1. THE NATURAL HISTORY OF MADAGASCAR

Madagascar lies in the Western Indian Ocean off the east coast of Africa, and is crossed by the Tropic of Capricorn. It is the fourth largest island in the world, covering 590,000 km² but is a relatively newly inhabited island with a sparse, but increasing human population. The population of Madagascar currently stands at approximately 14 million with a growth rate of around 3% a year.

Madagascar is also renowned for its high levels of terrestrial and marine biodiversity, and is home to numerous endemic species. For this reason, Madagascar is one of the biodiversity ‘hotspots’ of the world and is therefore considered to be of great international conservation importance. However, owing to the island’s size and remoteness, much of its terrestrial and marine environments remain relatively unknown and unexplored.

There are a number of reasons for the high levels of Madagascar’s biodiversity. These include its geographical history, climate and range of latitudes; Madagascar spans 14 degrees of latitude from temperate environments in the south to tropical environments in the north. These factors combined create a considerable range of habitats, in which a diverse biota has evolved.

1.1 A Brief Paleogeographical History

Madagascar was formed 650 million years ago, originally as part of the super continent known as Gondwana, which included the present day continents of India, South America, Africa, Antarctica and Australia (Fig 1.1).

The island of Madagascar began its formation during the split of the super continent. Madagascar drifted to the east with Africa, India and Antarctica, and in the late Jurassic the Indo-Malagasy plate separated from Africa. Madagascar broke away from India in the Late Cretaceous period, resulting in its current shape. This break has allowed the island’s unique wildlife to evolve in isolation for 165 million years, one of the main reasons for the country’s extraordinary biodiversity.

Today, Madagascar lies 400 kilometres west of east Africa, in the West Indian Ocean, separated from mainland Africa by the Mozambique Channel. Madagascar’s east coast is extremely exposed to the open ocean with a steep and narrow continental shelf and little diversity of habitats. In contrast, the west coast, which is comparatively sheltered by the African mainland, has a broad continental shelf and one of the highest tidal ranges along Africa, due to its placement in the Mozambique Channel. The west coast supports a greater diversity of habitats and numerous endemic species.

Fig. 1.1 The super-continent of Gondwana.
Fig. 1.2 A map of Madagascar showing the major marine and coastal habitat types. (Image courtesy of Andrew Cooke, 2003)
1.2 Modern Climate

The complex topography and the size of Madagascar means that the climate is varied both seasonally and geographically, and sea surface temperatures range from 20°C-30°C. Madagascar’s varied climate has resulted in a wide range of habitats, including evergreen forests, dry, spiny forests and rainforests. The central region displays a tropical mountainous environment, whilst lush green rainforests are found on the east and north east coasts.

Blue Ventures research site is based in the south west of Madagascar. Despite this area being furthest from the equator, it is one of the hottest areas as it is sheltered from the monsoon winds. The west of Madagascar also sits in a rain shadow and thus only experiences intermediate rainfall and storms. This produces a more arid environment and the associated flora and fauna are adapted to life with sporadic rainfall. In general, the south west of Madagascar has two seasons. December to April is the wet, summer season, experiencing high temperatures and occasional cyclones. The wind direction reverses in March resulting in the dry, winter season when temperatures and rainfall decline.

1.3 Conservation Importance of Madagascar

Madagascar is known as one of the biodiversity hotspots of the world. This is due to not only the large number of species found in Madagascar but also due to the high percentage of endemic species. Around 90% of the plants and mammals found in Madagascar are endemic to the island, as well as 96% of the reptiles and over 99% of the amphibians. Madagascar is also considered the major hotspot for primate endemism as a result of the 72 lemur species that reside in its forests. This is due to the 10’s of millions of years that the island was isolated from the African mainland allowing time for the animals and plants to evolve independently from the rest of the African biota. The huge variety of climatic and geographical habitats in Madagascar also provides a wide range of ecological niches providing a greater number and diversity of habitats for species to exploit.

As a result of a range of anthropogenic activities, including unsustainable land use practices, population growth and pollution, many of the islands vitally important ecosystems are being damaged and destroyed,
resulting in dramatic losses of habitats and wildlife. The increased occurrence of slash and burn agriculture has been responsible for the loss of at least 80% of Madagascar’s original forest cover, with over half this loss occurring in the last 100 years. With the continued growth of Madagascar’s coastal populations and the ever-increasing need for marine resources, the region’s marine life is also subjected to overexploitation and widespread degradation due to destructive fishing practices and increasing levels of unsustainable exploitation.

Therefore there is an immediate need for the development of environmental management plans to encourage the sustainable use of Madagascar’s environments but conservation in Madagascar can be difficult as much of the country’s economy relies on endangered habitats. Madagascar has recently increased their commitment to conservation, and Madagascar’s extensive marine and coastal environment is a principal focus of the third phase of the National Environmental Action Plan. President Marc Ravalomanana agreed to increase the area of nature reserves from 1.7 million hectares to 6 million hectares by 2008, following the country’s commitment to create 6 million hectares of protected areas within the framework of the “Durban Vision” at the 2003 World Parks Congress in Durban (Fig. 1.3).

The majority of previous exploration of the country has been carried out in terrestrial environments where staggering numbers of living and extinct endemic taxonomic groups have been catalogued. However, to date very little scientific research has been carried out on Madagascar’s marine and coastal environments because of the difficulties associated with carrying out marine research, and many of these habitats remain completely unknown and unexplored.

The coastline is also playing an ever more important economic role in Madagascar and traditional agricultural exports, such as vanilla, coffee and cloves are now supplemented by economic gains from frozen seafood and tourism. In fact, offshore fishing and shrimp farming have developed into the leading foreign exchange earners in recent years, attracting Japanese and European investors. In 1997 fishing and aquaculture contributed 7% to the national GDP and accounted for 31% of the total export. With 5000km of coastline, which includes 2,200km2 of coral reef, 300,000 ha of mangroves, and an economic marine area of about 1,000,000 sq km, there is no doubt that the marine environment will play an important part in the development and future of Madagascar.
Fig. 1.3 A map showing potential sites for marine conservation in Madagascar as part of the Durban Vision.
2. BLUE VENTURES CONSERVATION AND THE ANDAVADOAKA PROJECT

2.1 Blue Ventures aims and objectives ‘Conservation-Education-Research’

The three main aims of Blue Ventures in Andavadoaka are summarised in the following schematic flowchart.

2.2 Regional Context

The Grand Recif of Toliara (Great Reef of Toliara) and neighbouring reefs in southwest Madagascar constitute one of the West Indian Ocean’s largest coral reef systems and is the world’s third largest coral reef area in the world. It not only represents a significant biodiversity hotspot for the region but is home to several marine species listed as endangered or vulnerable to extinction that are known to exist in Madagascar’s waters, including the dugong, sea turtles, the whale shark and the coelacanth. To date, over 130 species of reefbuilding corals, more than 600 species of sponge and 552 species of reef fishes have been described from the Grand Recif of Toliara alone.
2.2.1 Impacts on coral reefs in Madagascar

Climate change and the associated El Nino phenomenon have resulted in severe coral bleaching events in Madagascar and represent the single greatest natural threat to reef systems. A study on the unprecedented 1998 coral bleaching event showed that some of the most severely damaged reefs in the East Indian Ocean suffered levels of coral mortality between 50 to 90% (Obura 2002). For example, the coral cover at monitoring sites in Tanzania decreased from 73% to 19% after the bleaching and similarly in Zanzibar from 46% to 32%.

Large areas of forest have also been destroyed in Madagascar by expansion of slash and burn agricultural systems. Wide-scale burning has exacerbated soil erosion, which now affects more than 80% of the total land area. Elevated levels of siltation on the coral reefs, particularly in west Madagascar, have already been widely reported. Other anthropogenic impacts on the coastal environment include coral, sand and rock mining, mangrove destruction and destructive and unregulated fishing (Fig. 2.2). Over 50% of the artisanal fishing in Madagascar occurs along the reef systems of the southwest, and the collection of species such as octopus and sea cucumbers for commercial export rely on methods that may damage the physical structure of the reef. Furthermore, net fishing in nearshore habitats such as mangroves, intertidal pools and seagrass beds are likely to cause serious declines in reef fish species since these habitats act as nurseries for the juvenile reef fish.
Despite these imminent anthropogenic and natural threats, marine and coastal habitats in Madagascar have historically taken a back seat to terrestrial conservation. The current knowledge of coral reefs in Madagascar is fragmentary and the majority of coral reefs in Madagascar are poorly known. Recently marine and coastal conservation has received an increasing amount of attention as a principal focus of the third phase of Madagascar’s environmental plan (EP3), following President Marc Ravalomanana’s commitment to create 6 million hectares of protected areas as part of the Durban Initiative. However, at this stage there are no Malagasy institutions with the technological resources or technical capabilities to undertake research or assessment studies that support site specific or regional level coastal management planning.

Fig. 2.2 Artisanal Vezo fishermen seine fishing off the shore, octopus fishing and net fishing off a small pirogue in Andavadoaka.

2.3 Andavadoaka: An opportunity for community based marine resource management

The village of Andavadoaka (Fig.2.3), population 1200, sits at the northern end of the Grand Recif of Toliara, which extends a further 250km southwards. The reefs of Andavadoaka and its nearby offshore islands represent some of the most remote and diverse coral habitats in the region. Aside from their enormous biodiversity value, the Andavadoaka reefs are critical to the livelihoods and cultures of the local Vezo people whose economy is almost entirely dependant on marine resources.

