–273.
- Lord Howe Island Board 1985, '*Lord Howe Island: regional environmental study*', Lord Howe Island Board, Sydney.
- Marine Parks Authority 2004, '*User's guide to the zoning plan, Lord Howe Island Marine Park*', NSW Marine Parks Authority.
- Marine Parks Authority 2008, '*Natural values of the Solitary Islands Marine Park*', NSW Marine Parks Authority.
- Marine Parks Authority 2010, '*Benthic fish assemblages in deep water habitats around Lord Howe Island*', NSW Marine Parks Authority.
- Martinez JI 1994, 'Late Pleistocene palaeoceanography of the Tasman Sea: implications for the warm pool in the western Pacific', *Palaeogeography, Palaeoclimatology, Palaeoecology* 112, pp 19–62.
- McDougall I, Embleton BJJ and Stone DS 1981, 'Origin and evolution of Lord Howe Island, south-west Pacific Ocean', *Journal of the Geological Society of Australia* 28, pp 155–176.
- Millar AJ 2004, 'New records of marine benthic algae from New South Wales, eastern Australia', *Phycological Research* 52, pp 117–128.
- Millar AJK and Freshwater DW 2005, 'Morphology and molecular phylogeny of the marine algal order Gelidiales (Rhodophyta) from New South Wales, including Lord Howe and Norfolk Islands', *Australian Systematic Botany* 18, pp 215–263.

- Millar AJK and Kraft GT 1993, 'Catalogue of marine and freshwater red algae (Rhodophyta) of New South Wales, including Lord Howe Island, south-western Pacific', *Australian Systematic Botany* 6, pp 1–90.
- Millar AJK and Kraft GT 1994a, 'Catalogue of marine benthic green algae (Chlorophyta) of New South Wales, including Lord Howe Island, south-western Pacific', *Australian Systematic Botany* 7, pp 419–453.
- Millar AJK and Kraft GT 1994b, 'Catalogue of marine brown algae (Phaeophyta) of New South Wales, including Lord Howe Island, south-western Pacific', *Australian Systematic Botany* 7, pp 1–46.
- Miller KJ and Ayre DJ 2004, 'The role of sexual and asexual reproduction in structuring high latitude populations of the reef coral *Pocillopora damicornis*', *Heredity* 92, pp 557–568.
- Nilsson CS and Creswell GR 1980, 'The formation and evolution of east Australian current warm-core eddies', *Progress in Oceanography* 9, pp 133–183.
- O'Hara TD 2008, *Bioregionalisation of the waters around Lord Howe and Norfolk Islands using brittle stars (Echinodermata: Ophiuroidea)*, Department of the Environment, Water, Heritage and the Arts (Australia) and Museum Victoria.
- Parker P 1993, 'Lord Howe Island Marine Reserve: the final stages of planning', *National Parks Journal* 37, pp 15–17.
- Parker P 1994, 'The rediscovery of the Ballina Angelfish *Chaetodontoplus ballinae*, two new fish records for Lord Howe Island, Australia', *Freshwater and Marine Aquarium* August, pp 112–115.
- Patterson HM, Lindsay M and Swearer SE 2007, 'Use of sonar transects to improve efficiency and reduce potential bias in visual surveys of reef fishes', *Environmental Biology of Fish* 78, pp 291–297.
- Patterson HM and Swearer SE 2007, 'Long-distance dispersal and local retention of larvae as mechanisms of recruitment in an island population of a coral reef fish', *Austral Ecology* 32, pp 122–130.
- Patterson HM and Swearer SE 2008, 'Origin of yellowtail kingfish, *Seriola lalandi*, from Lord Howe Island, Australia, inferred from otolith chemistry', *New Zealand Journal of Marine and Freshwater Research* 42, pp 409–416.
- Picard J 1983, 'Vegetation of Lord Howe Island', *Cunninghamia* 1, pp 133–265.
- Pichon M 1995, *An assessment of the nature conservation values of the Commonwealth waters surrounding Lord Howe Island*, report prepared by the Australian Institute of Marine Science, Townsville, for the Australian Nature Conservation Agency.
- Pollard D and Burchmore J 1985, *Lord Howe Island regional environmental study: marine environment with a proposal for an aquatic reserve*, report prepared by the Department of Agriculture, Sydney, for the Lord Howe Island Board.
- Ponder WF 1981, 'Marine mollusca', in HF Recher and WF Ponder (eds) *Lord Howe Island: a summary of current and projected scientific and environmental activities*, Occasional Reports of the Australian Museum No. 1, p 10.
- Ponder WF, Loch I and Berents P 2000, *An assessment of the marine invertebrate fauna of the Lord Howe Island shelf*, report prepared by the Australian Museum, Sydney for Environment Australia.
- Poore GCB, Just J and Cohen BF 1994, 'Composition and diversity of Crustacea Isopoda of the southeastern Australian continental slope', *Deep-Sea Research* 41, pp 677–693.