Traditionally, the Andavadoaka economy has relied on selling dried fish and sea cucumbers to collectors from inland Madagascar. However, a number of developments have changed the local economy and how the community interacts with the region’s fragile coastal and marine ecosystems. The major change occurred in October 2002 when Copefrito, a Reunion-based fish exportation company, arrived in Andavadoaka. This created an entirely new and lucrative market for fresh octopus and large reef fish (such as emperor, snapper and grouper) as well as for pelagic species like tuna and mackerel. Over the last 2 years, collection vessels have based themselves at Andavadoaka each spring tide, returning to Toliara twice a month with up to 35 tons of seafood. In addition to this new market force, a recent growth in visitor numbers to the village’s two hotels has increased Andavadoaka’s reputation for coastal tourism.
Considering the biological diversity and threats to the marine environment in the region, it was considered critical that data be gathered for use in local environmental management plans. As a result of this need for data collection, Blue Ventures Conservation working in collaboration with Madagascar’s national marine research institute, the Institut Halieutique et des Sciences Marines (IHSM), established a three-year marine research program in Andavadoaka.

As a result of these developments, and in the context of the recent Durban Initiative and renewed interest in Madagascar’s coastal ecosystems, Andavadoaka presents a unique opportunity for the creation of a coastal zone management pilot program incorporating all of the stakeholders currently living and/or working in the region.

**Fig. 2.3** An aerial view of the location of the village of Andavadoaka in SW Madagascar and the Blue Ventures study site.

**Fig. 2.4** Aerial view of the village of Andavadoaka
2.4 The Andavadoaka Partnership

In June 2003 a collaborative project was launched in Andavadoaka by Blue Ventures Conservation and the IHSM, in the hope of developing the understanding of the area’s unique marine and coastal habitats. This collaboration quickly expanded to include a range of additional partners, both within and outside the village. These partners include the following:

- ‘Cooperation Maritime du 22ème Parallele’ (Andavadoaka’s newly-created fisheries consortium comprising local stakeholders including community leaders and representatives, hoteliers, and the local fisheries collection company Copefrito).

- Wildlife Conservation Society (WCS) - An international NGO that performs site-specific conservation throughout the world and has extensive experience developing conservation programs in Madagascar.

- Institut de Recherche pour Development (IRD) - A French-based research and education institute specialising in multidisciplinary approaches to research throughout the developing world.

Blue Ventures and the IHSM are the principal research partners, involved in carrying out day-to-day research, monitoring and education activities in Andavadoaka. Through its in-country representatives, WCS provides on-hand technical guidance to the project for ecological and fisheries research undertaken on site, and IRD aims to continue its support of the partnership with ongoing guidance on socio-economic and ecotourism-related research activities. This partnership has enabled the pooling of resources, talents and experiences from a range of local, national and international organisations, providing a wealth of technical expertise to assist in the successful development of this initiative.

The partnership’s work in the region aims to identify strategies and targets that the local community can work towards to develop sustainable local environmental management plans for Andavadoaka’s marine and coastal environment. These plans focus on improving the quality of life of the local communities who depend on the area’s marine resources, whilst maintaining the biological diversity and productivity of the areas ecosystems.

![Fig. 2.5 IHSM student carrying out a traditional ecological knowledge interview with fisherman in Andavadoaka village.](www.blueventures.org)
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The project in Andavadoaka is also providing IHSM research students with experience in local level coastal management as well as in environmental and social assessment and monitoring activities. In doing so the project is developing staff and students’ technical capabilities to enable the IHSM to take a lead in integrated coastal management efforts.

2.4.1. The first octopus no take zone in Madagascar

The partnership is working to develop management solutions to help sustain the traditional artisanal fishing economy through the implementation of Madagascar’s first community-run octopus no take zones (NTZ).

These no take zone also aim to minimize the environmental impacts of human activities on the region’s marine and coastal environments. The Andavadoaka project aims to improve the quality of life of the local community by protecting environmental and cultural heritage and increasing local people’s income.

In November 2004 Nosy Fasy, a highly exploited octopus fishing site, was closed from octopus collection for 7 months. The time and penalties for not adhering to the closure were decided by the village with all stakeholders involved and a “Dina” (local law) was produced giving it legal standing. The Nosy Fasy octopus NTZ was reopened on the 6th June 2005, after 7 months of closure. Data collected after the reopening of the reserve indicated that the average weight and catch per unit effort of octopus increased and that an octopus no take zone can work to increase the productivity and sustainability of octopus fisheries. However, the importance of managing the intensity of fishing after the reopening of a NTZ was highlighted. Blue Ventures now plans to develop a system of rotational octopus no take zones over a larger area to prevent the overfishing of a single no take zone and to spread the benefits to more villages and a larger population.

2.5 Building the Partnership and Implementing the Project

All management decisions regarding the Andavadoaka project are achieved in collaboration with the local community. Regular discussion meetings and workshops are held for Andavadoaka’s fishermen, women and children. It is vital that all community members have a sound understanding of the work, objectives and intended benefits of proposed management plans. It is through these meetings that the need for an octopus NTZ was highlighted in order to improve the quality of the fisheries in Andavadoaka.

Fig. 2.6 A workshop with local fishermen from Andavadoaka discussing the feasibility of, and attitudes towards the proposed marine protected area, led by the village president.
Revenue generated by Blue Ventures research program is used to not only manage the project but also to train local MPA guides and managers from within the local community and to also further develop the capacity-building and education programs initiated by the partnership.

Fig. 2.7 The graduates of Blue Ventures first marine guide training program.

Fig. 2.8 Blue Ventures work with the local population includes a village board which contains the latest news and information on Blue Ventures work.
2.6 Capricorn Coastal Alliance (CCA)

Blue Ventures is one of a number of governmental and non-governmental organisations performing coastal research in Madagascar. As a result, with the assistance of our scientific steering committee within Madagascar, we have worked towards developing a more integrated and coordinated approach to the studies carried out by NGOs and other research organisations in southern Madagascar, to ensure that data collected are of maximum utility to regional coastal management plans.

With the help of Resolve in Antananarivo, the result of this effort to coordinate research activities in the region has been the establishment of the ‘Capricorn Coastal Alliance’ (CCA), whose members include:

**Institut Halieutique et des Sciences Marines (IHSM)**

The principal permanent institution for the teaching of and research into conservation matters and the management and development of natural marine resources in the south of Madagascar and is the main partner of each of the other signatories to this agreement.

**COUT (Cellulle d'Oceanographes de l’Université de Toliara)**

An association of young Malagasy marine scientists, established through the IHSM in 1995, which participates in programs of marine and coastal conservation in the region of Toliara.

**FRONTIER** ([www.frontier.ac.uk](http://www.frontier.ac.uk))

Frontier has been conducting marine and terrestrial research projects in the region to the south of Tulear since 2001.

**REEF DOCTOR** ([www.reefdoctor.org](http://www.reefdoctor.org))

Founded in 2000 as a not for profit marine conservation organisation which has been conducting a project for the restoration and amelioration of the coral reefs in the bay of Ranobe, south of Toliara, since 2001. The current goals of this Capricorn Coastal Alliance consortium have been identified as follows:

- To promote a better awareness of the marine and coastal ecosystems of SW Madagascar through scientific research, dissemination of results, and communication between members
- To promote, through scientific research, conservation and sustainable development of the coastal ecosystems of the region
- To collaborate on the identification, implementation and management of a network of conservation sites and marine protected areas in the region
- To promote novel approaches to the management of marine and coastal resources in Madagascar
- To promote identification and practice of alternative sustainable use of marine resources in the region, such as ecotourism and marine aquaculture
2.7 Other important organizations and policies in Madagascar

**National Environmental Action Plan (NEAP)**

As part of an economic restructuring program required by the International Monetary Fund and as a response to international pressure to conserve biodiversity, Madagascar established a National Environmental Action Plan (NEAP). Madagascar’s NEAP is regarded as one of the most advanced plans of its type in all developing countries’ (World Bank), and consists of three 5-year Environmental Programmes (EPs):

**EP 1 (1991-1997)**, The initial set up was known as the ‘integrated conservation and development’ plan (http://www.pbs.org/edens/madagascar/paradise.html) this set-up the initial policy, regulation and the relevant environmental institutional framework.

**EP 2 (1997-2002)**, During this phase, the newly established institutions gained control of the existing management issues.

**EP 3 (2002-2007)**, The final phase of the plan was given the largest ever single grant by the World Bank in its 60 year history. The final action is mainly focused on the strengthening of the previous two phases. It plans to achieve this by expanding the protected areas to include a variety of habitats such as coastal and marine sites and to shift some management responsibility to local communities.

So far the plan has achieved mixed results. It has no doubt raised the capacities of institutions and aided in the establishment of a number of protected areas. However, the success of these many projects and community integration is still unclear.
3. INTRODUCTION TO CORAL REEFS

3.1 Coral reefs

Coral reefs comprise less than 0.5% of the ocean floor, an area of 600,000 square miles, yet it is estimated that more than 90% of marine species are directly or indirectly dependent on them. They are home to a third of all the species in the ocean and includes 4000 coral reef fish species, which accounts for approximately a quarter of all marine fish species. Coral reefs are the most productive ecosystems in the marine environment and are also able to fix large amounts of carbon dioxide making them vital to the future health of the planet.

3.2 Structure of Corals Reefs

Coral reefs are composed of massive deposits of calcium carbonate, the majority of which is produced by the hard corals. Hard corals form the Order Scleractinia, part of the anthozoans, a class of animals that belong to the phylum Cnidaria (see Chapter 8 ‘Introduction to Invertebrates’). They are characterised by radial symmetry and specialised stinging cells called nematocysts. Corals are normally formed from colonies of polyps and are closely related to the sea anemones. Figure 3.1 shows the structure of a polyp. The hard corals secrete calcium carbonate around the body of the polyp which provides an external skeleton to house the polyps. The polyps sit in tiny cavities in the calcium carbonate skeleton, known as corallites, and can vary in size from a few millimetres to several centimetres.

The living part of the coral is only found as a thin veneer which covers the old coral skeleton which acts as the foundation from which the coral grows. The foundation of the reef may also be composed of other calcium carbonate deposits, including shells, hard parts of crustaceans and the green algae species which secrete calcium carbonate.

Fig. 3.1 Diagram of a cnidarian polyp (NOAA photo)
The polyps are typically carnivorous and coral polyps consist of a ring of tentacles surrounding a mouth (Fig. 3.2) into which the food captured by the nematocysts is passed. The nematocysts also act as the corals’ defence and the tentacles also clear debris away from the mouth.

**Fig. 3.2 Photograph of a coral polyp showing the ring of tentacles surrounding the central mouth.**

Although hard corals are found in warm and cold waters it is only in the tropics that coral reefs develop. This is because there are two groups of corals, the hermatypic and ahermatypic corals. The main difference between the groups of corals is that most hermatypic corals contain symbiotic algae; the role of the algae will be considered later in section 3.3. The hermatypic corals are the reef-building corals and are found exclusively in warm, subtropical waters.

**Fig. 3.3 Cross section through skeleton of a hard coral showing the structure of a corallite.**

Figure 3.3 shows the structure of the skeleton of a hard coral. The walls or ridges that radiate from the centre of the corallite are known as septa and are clearly visible in the photograph above. It is often this skeletal detail that must be examined closely under a microscope to identify several species of hard coral.

The polyps of most hard corals are not visible during the day and are drawn into the skeleton.
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3.3 The coral-algae symbiosis

The hermatypic corals contain symbiotic algae, known as zooxanthellae. The zooxanthellae are microscopic algae that are located in the gut lining of the polyp and can number up to 30000 cells/mm³. The zooxanthellae are plants and therefore photosynthesise in order to fix carbon. The zooxanthellae are also responsible for the colour of corals and it is through the loss of these algae during coral ‘bleaching’ that makes the coral appear white (See Box 2).

The relationship between the zooxanthellae and the coral is known as mutual symbiosis. This means that the two organisms are both benefiting from living together. The polyp provides protection, living space and nutrients, such as carbon dioxide, nitrate and ammonium, to the zooxanthellae. The zooxanthellae provide oxygen and most importantly food, in the form of glucose and amino acids, to the coral polyp. It is thought that in some corals the zooxanthellae provide up to 90% of their daily energy requirements which in turn allows the corals to use extra energy for increasing their calcification rates.

The high primary productivity of the hermatypic corals fuels the rest of the trophic levels within the coral reef ecosystem and leads to the high diversity found on coral reefs. It is estimated that corals fix between 1500-5000g carbon/m²/year compared to that of the open tropical oceans at 18-50g C/m²/year. The benefits that the corals gain in the symbiosis are responsible for their high rates of calcification and therefore the creation of coral reefs. The variety of symbiotic zooxanthellae living within a coral is dependant on the coral species and also the environment within which the coral is found.
Although all hermatypic hard corals secrete calcium carbonate, not all are reef builders. The *Fungia* are a group of corals that are solitary. They consist of a single polyp that can reach up to 25cm in diameter.

![Fungia coral](image)

**Fig. 3.6 Photograph of a member of the coral genus *Fungia* which do not form colonies but are in fact large single polyps.**

As mentioned earlier, the ahermatypic corals do not contain symbiotic algae. Ahermatypic corals do not build large reef structures because their capacity to secrete limestone is reduced and tend to live in deep and/or cold waters. Interest in cold water corals did not start until the 1990s (Box 1).

**BOX 1: COLD WATER CORALS**

Cold water corals, also known as deep water corals, can grow in dark and cold waters. They are found globally, from coastal Antarctica to the Arctic Circle, at depths from just below the surface to 2000m. They have no zooxanthellae and rely on actively feeding on suspended organic material in the water. Although they do not form the large reef structures of their tropical counterparts, they do provide an important habitat for many commercial fish but are threatened by destructive bottom trawling practices. Although the existence of cold water corals has been known for several centuries, scientists still know very little about their biology and behaviour.

### 3.4 Factors controlling coral reef distribution

Coral reef distribution is restricted by the factors that limit coral productivity and survival. The most important factors that control coral reef distribution are:

- **Light**

Light is an important factor in the growth and survival of corals because the symbiotic zooxanthellae require sunlight to photosynthesise. As depth increases so the light intensity decreases along with the rate of photosynthesis, thereby restricting the growth of corals at greater depths. The change in light intensity through the water column is also responsible for the different growth patterns of a hard coral species at different depths. From shallower to deeper water the morphology of a coral species may change from a mound to a more tabulate formation in order increase the efficiency of gathering available sunlight.
• Temperature

Coral reefs are found within the 20° surface isotherm which limits their distribution to a belt that runs around the earth between 30° latitude north and south of the equator. Optimal reef development occurs where the mean annual temperature is between 23-25°C, but can sometimes tolerate temperatures up to 36-40°C, but will not develop where mean annual minimum temperature is below 18°C. The lack of reefs on the west coast of Central and South America illustrates the corals dependence on warm water temperature. This area is subjected to upwellings of cold water as well as the cold Peru Current which both aid to cool the surface water temperatures and limit coral growth. However, corals are also sensitive to increases in water temperature which can result in coral bleaching (see Box 2).

BOX 2: CORAL BLEACHING

An increase in the temperature of the surrounding water to the reef can cause the breakdown of the algal-coral symbiosis. High water temperature, also often associated with high light, damages the zooxanthellae and this stimulates the corals to expel them. The results are seen as 'coral bleaching'. Without the algae the coral has reduced productivity and unless the coral re-establishes the symbiosis in the near future when conditions have improved, they will perish. Widespread coral bleaching occurred in the Caribbean in 1987-88 following an El Niño event. Coral bleaching occurred extensively in Madagascar in 1998 and 2001.

• Salinity

Coral reefs are not found in warm fresh waters because they can only survive in marine water since corals are intolerant of salinities that differ greatly from that of seawater, 32-35psu. Coastal waters that are near the mouth a large river system (e.g. the Amazon) have limited coral reef development because of the frequent influxes of fresh water reducing the salinity of the surrounding sea.

• Nutrients

As with all living systems, coral reefs require nutrients to survive. However, the effect of elevated nutrient levels on coral reefs has become evident recently. Elevated nutrient levels have resulted from increased anthropogenic ('man-induced') inputs such as sewage outfalls, cruise ships' septic tank discharge, high levels of nutrients and fertilisers in rivers (originating from agriculture and aquaculture) combined with traditional terrestrial inputs and oceanic upwellings. The mechanisms by which high nutrient levels damage coral reefs is not fully understood but it is thought that high nutrient levels favour algae and sponge growth which can outcompete hard corals.

• Sediment

Although corals can survive a short period of increased sediment load, often lower levels of increased sediment over an extended period of time can potentially kill corals. Increased sediment loads can arrive on coral reefs from terrestrial and marine inputs. Rivers that have experienced upstream erosion as a result of deforestation are often responsible for bringing high sediment loads to coral reefs, and reefs in Madagascar, www.blueventures.org
which has experienced severe deforestation, has suffered as result. Excess sediments damage reefs through the following methods:

a) Shading

Shading is the most important effect caused by sedimentation. An increase in the level of sediment in the water leads to a decrease in the amount of sunlight that reaches the corals’ zooxanthellae. Therefore their capacity to grow is reduced and can result in the death of the coral. However it is important to note that high temperatures may be reduced through shading and reduce the potential of coral bleaching.

b) Abrasion

Physical abrasion from a high sediment load in the water can cause damage to the thin veneer of living coral tissue. The movement of the water loaded with sediment against the fragile coral structures can lead to scouring of the coral so that severe damage or death may result.

c) Smothering

Large volumes of sediment in the water can exceed the capabilities of the corals self-cleaning mechanism. Corals become covered or smothered by excess sediment and bacteria in the sediment create large, sticky particles which can clog the coral polyps and eventually kill them.

d) Inhibition of recruitment

Sediment can inhibit coral recruitment through reducing the area of suitable substrate for coral larvae to settle on or by smothering young coral recruits.

The next chapter will elaborate further on the distribution, development and ecology of coral reefs.
4. CORAL REEFS

4.1 Introduction

Coral reefs are often called the ‘rainforests of the sea’, and this comparison reflects the enormous biodiversity that is immediately apparent to anyone who has had first-hand experience of visiting a coral reef. Coral reef ecosystems are known for their spectacular structures, colours and marine life that has the greatest diversity per unit area of any marine ecosystem. Coral reefs are unique ecosystems and they are characterised by high productivity, a great diversity of competitors and a complex set of interactions between all the species. Although they are rich in biodiversity they are in fact fragile and it is only through their efficient use of all available nutrients that enable them to maintain such a high degree of biodiversity in the otherwise nutrient sparse tropical marine waters.

4.2 Where reefs exist

Reef-building corals are restricted in their distribution as a result of the algal-coral symbiotic relationship. This relationship requires a consistent environment in which the temperature, salinity and pH remain within a certain band. Therefore coral reef formation requires a sea temperature that does not fall below 18°C for any extended period. Most require a salinity that ranges from 32 to 42 parts per thousand, and the water must also be clear to allow sufficient light to penetrate. The corals’ requirement for high light for photosynthesis also explains why most reef-building species are restricted to the euphotic (light penetration) zone, approximately up to 70m in depth. The number of species of corals on a reef declines with depth, and as the light intensity diminishes the ability for corals to secrete limestone is reduced.