- Roff JC, Taylor ME and Laughren J 2003, 'Geophysical approaches to the classification, delineation and monitoring of marine habitats and their communities'. *Aquatic Conservation: Marine and Freshwater Ecosystems* 13, pp 77–90.
- Smale MJ 1992, 'Predatory fish and their prey – an overview of trophic interactions in the fish communities of the west and south coasts of South Africa', *Buenguela Trophic Functioning* 12, pp 803–821.
- Smith KL, Schwab WC, Noble M and de Moustier C 1989, 'Physical, geological and biological studies on four Pacific seamounts: introduction', *Deep Sea Research* 36, pp 1785–1790.
- Smith SDA 2005, 'Rapid assessment of invertebrate biodiversity on rocky shores: where there's a whelk there's a way', *Biodiversity and Conservation* 14, pp 3565–3576.

- Smith SDA and James KA 1999, *Surveys of rocky shore habitats – Sandon Bluffs and Station Creek Headland, Solitary Islands Marine Park*, report prepared by the University of New England, Armidale, for the NSW Marine Parks Authority.
- Speare P, Cappo M, Rees M, Brownlie J and Oxley W 2004, *Deeper water fish and benthic surveys in the Lord Howe Island Marine Park (Commonwealth Waters): February 2004*, report prepared by the Australian Institute of Marine Science, Townsville, for the Department of the Environment and Heritage, Canberra.
- Spencer HG, Waters JM and Eichhorst TE 2007, 'Taxonomy and nomenclature of black nerites (Gastropoda: Neritimorpha: *Nerita*) from the South Pacific', *Invertebrate Systematics* 21, pp 229–237.
- Stanton BR 1981, 'An oceanographic survey of the Tasman Front', *New Zealand Journal of Marine and Freshwater Research* 15, pp 289–297.
- Taylor L 2003, 'Distribution and abundance of the crown of thorns seastar (*Acanthaster planci*) and its effects on the coral reef communities of Lord Howe Island', Honours thesis, Southern Cross University.
- Thrush SF, Hewitt JE, Funnell GA, Cummings VJ, Ellis J, Schultz D, Talley D and Norkko A 2001, 'Fishing disturbance and marine biodiversity: the role of habitat structure in simple soft-sediment systems', *Marine Ecology Progress Series* 223, pp 277–286.
- Underwood AJ and Chapman MG 1995, 'Rocky shores' in Underwood AJ and Chapman MG (eds), *Coastal Marine Ecology of Temperate Australia*, pp 55–82.
- United Nations Environment Program 2008, *Lord Howe Island Group, New South Wales, Australia*, United Nations Environment Programme.
- van Herwerden L, Almojil D, and Choat H 2008, *Population genetic structure of Australian Galapagos reef sharks Carcharhinus galapagensis at Elizabeth and Middleton reefs, Marine National Nature Reserve and Lord Howe Island Marine Park*, final report prepared by James Cook University, Townsville, for the Department of the Environment, Water, Heritage and the Arts.
- Veron JEN 1993, *Corals of Australia and the Indo-Pacific*, University of Hawaii Press, Honolulu.
- Veron JEN and Done TJ 1979, 'Corals and coral communities of Lord Howe Island', *Australian Journal of Marine and Freshwater Research* 30, pp 203–236.
- Ward TJ, Vanderklift MA, Nichols, AO and Kenchington RA 1999, 'Selecting marine reserves using habitats and species assemblages as surrogates for biological diversity', *Ecological Applications* 9, pp 691–698.
- Willcox JB, Symonds PA, Hinz K and Bennett D 1980, 'Lord Howe Rise, Tasman Sea – preliminary geophysical results and petroleum prospects', *BMR Journal of Australian Geology and Geophysics* 5, pp 225–236.
- Williams A and Bax NJ 2001, 'Delineating fish-habitat associations for spatially based management: an example from the south-eastern Australian continental shelf', *Marine and Freshwater Research* 52, pp 513–536.
- Woodroffe CD and Brooke B 2008, *Morphology and Chronostratigraphy of fossil reefs around Lord Howe Island, CSIRO Voyage Summary, Voyage SS06/2008*, University of Woollongong and Geoscience Australia.
- Woodroffe CD, Dickson ME, Brooke BP and Kennedy DM 2005, 'Episodes of reef growth at Lord Howe Island, the southernmost reef in the south-west Pacific', *Global and Planetary Change* 49, pp 222–237.
- Woodroffe CD, Kennedy DM, Brooke BP, Dickson ME 2006, 'Geomorphological evolution of Lord Howe Island and carbonate production at the latitudinal limit to reef growth', *Journal of Coastal Research* 22, pp 188–201.
- World Heritage Nomination 1981, *Nomination of the Lord Howe Island Group by the Commonwealth of Australia for inclusion in the World Heritage List*, December 1981, New South Wales Government, Australian National Parks and Wildlife Service and Australian Heritage Commission.
- Zann LP 2000, 'The Eastern Australian Region: a dynamic tropical/temperate biotone', *Marine Pollution Bulletin* 41, pp 188–203.