As a result of these environmental conditions that coral reefs require to develop, they are found within the 20° surface isotherm, the tropical and semitropical waters. This limits their distribution to a belt that runs around the earth between 30° latitude north and south of the equator. The diversity of reef corals, the number of species, decreases in higher latitudes up to about 30° north and south, beyond which reef corals are usually not found. The diversity of coral species is also dependent on the ocean in which they are located. At least 500 reef-building species are known to exist in the waters of the Indo-Pacific region whereas in the Atlantic Ocean contains approximately 62 species are known. In Madagascar, coral reefs cover an area of 2000km², more than 20% of Madagascar’s coastline.
4.3 Reef development

Coral reefs start to develop when free-swimming coral larvae attach to the substrate of the underwater edges of islands or continents. As the corals grow, reefs can take on one of three major characteristic structures: fringing, barrier or atoll. Fringing reefs, which are the most common, grow in shallow waters, projecting seaward, and border the coast closely or are separated from it by a narrow stretch of water. These reefs grow parallel to the coast and are large and continuous. Barrier reefs also border shorelines, growing parallel to the coast and are large and continuous. They are separated from land by a lagoon of open, often deep water.

Atolls are usually circular or oval reefs, with a central lagoon and parts of the reef may emerge as one or more islands. Breaks in the reef may provide access to the central lagoon. There are two types of atolls: deep sea atolls that rise from deep sea and those found on the continental shelf.

Charles Darwin was one of the first to suggest that these three main categories of reef were all related stages in the formation of atolls. The diagram below illustrates Darwin's theory of the evolution of coral reefs.
Barrier reefs are formed from fringing reefs that have become separated from the mainland through the land mass subsiding or from sea level rising. If a fringing reef forms around a volcanic island that subsides completely below sea level while the coral continues to grow upward, an atoll forms.

**Fig. 4.3 Darwin’s theory of the evolution of coral reefs and the formation of an oceanic atoll.**

All three reef types share similarities in their underwater profiles, with characteristic horizontal and vertical zones that are created by changes in the bottom topography, depth, wave and current strength, light, temperature and suspended sediments. While these zones vary according to the location and type of reef, the major divisions common to most reefs, as they move seaward from the shore, are the reef flat, reef crest or algal ridge, buttress zone, and seaward slope.

### 4.4 The structure of coral reefs

The reef flat, or back reef, is located on the sheltered side of the reef. It extends outward from the shore and may be highly variable in character. Varying in width from 20 or 30 meters to more than a few thousand, the
reef flat may range from only a few centimeters to a few meters deep, and large parts may be exposed at low tide. The substrate is formed of coral rock and loose sand. Beds of sea grasses often develop in the sandy regions, and both encrusting and filamentous algae are common.

This area experiences the widest variations in temperature and salinity, since it is so shallow, but is protected from the full force of breaking waves. Coral growth is limited as a result of the reduced water circulation, the accumulation of sediments and periods when the reef is exposed during low tide. Although living corals may be scarce except near the seaward section of this zone, its many microhabitats support the greatest number of species in the reef ecosystem, with large numbers of molluscs, worms and crustaceans.

The reef crest, or algal ridge, is the highest point of the reef, and may be exposed at low tide. Lying on the outer side of the reef, it is exposed to the full force of the incoming waves. The width of this zone typically varies from a few, to perhaps 50m. Where wave action is particularly strong, living corals are practically nonexistent, but in places of more moderate wave action, the reef crest tends to be dominated by sturdy branching corals. Small crabs, shrimps, cowries and many other animals reside in the cavities of the reef crest, protected from waves and predators.

The outermost seaward slope (also called the fore-reef) extends from the low-tide mark into deep water. Just below the low-tide mark to approximately 20 m depth is a rugged zone of spurs, or buttresses, radiating out from the reef. Deep channels that slope down the reef face are interspersed between the buttresses. These alternating spurs and channels may be several meters wide and up to 300m long.

The buttress zone serves two main purposes in the reef system. First, it acts to dissipate the tremendous force of the waves and stabilizes the reef structure. Second, the channels between the buttresses drain debris and sediment off the reef and into deeper water. Massive corals and encrusting coralline algae thrive in this zone of breaking waves, intense sunlight, and abundant oxygen. Small fish inhabit the many holes and crevices on this portion of the reef, and many larger pelagic fish including sharks, jacks, barracudas and tunas patrol the buttresses and grooves in search of food.

Continuing down the seaward slope to about 20m, optimal light intensity decreases, but reduced wave action allows the maximum number of coral species to develop. Beginning at approximately 30 to 40m, sediments accumulate on the gentle slope, and corals become patchy in distribution. Sponges, sea whips, sea fans, and ahermatypic (non-reef-building) corals become increasingly abundant and gradually replace hermatypic corals in deeper, darker water.
4.5 Ecosystem Interactions

Seagrass beds and mangrove forests are often important in the success, survival and stability of coral reefs. The three ecosystems are closely linked and their interactions are often vital in the continued health of the reef. The structure and function of each of these three ecosystems vary:

**Coral Reefs:**
- accrete CaCO₃ (calcium carbonate)
- attenuate wave energy, protect shoreline
- offer refuge and food
- recycle Particulate Organic Material (POM)

**Sea grasses:**
- stabilise and bind sediment
- produce POM and DOM (dissolved organic matter)
- recycle and export nutrients
- produce floating leaf litter
- attenuates storm surges

**Mangroves:**
- trap sediment
- reduce wave action
- buffer salinity changes (from sea and from freshwater runoff)
- act as a secondary nursery ground for fish and crustaceans

As well as having their own specialised associated organisms, mangroves and seagrass beds are also important nurseries for many juvenile coral reef species. Juvenile fish, crustaceans, molluscs and echinoderms take advantage of the safer and more sheltered environment with fewer predators that the mangroves and seagrass beds provide.

A second important function of seagrass beds and mangrove forests in relation to reef health is their ability to trap the sediment carried in rivers. This sediment discharge may otherwise run the risk of damaging the reefs by sediment shading or smothering. As the trapped nutrients are broken down a large volume of the oxygen in the water surrounding the mangroves is used. This results in the mangroves having a low level of oxygen in the water surrounding them and leaving only a thin layer of oxygen at the surface available for use by the animals that inhabit the mangroves.

Mangroves and seagrass beds are also very important in the stabilisation of the coastline by providing protection from storm damage and reducing the level of erosion.
Sea grass beds in addition to being nurseries are also used as feeding grounds for megafauna such as turtles and dugongs. They also act as a second stage of filter for any sediments that have not been trapped in the mangroves and soak up any excess nutrients that may promote eutrophication (the proliferation of algae as a result of increased nutrients in the water) out on the reef.

Regular problems for these habitats are almost exclusively anthropogenic in forms. Mangrove wood is exceptionally dense and this makes it ideal for burning beneath the kilns used to make lime because it will burn for a long time and at a very high temperature. It is also a desirable material for building and so in an area where building materials are scarce they are often exploited. Seagrass beds are extremely delicate so one of the problems is propeller scarring, where the wash of the propeller actually destroys the bed, fragmenting it and severely restricting the movements of some species that live there.

The diagram below illustrates the interactions between the mangroves, seagrasses and coral reefs. The blue arrows show the decrease in wave energy towards land, whilst the green arrows show the decrease in sediment load towards the sea.

Fig. 4.5 Diagram to show the interactions between the 3 ecosystems.
5. CORAL REPRODUCTION AND RECRUITMENT

5.1 Coral Reproduction
Corals have evolved the ability to propagate themselves through asexual and sexual modes of reproduction.

5.1.1. Asexual reproduction
Asexual reproduction is generally accomplished by a new individual budding off the parent, as a mechanism to increase the size of the colony. In asexual reproduction new clonal polyps bud off from the parent polyp and will occur as a parent polyp reaches a certain size and divides. This process of polyp budding continues throughout the coral’s life. Asexual reproduction is not normally used as a method to produce new, separate colonies although it has been reported as a means of starting new colonies in some species.

Asexual reproduction can be the result of three different processes:

- Fragmentation: this results through either pedal laceration (the production of small clonal individuals by the fragmentation of the foot of the organism), or longitudinal fission (the body randomly divides into two parts parallel to the anterior and posterior planes of the body).
- Polyp bailout: the process where some coral polyps eject themselves from their skeleton and drift to a new location. Once the polyp settles, a new skeleton is formed and a new colony begins.
- Occasionally through parthenogenesis (the development of an unfertilised egg into a new individual)

The new polyps resulting from asexual reproduction are genetically identical to the parent polyp and this lack of variability means that all colonies will respond similarly to a change in the environment. This method of reproduction is also only capable of a limited amount of dispersal. However, asexual reproduction is advantageous for the growth of existing colonies since it can produce larger colonies fast and can allow for the growth of a colony from only one individual.

5.1.2. Sexual reproduction
Sexual reproduction requires the fusion of egg and sperm (gametes) that develop into planktonic larvae (planulae), and initiate the development of a new coral colony when they settle.

Sexual reproduction creates offspring that are genetically different to the parents. These genetic differences result from:

- Crossing over of DNA strands during gamete formation (meiosis)
- Contribution of both egg and sperm to the embryo

The production of planulae larvae allows for the dispersal of offspring over longer distances than asexual reproduction. However, larvae are smaller and take longer to reach reproductive maturation, and are potentially more susceptible to mortality than the larger fragments produced by budding.
5.2 Reproductive Behaviour

The sexual reproductive behaviour of corals varies between individual species. Reproductive behaviour between coral species can differ in (1) the types of gametes a colony can produce and (2) the way in which the larvae develop and are released.

(1) Hermaphroditism vs. Gonochorism

Coral species can be hermaphroditic, the presence of both male and female reproductive organs in a colony, or gonochoristic, the separation of the sexes in different colonies.

Approximately three-quarters of all hard corals form hermaphroditic colonies, and therefore have the ability to produce both male and female gametes. Some hermaphroditic species are known as simultaneous hermaphrodites and produce eggs and sperm at the same time during the reproductive cycle. Other hermaphroditic species are sequential hermaphrodites and produce only either eggs or sperm at any one time. Protandrous hermaphrodites are first male then female in their life cycle, whilst protogynous hermaphrodites are first female then male.

Gonochoristic colonies can produce either male or female gametes, but not both. The sexuality of corals is normally consistent within species and genera, although there are exceptions.

(2) Brooding vs. Spawning

Approximately three-quarters of hard coral species employ broadcast spawning. Broadcast spawning involves the release of millions of eggs and sperm into the water. The eggs and sperm fuse in the water, and fertilisation occurs externally of the parent coral colony, to form planulae. Corals can produce several thousand planulae a year. Large numbers of gametes are produced to maximise the chance of fertilisation and to ensure that some offspring survive the multiple hazards and predators, which lead to high mortality rates amongst the planulae.

In contrast, some coral species brood their offspring (10-20% of studied species), and the eggs are fertilised internally. The planulae are also developed internally and brooding corals will generally produce fewer, but larger, and more well-developed larvae than spawning species. The planulae are fully competent to settle and metamorphose into polyps as soon as they are released and may already also contain symbiotic zooxanthellae passed on from the parent colony. This allows the planulae to feed using the sunlight whilst still in the water.
column, before it has settled. Long distance dispersal in brooding corals may be promoted through the provision of larger lipid stocks in the larvae which acts as an extra food source.

Differences in these two modes of reproduction influence many aspects of coral ecology including:

- success of larval formation
- transfer of symbiotic algae to larvae
- larval competency period (duration during which larvae can survive and still settle and metamorphose)
- larval dispersal ability
- genetic variability
- biogeographic distribution patterns
- rates of speciation and evolution

5.3 Spawning Events

Spawning corals release their gametes in synchronized events. The timing of the mass release of gametes into the water column is very important because males and females cannot move into reproductive contact and therefore must release their gametes into the water simultaneously. Since colonies may be separated by wide distances, this release must be both precisely and broadly synchronized, and is usually done in response to multiple environmental cues.

The long-term control of spawning (control of the maturation of gonads) may be related to:

- temperature
- day length
- rate of temperature change (either increasing or decreasing)

The short-term (getting ready to spawn) control is usually based on lunar cues. The final release, or spawn, is usually based on the time of sunset. Cues may also be biological (involving chemical messengers) or physical. Many species tend to spawn at the same time of the year in what have been described as mass spawning events. Spawning species require synchrony within a time frame of hours. This regional synchrony varies geographically. In Australia's Great Barrier Reef, more than 100 of the 400 plus species of corals spawn simultaneously within a few nights during spring or early summer. In western Australia and the Flower Garden Banks of the northern Gulf of Mexico, spawning occurs in late summer or fall, and not necessarily simultaneously. In the northern Red Sea, none of the major coral species reproduce at the same time. In addition, individual corals do not necessarily breed every year. Evidence indicates that slow-growing, longer-lived corals are less likely to spawn every year than faster-growing, shorter-lived species.

Brooding species can store unfertilized eggs for weeks, and thus, require less synchrony for fertilization. The release of planulae by brooding coral species is also coordinated by the lunar cycle.

Simultaneous hermaphroditic corals typically release packets of egg and sperm bundled together. Each polyp releases a gamete bundle with approximately 5 to 180 eggs surrounding or embedded within a mass of
sperm. Eggs are typically pink or reddish when released and for most species, do not contain zooxanthellae (they appear brown if they do, for example in Montipora spp.). Due to the high levels of lipids in the eggs, the bundles are positively buoyant and float to surface where they break up and fertilization can occur. Typically, there is some sort of mechanism/barrier that prevents fertilization of the eggs until the bundles break apart as well as some sort of mechanism that prevents self-fertilization within a colonies gametes. These self-fertilization barriers seem to break down with time. Eggs are generally viable (able to be fertilized) for only up to a few hours after release.

Diagram to show the reproduction stages of corals. (a) Adult polyp. (b) Planula larvae. (c) Later planula with developing septa. (d) Young polyp after attachment. (McGraw-Hill)

5.4 Larval recruitment

Successful reproduction is only the first step in maintaining coral populations. Recruitment of new members to a population from either sexually or asexually generated larvae is the next step. Successful recruitment depends on the ability of larvae to identify an appropriate site for settlement (the polyp changes from a planktonic existence to a benthic lifestyle) and metamorphosis. These processes are distinct and appear to depend on chemical signals as well as environmental signals. The rate of recruitment of new coral colonies is variable in space and time and even the same genus can have markedly different recruitment rates in different parts of the world. This has implications in the recovery of the reef after catastrophic events and the future ecology of the disturbed reef.

(1) Settlement
Once the planulae are in the water column they swim upwards towards the light (positive phototaxis) to enter the surface waters and be transported by the current. After floating at the surface for some time, the planulae swim back down to the bottom, where, if conditions are favorable, they will settle and begin a new colony. In most species, the larvae settle within two days, although some will swim for up to three weeks, and in one known instance, two months.

Site selection may be made on the basis of receptors located on the outer surface of the larvae. Planulae are able to react:

- substratum type
- water motion
- salinity
- light levels
- specific algal species (especially crustose coralline algae)
- biological films of diatoms and bacteria

(2) Metamorphosis

Once the planulae settle, mortality rates drop steadily as they metamorphose into polyps and form colonies which increase in size. Once the larvae has settled in must undergo a series of biochemical and morphological changes to survive as a benthic polyp. Planulae larvae do not have tentacles for feeding, a mouth connected to a gastrovascular cavity (“stomach”), are not able to produce digestive enzymes and are not involved with any calcification. During metamorphosis, larvae “commit” themselves to a specific site and secrete a calcified skeletal cup that is the beginning of the coral colony’s skeleton. It is also at this stage that zooxanthellae are acquired from the water column if they were not present in the eggs or brooded larvae. The new colony becomes sexually mature at a minimum size, depending on the species. Some massive species, like Favia doreyensis, reach sexual maturity when polyps grow to about 10 cm in diameter, which occurs when they are about eight years old. However, some faster-growing, branching corals, including species of Acropora, Pocillipora, and Stylophora, reach sexual maturity at a younger age.

5.5 Summary of the critical steps in the persistence of coral populations

1. Gamete production
2. Synchronized gamete release (spawning corals)
3. Successful fertilization (egg/sperm interactions)
4. Larval development
5. Larval settlement
6. Larval metamorphosis
7. Acquisition of zooxanthellae
6. DISTURBANCES TO CORAL REEFS

Disturbances to coral reefs can be the result of both natural and anthropogenic hazards and threats. As human populations and coastal pressures increase coral reefs are becoming more heavily exploited. Current estimates put 10% of coral reefs as degraded beyond recovery, with a further 60% predicted to die by 2050 if current pressures and disturbances continue unchecked. The boundaries between natural and anthropogenic threats have become increasingly blurred as the effects of natural disturbances are exacerbated by anthropogenic stresses. Human activities can reduce the resilience of coral reefs and their ability to recover from disturbances. They can also intensify the effects of natural disturbances, such as increasing the frequency of disease outbreaks and tropical storms.

6.1 Storms and Cyclones

Extreme weather is one of the most obvious and major stresses to coral reefs, as coral reefs occur in the tropics, areas that are subjected to severe storms. During storm periods, not only are the delicate coral skeletons broken but large blocks of limestone can be dislodged allowing boulders to roll over the reef breaking any coral it comes into contact with. This disturbance is especially felt by reefs which are infrequently hit by severe storms, for example those found in the southern Caribbean, which often have delicate coral structures that are easily broken. In regions prone to storm damage, corals are often stunted and sturdy in order to withstand the regular periods of increased wave energy.

6.2 Coral bleaching

Corals and their zooxanthellae are vulnerable to a variety of environmental stresses that can disrupt the symbiotic relationship and cause bleaching: the loss of the zooxanthellae and their photosynthetic pigment (Fig. 6.1). Stresses that can lead to coral bleaching include:

- Elevated or decreased sea water temperature
- Pollution
- Sedimentation
- Disease
- Increased or decreased light levels
- Fresh water flooding

Corals are particularly sensitive to temperature fluctuations (see Chapter 3) and often survive at the upper levels of their thermal tolerance. The occurrence of coral bleaching is becoming more frequently documented as a result of increases in sea water temperature.
During coral bleaching the individual coral polyps become stressed which can lead the coral to expel their symbiotic algae. The coral is left with only the clear mucus membrane to cover its surface, through which it is possible to see the calcium carbonate skeleton, giving the bleached coral its characteristic white colour. If the environmental conditions return to normal the zooxanthellae may be recovered and the coral may survive the bleaching incident. However, if the stressful conditions persist and the coral remains bleached for a sustained period of time, the polyps will die leaving behind the white calcium carbonate skeletons.

In 1998 a mass bleaching event occurred worldwide and in a report presented to the U.S. Coral Reef Task Force in 1999, by the U.S. State Department warned: "In 1998 coral reefs around the world appear to have suffered the most extensive and severe bleaching and subsequent mortality in modern record. In the same year, tropical sea surface temperatures were the highest in modern record, topping off a 50-year trend for some tropical oceans. These events cannot be accounted for by localized stressors or natural variability alone. The geographic extent, increasing frequency, and regional severity of mass bleaching events are likely a consequence of a steadily rising baseline of marine temperatures, driven by anthropogenic global warming.” The U.S. Coral Reef Alliance estimated that 80 percent of coral near the Seychelles, and 90 percent near Indonesia died in the 1998 bleaching event.

6.3 Outbreaks of Acanthaster planci (Crown-of-Thorns starfish)

The crown-of-thorns (Fig. 6.2), Acanthaster planci, is the infamous predator of coral reefs globally, and there have been several, major, well-reported outbreaks, especially on the Great Barrier Reef in Australia. The crown-of-thorns starfish ranges in size from 25cm to 50cm, has numerous arms, is covered in long, sharp venomous spines. It is a naturally occurring predator of corals and feeds directly on the polyps by inverting its stomach and digesting the underlying coral tissue. As the starfish moves across a coral colony it leaves behind a white, dead skeletal patch which will be colonised by algae.
The term “outbreak” is often used by marine scientists when referring to large populations of *Acanthaster planci*. It is often very difficult to define and quantify an “outbreak” but it is generally considered that an outbreaking population consists of thousands to tens of thousands of starfish causing high coral mortality within isolated areas or over much of a reef.

The number and frequency of crown-of-thorns outbreaks has increased over the last decade and huge outbreaks have been seen in many regions of the world. However, the direct causes for these outbreaks are unknown. There are several explanations that have been put forward to explain these outbreaks and at present the most likely explanation is thought to be as a result of increased nutrients into tropical waters. There are no effective measures to control outbreaks of *Acanthaster planci* since disturbing them can initiate spawning, they are able to regenerate if cut and are resilient to flipping over. The most effective method at present that is used to reduce the impact of an outbreak is to inject cyanide directly into the starfish. However, this is extremely time consuming and expensive and therefore can have little impact over large areas.

### 6.4 Coral Diseases

Corals, like any other living organism, are susceptible to diseases, such as white band disease (WBD), black band disease (BBD) and yellow blotch disease. WBD and BBD kill the coral tissue in an advancing band around the colony leaving only the white calcium carbonate skeleton underneath. It is thought that not only do these diseases kill the live coral but also lead to the degradation of the reef structure as the coral skeleton is weakened and invertebrates are able to colonise and bore into it, leaving the reef more susceptible to storm damage.
Chapter 6

**Fig. 6.3 Black band disease in Symphyllia spp.**

The exact method by which diseases are transmitted between corals is unknown. Healthy corals may catch BBD through direct contact with an infected coral, but often diseased corals are separated by great distances on a reef, and consequently it is also suggested that BBD may be spread by currents.

Corals under stress are more susceptible to diseases, and BBD has a higher rate of infection in warmer water. Therefore not only do the seasonal temperatures affect the spread of BBD, but also any anthropogenic seawater warming could increase the frequency of diseases in coral reefs. BBD has also found to be more abundant near anthropogenic disturbances. Corals have a range of defences against diseases and pathogens, including the the secretion of mucus and the production of antibiotic compounds. These compounds may be important sources for natural product based drugs and medicines. Screening of other marine organisms began in 1975. That program has produced four anticancer candidates that are now in preclinical or clinical development. Their sources are a large sea slug from the Comoros Islands in the western Indian Ocean, a Caribbean sea squirt, a tiny moss animal called a bryozoan that was collected off the California coast, and a New Zealand sponge.

6.5 Nutrient enrichment

Nutrient enrichment in coral reefs normally occurs as a result of anthropogenic inputs, such as sewage, or fertiliser and pesticide runoff.

These anthropogenic inputs lead to excesses of nutrients, nitrates and phosphates, in the water surrounding the coral reefs and can cause eutrophication. Eutrophication results as the increase in the mineral and organic nutrient levels of the waters promote a proliferation of plant life, and causes a sudden bloom of algae in the previous nutrient poor tropical waters. The increase in algae reduces the dissolved oxygen content of the water which can lead to the suffocation of marine species. Eutrophication also reduces the turbidity of the water and decreases the amount of light that can reach the corals. The increase amounts of nutrients can also enhance the growth of other reef organisms, such sponges and algae, which can outcompete the slower growing corals for space. As mentioned previously, outbreaks of *Acanthaster planci* have also been linked to increased nutrient levels.
6.6 Sedimentation

Excess sediment in the water column is a major threat to coral reefs throughout the world. This is because not only do large volumes of sediment over a coral reef reduce the coral’s ability to survive but also because the leading cause of excess sediment in the water, deforestation, is an extremely widespread problem. In Madagascar alone, 70% of forests have been felled resulting in huge volumes of sediment entering the river systems and ultimately the sea.

Sedimentation affects the coral reef by reducing the amount of light that can penetrate through the water column, thereby reducing the light available for photosynthesis by the zooxanthellae in the coral. Excess sediment not only shades the coral but can also physically disturb the coral by smothering the polyps.

Problems caused by high levels of sedimentation around the world has highlighted the importance of the role that other ecosystems have to play in the continued health of reefs. Seagrass beds, mangrove forests and terrestrial forests are all pivotal in trapping sediment in bays, lagoons and on land and providing natural protection against excess sediment smothering coral reefs. For this reason it is important that a multiecosystem approach is taken in the conservation of coral reefs.

6.7 Overfishing and destructive fishing practices

Increasing coastal populations have increased the pressure on marine resources. The majority of coral reefs also occur in regions of high poverty and this has led to the overfishing and unsustainable exploitation of fish and invertebrate populations. Overfishing can be particularly damaging to populations of slow maturing species, such as marine turtles.

Destructive fishing practices can not only lead to overfishing but are often indiscriminate and damage the coral reef itself therefore destroying the habitat for future fish and invertebrate populations. Cyanide poisoning is a method of targeting fish for the aquarium trade. Cyanide is squirted into cracks in the reef and causes fish to become temporarily stunned. The fish can then be easily handled and removed from the reef for export. However, not only do many fish not survive the cyanide poisoning but coral polyps are killed when they come into contact with even dilute volumes of cyanide.

Dynamite fishing involves throwing lit dynamite into the water over coral reefs and collecting the dead fish after detonation. This method can also create a shock wave large enough to flatten areas of coral reef as well
as disturbing fish and benthic animals over a large area. Greater damage can result if the fuse has not been set properly and the dynamite detonates on the seabed which causes huge disturbances to the benthic habitat, breaking the corals in that vicinity.

Fig. 6.5 Octopus in Madagascar are often harvested before they have reached maturity.

Fig. 6.6 Local fish catch in Andavadoaka

6.8 Anchor, Diver Damage and Coral Mining

Physical damage to the reef can occur as a by product of large numbers of people using the reef or through targeted extraction of items from the reef. Tourist dive boats anchoring repetitively at certain dive sites can cause huge damage but permanent moorings prevent this, such as those used in the Red Sea. Accidental damage also occurs as a result of divers who are unable to maintain neutral buoyancy or swim too close too the reef.

Corals and shells are still removed from the reef by local communities and tourists as souvenirs. In this region corals and shells are also collected and used to create lime by burning them. This turns the calcium carbonate found in the corals and shells into calcium oxide which, when combined with sand, creates a cheap, simple building material.

Fig. 6.7 Shells and corals mined from the reefs in Andavadoaka

7. INTRODUCTION TO FISHES

The superclass Pisces is divided into two classes, the Osteichthyes (the bony fish) and the Chondrichthyes
7.1 Class Osteichthyes - Bony Fish

The bony fish comprise the largest class of the vertebrates, with over 20,000 species worldwide, of which 7,000 are coral reef fish species. The bony fish have calcified skeletons, making their bones much harder than the cartilage skeleton of the chondrichthyes. The bony fish have great maneuverability and speed, and highly specialized mouths equipped with protrusible jaws. Most bony fish have a swim bladder, a gas-filled internal pocket that can be inflated and deflated at will in order to maintain neutral buoyancy and to stay upright. The majority of fish propel themselves by sweeping their caudal (tail) fin from side to side, whilst the dorsal fin maintains the vertical axis of the fish and prevents rolling. Fish have a well-developed sense of smell and some species possess barbels, which are covered in taste receptors and used to locate food.

Fish respire by passing water over their gills, through which they absorb dissolved oxygen, and are able to move an estimated 74% of the dissolved oxygen from the water. Their skin is covered in mucus glands and is protected by dermal scales. A hard bony plate, known as the operculum, protects the gills, a feature absent in the elasmobranches (chondrichthyes). Osteichthyes also possess a line of small perforated tubes, called the lateral line, that run just under the skin along the midlateral part of the body, and are often visible. These tubes detect minute vibrations in the water, allowing fish to sense the movement and motion of other animals in the water.

The majority of fish species release eggs that are fertilised externally. Many species are broadcast spawners where the eggs are released into the open sea and not cared for subsequently. Some species lay their eggs in nests and will guard them until they hatch. Fertilised eggs hatch into larvae and go through several stages of development until they become juveniles. Juvenile fish often have distinct colouration and patterns from their parents. Many fish species are also able to change sex during their lifetime, and are known as sequential hermaphrodites. Species that change from female to male are known as protogynous hermaphrodites and
include the Labridae (wrasses) and Scaridae (parrotfish). Other species change from male to female and are known as protandrous hermaphrodites and include the Amphiprioninae (anemonefish).

7.2 Class Chondrichthyes - Cartilaginous fishes

The Chondrichthyes (sharks and rays) have skeletons that are composed of cartilage. Unlike the bony fish they have no internal swim bladder to keep buoyant but instead have a greatly enlarged oily liver running the length of their body. Oil is lighter than water and serves to make the animal more buoyant. Sharks must continually swim to remain elevated in the water column and their fins provide hydro-dynamic lift in a similar fashion to the wings of an aeroplane. Males are distinguished from females by two long finger-like fins behind their pelvic fins, known as claspers, and are used for mating. The skin of the Chondrichthyes is not covered in scales but is either smooth or covered in many microscopic teeth known as dermal denticles, which serve to break the water tension as they swim through the water.

Sharks have a highly developed sense of smell and this allows them to detect minute traces of scent in the open ocean to locate food. Sharks sight varies from species to species although all have excellent low light vision because of a light reflective membrane on the retina. This results in light being reflected back through the eye allowing them to see very well at dusk and night time when these animals normally hunt. Sharks and rays have electro-receptors that are sensitive to the magnetic fields produced by other living animals and allows sharks to close a membrane over their eye for protection in the last few moments before they strike. These finely tuned senses allow sharks to be very effective predators in murky and low levels of light.

Reproduction in the Chondrichthyes can take one of three forms. Once the eggs are fertilized they develop either encased in a hard envelope outside the parent’s body (oviparity), or encased eggs develop within the parent’s body (oviviparity), or finally eggs develop attached to a placenta-like structure within the parent and are born live (viviparity).
7.3 Introduction to common fish families

Identifying fish families

When confronted with the large numbers of fish on a coral reef it is easy to feel overwhelmed with trying to identify families let alone individual species. It is important to not rely too heavily on the colour of fish when trying to identify fish families but instead to observe their size, body shape and behaviour closely. The colour of fish is only really useful in identifying individual species within a family and even then it can be difficult as species colour can be different for each sex or can change as they age. Some fish species also mimic the colour of other species making it even more important that anyone trying to identify fish are familiar with the body shape of each fish family.

Pomacentridae – Damselfish & Anemonefish

The Pomacentridae are a large family with over 100 species and are some of the most commonly seen reef fish. They are small and generally no larger than 15cm. They have moderately deep compressed bodies, continuous dorsal fins, and small terminal mouths. Some species are highly territorial and will confront divers underwater. Many species are often seen in medium sized shoals living closely associated with a coral head which they retreat into if approached. All lay demersal eggs that are defended by males. The anemonefish are part of this family and are best known for their symbiotic relationship with anemones, although other species of damselfish are also known to live in anemones. Anemonefish are protandrous hermaphrodites, and they live in groups that include a large dominant female, a smaller male mate and several immature juveniles. If the female is removed the male changes sex and one of the immature juveniles matures into a male.

\[\text{Chromis lepidolepis (Scaly Chromis)}\]

- Very common small fish
- Two spines on anal fin
- Continuous dorsal fin
- Often found in small shoals living amongst branched corals
- 3-15cm
Labridae – Wrasses

Wrasses are among the most diverse group of fishes in both size and body shape which also make them one of the hardest families to identify species correctly. Typically wrasse have elongate bodies, terminal mouths (usually with thickened lips), and one or more pairs of protruding canine teeth. Wrasse have a distinct swimming pattern, which they share with the parrotfish family, using primarily their pectoral fins in a flapping motion. Wrasse also generally have a single, unnotched dorsal fin.

Individual wrasse species can be particularly difficult to identify because most species have complex and brilliant colour patterns that change with growth or sex. They also range in size from the smallest cleaner wrasses at 10cm to the largest Humphead or Napoleon wrasse at 200cm.

Most wrasses are carnivores of benthic invertebrates or fishes although some are planktivores, corallivores, or feed on ectoparasites on other fishes (cleaner wrasses). Wrasses are normally seen swimming rapidly around the reef alone or in small groups.

- Diverse and large family
- Swim using their pectoral fins only
- Usually elongated with a continuous dorsal fin
- Thickened lips with protruding teeth
- Most species change colour and sex with growth
- 8 – 50cm (max 200cm)

Halichoeres hortulanus (Checkerboard Wrasse)

Chaetodontidae – Butterflyfish and Bannerfish

The butterflyfish are among the most colourful and conspicuous reef fishes. They have highly compressed, disk-like bodies covered with small scales, a small protractible mouth with small brush-like teeth, and a long continuous dorsal fin. They are typically diurnal and have minimal home-ranges. Most species of butterflyfish live closely associated with coral and feed on coral polyps. Butterflyfish also feed on small invertebrates, fish eggs and filamentous algae. Butterflyfish tend to be gonochoristic with most species mating in pairs for years, if not for life, and are therefore often seen in pairs on the reef. Many species of butterfly fish have a dark strip that camouflages their eyes, and juveniles are often a different colour and pattern to adults. Butterflyfish tend to be timid and are likely to swim away from divers.

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Chaetodon vagabundus (Vagabond Butterflyfish)  Forcipiger longirostris (Big Longnosed Butterflyfish)

- Small, colourful disc-like fishes
- Small ‘sticking out’ mouth
- Continuous dorsal fin
- Emarginate to rounded tails
- Often seen in pairs
- Closely associated with coral
- 15-20 cm (max 30 cm)

Pomacanthidae – Angelfish

Angelfish have a compressed body with a small mouth. The key identification feature of the angelfish family is that they all possess a spine that extends backwards from the front of their operculum (a pre-opercular spine is highlighted in the picture below). Juveniles and adults often have strikingly different colour patterns. They are active by day and generally seek shelter in caves and crevices at night. All species are protogynous hermaphrodites (change from female to male) with a harem social system, usually one male with up to five females. Most species feed on sponges, some soft bodied invertebrates, algae and fish eggs, whilst other species feed on small invertebrates and filamentous algae. Angelfish tend to be quite shy and many species will retreat into crevices and under coral when approached by a diver. Angelfish are usually observed as individuals or pairs.

- Small to medium sized fish
- Deeply compressed bodies
- Pre-opercular spine
- Small spines on head
- 10 – 40cm (max 50 cm)
Apogonidae – Cardinalfish

Cardinalfish are small, nocturnal fish with large eyes that hide during the day and feed on zooplankton and small crustaceans at night. They are normally seen in dense aggregations in caves, overhangs and among branching corals. The cardinalfish body shape and fins is symmetrical along the midlateral bodyline. Their common name originates from the fact that several species are red but many are drab coloured, striped, or transparent. Male cardinalfish incubate the eggs in their mouths until hatching.

- Largely nocturnal
- Large mouth and eyes
- Found in dark parts of the reef during the day
- Two dorsal fins
- Body shape and fins are symmetrical
- 5 – 12cm (max 18cm)

![Cheilodipterus quinquelineatus](Five-Lined Cardinalfish)

Serranidae – Groupers, Anthias, Basslets, Soapfish

Groupers, Anthias, Basslets and Soapfish are a large and diverse family of reef fish. The family all share a distinctive shaped pupil:

![Serranidae pupil]

Groupers are large, robust-bodied bottom dwellers with large, down-turned mouths that they use to suck in prey. Groupers are normally seen as solitary individuals and are voracious predators of crustaceans, fishes, and cephalopods. Some species of groupers often hide from divers and the most seen of an individual are their tails disappearing under a rock, whilst others rest on coral heads and rock. Groupers also like to rest in caves and holes. Large species may live for several decades and reach weights of up to 400kg and 3m in length. Many species are sequential hermaphrodites (first female then male) and if larger fish are harvested the population could contain a disproportionate number of smaller females.

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Cehalopholis argus (Peacock Grouper)  
Epinephelus spiloceps (Foursaddle Grouper)

- Single well defined dorsal fin
- Robust body and large, down-turned mouth
- Serranidae shaped pupil
- Normally seen resting in holes or on rocks during the day
- 30 – 70 cm (max 270 cm)

Anthias and basslets are small, colourful fishes that are found in large, conspicuous shoals swimming close to the reef. Anthias are normally most abundant along current-swept drop-offs. They are planktivores and aggregate in groups of many females to a few males over coral heads into which they retreat when approached by divers.

- Single well defined dorsal fin
- Mostly small and colourful
- Mostly small mouthed
- 7 – 15cm (max 20cm)

Pseudanthias squamipinnis (Lyretail Anthias) [female]

Soapfishes are large-mouthed grouper-like fish which often have a notched dorsal fin. They produce a bitter toxin (grammistin) secreted in mucus that protects them from predation. Soapfish are seen as solitary individuals on reefs but are rarely seen by divers.
• Small and grouper like
• Solitary predators
• Dorsal fin may be notched
• 14 – 40 cm

*Scaridae – Parrotfish*

The parrotfish closely resemble wrasses but have teeth fused into beak-like plates, which is not only the origin of their name but also the defining characteristic of the family. They are herbivores and most scrape algae from the reef. This is often achieved by crushing algae-encrusted rock and live coral with their beak-like teeth and digesting it. This leads to parrotfish excreting plumes of sand which is a second distinguishing characteristic of this family, and makes them the biggest producers of sand on coral reefs. Similar to the wrasse family, the parrotfish also swim in a flapping motion using their pectoral fins. Individual parrotfish species can also be difficult to identify since they also change colour with age and sex.

During the day parrotfish are seen swimming alone or small shoals around the reef, biting chunks of rock or coral with their teeth and excreting puffs of sand. At night parrotfish sleep wedged in holes and crevices on the reef and some species can surround themselves with a mucus cocoon that may help to protect them from predators by hiding their scent.

• Teeth fused into a distinctive beak
• Large scales
• Distinctive swimming style (flapping)
• Hermaphroditic; change colour with age and sex
• 30 – 50 cm (max 150 cm)

*Chlororus sordidus* (Bullethead Parrotfish) [female]

*Acanthuridae – Surgeonfish and Unicornfish*

Surgeonfish and Unicornfish have ovate or elongate compressed bodies, small terminal mouths and a continuous dorsal and anal fin. The distinguishing feature of this family, and the origin of their common name, are the sharp blades which sit on each side of the caudal peduncle (the area between the body and the tail). Surgeonfish have one blade whilst unicornfish have two blades and some but not all have a unicorn-like
protrusion from their heads. Most species graze on algae and have a gizzard like stomach which grinds sand to help digest the algae.

‣ Oval body with small mouth
‣ Continuous dorsal and anal fins
‣ Scalpel blade(s) on caudal peduncle
‣ 25 – 35 cm (max 55 cm)

**Gobiidae – Gobies**

This is the largest family of marine fishes with over 1500 species worldwide. The family is characterized by small, elongate, blunt-headed fishes with large mouths. Gobies tend to have well developed pelvic fins and the dorsal fin is often in two parts. Most species are bottom-dwellers and live closely associated to the substrate, with some species living in burrows in the sand, and others living deep in coral heads. They are carnivores of small invertebrates, but many are also detritivores or planktivores. Many of the species that live in burrows in the sand have formed a symbiotic relationship with a partly-blind alphaeid shrimp. The relationship is beneficial to both partners; the shrimp digs and maintains the burrow whilst the goby watches for predators. At the first sign of danger the goby will warn the shrimp with a flick of its tail and both retreat down the burrow.

‣ Small elongate body with blunt head
‣ Large mouths
‣ Well developed pelvic fins
‣ Often have two dorsal fins
‣ Some species live in burrow with shrimp

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*Naso elegans* (Orangespine Unicornfish)  
Two blades coloured orange

*Acanthurus leucosternon* (Powderblue Surgeonfish)  
[One blade coloured yellow]

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**Oplopomus oplopomus** (Spinecheek Goby)

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• Mostly small, less than 10cm

Blenniidae – Blennies

Blennies are a large group of small, elongate, bluntheaded fishes that often have a long continuous dorsal fin and a fleshy crest on their head. Most species in the family are bottom dwelling territorial fishes that lay demersal eggs that are guarded by the males. Blennies feed on algae, small invertebrates and zooplankton. A group of blennies, the fangblennies, also feed on the scales, fins and skin of larger fish. Some species of fangblennies have evolved the same colouration and behavior of the harmless cleaner fish, which eat the parasites and dead scales from larger fish. The mimic blenny, *Aspidontus taeniatus*, mimics the cleaner wrasse which allows it approach unsuspecting larger fish to take a bite from them.

• Elongate body
• Rounded head and large eyes
• Long continuous dorsal fin
• Many species have a fleshy crest on head
• Small size, 15cm max

*Plagiotremus tapeinosoma* (Scale-Eating Fangblenny)

Caesionidae – Fusiliers

Fusiliers are medium sized schooling fish with elongate, tapering (fusiform) bodies and a deeply forked tail. During the day they are usually found in large, mixed-species schools that roam feeding on zooplankton. Divers normally see fusiliers swimming in schools up or down the reef slope and are usually more abundant along steep outer reef slopes.
• Elongate, fusiform bodies
• Continuous dorsal fin
• Forked tails
• Fast swimming in shoals away from the reef
• 15 – 25 cm (max 53 cm)

Siganidae – Rabbitfish

Rabbitfish have highly compressed bodies with venomous fin spines. Their name originates from the fact that they are diurnal herbivores of seagrasses and algae. They are often seen in pairs or small shoals swimming close to the reef and seagrass beds.

• Highly compressed bodies
• Venomous dorsal fins and minute scales
• Small terminal mouth
• Complete lateral line
• 30 – 40 cm (max 53 cm)
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Balistidae – Triggerfish

Triggerfish are characterized by a first dorsal fin with three spines that can lock upright and a swimming motion that involves undulating the second dorsal fin and anal fin simultaneously. They have a relatively deep, compressed body with eyes set high on the head, a small terminal mouth and large snout with sharp teeth. Triggerfish are carnivores of urchins and other echinoderms, corals, fish, molluscs and crustaceans. Most species lay demersal eggs which are often viciously guarded by at least one of the parents and they will protect a cone shaped area that radiates upwards from their eggs. Divers are often chased by brooding triggerfish. Most species of triggerfish are seen solitary, often in sandy patches, but some are found in large shoals such as *Odonus niger*, the Redtooth triggerfish.

- First dorsal fin with a large spine
- Swim by undulating second dorsal fin and anal fin
- Deep bodied and compressed
- Pelvic fin reduced to a knob
- Eyes high on head
- 25 – 35 cm (max 75 cm)

Lutjanidae – Snappers

Snappers are medium to large robust fish that are commonly seen in schools swimming off the reef. They have continuous dorsal fins, large coarse scales and normally an emarginate to forked tail. Most species are predators of crustaceans and smaller fish. Many smaller species school by day, and disperse to feed on benthic invertebrates at night, whilst some larger species tend to be solitary. Some juveniles’ species look distinctly different from their adult versions, for example the Black Snapper, *Macolor niger*.

*Lutjanus lutjanus* (Bigeye Snapper)  
*Lutjanus fulviflamma* (Black-Spot Snapper)
Perch-like fish
Continuous dorsal fin
Coarse scales
Often in shoals, swimming off the reef
35 – 45 cm (max 100 cm)

Haemulidae – Sweetlips

Sweetlips are most easily confused with snappers, and are medium to large fish with noticeably thickened lips. Sweetlips are also distinguished by a caudal fin with a straight posterior margin and an undulating swimming motion. Like snappers, many species undergo dramatic changes in colour as they grow. Sweetlips are normally seen in small groups or solitary, swimming slowly near the reef. They generally feed at night on benthic invertebrates and small fish.

Thickened lips
Sloping forehead
Adults straight posterior of caudal fin
Swim in undulating motion
40-80cm (max 100cm)

Mullidae – Goatfish

Goatfish have elongate bodies with two barbels (whiskers) under the chin from which they derive their common name. The barbels contain chemosensory organs and are used to probe the substrate for small benthic invertebrates or fishes. Goatfish are therefore normally seen foraging on sandy areas of the reef for food. Their mouths are also found on the base of their heads sp when they are hunting they can easily consume the food they locate with their barbells.

Pair of distinct barbels on chin
Mouth located on lowest point of head
2 separate dorsal fins
• Forked tail
• 30 – 40 cm (max 60 cm)

*Parapeneus barberinus* (Dash and Dot Goatfish)

**Lethrinidae – Emperors**

Emperors are medium to large fish that can also be confused with snappers. However, they tend to have a steeper sloping forehead and eyes that are placed higher on their head than the snappers. They primarily feed at night on invertebrates (hard shelled molluscs, urchins), crustaceans, cephalopods, and fishes.

• Steep forehead
• Eye placed high on head
• Emarginated to forked tails
• Continuous dorsal fin
• 40 – 50 cm (max 100 cm)

*Lethrinus borbonicus* (Snubnose Emperor)

**Nemipteridae – Spinecheeks, bream, whiptails, and threadfins**

Spinecheeks are small to medium sized elongate fish, with a continuous dorsal fin and an emarginated or forked caudal fin. Spinecheeks derive their common name from the presence of a sharp, backward pointing spine found immediately under the eye. They are normally observed solitary or in small groups on sandy patches of the reef and feed on soft-bottom dwelling invertebrates. They have a characteristic swimming motion that involves stopping and starting in which they appear to be hovering on the spot.

• Sharp, backward pointing spine under the eye
• Stop and start when swimming
• 20 – 35 cm
**Holocentridae – Solderfish & Squirrelfish**

Soldierfish and squirrelfish are medium sized fish with large eyes, large scales with spiny dorsal fins. Most species are nocturnal and predominately red (a colour that looks black in low light in the water) and during the day hover in or near caves and crevices. Soldierfish have blunt snouts and feed on zooplankton and larval crustaceans. Squirrelfish have longer snouts, smaller scales, and a sharp spine on front of head that extends over the operculum and feed mainly on benthic invertebrates and small fishes.

- Medium sized fish with bony heads
- Stout fin spines and large spiny scales
- Large eyes
- Predominantly red in colour
- Found in dark areas of the reef during the day
- 10 – 30cm

**Priacanthidae – Bigeyes**

Bigeyes have very large eyes along with upward oriented mouths, a projecting lower jaw and a continuous dorsal fin. During the day they hide under ledges and in cracks on the reef, while at night they migrate above and away from the reef to feed on larger zooplankton.

- Upward orientated mouths
- Very large eyes
- Hide under ledges and in cracks during the daytime
- 30 – 40 cm

**Pempheridae – Sweepers**

Sweepers are distinctive hatchet shaped fish with large eyes. During the day they tend to hover in schools under ledges or in crevices, while at night they disperse above the reef to feed on benthic and planktonic...
crustaceans, other small invertebrates and sometimes fishes.

- Hatchet shaped
- School under ledges and in crevices during the day
- 15 – 20cm

**Syngnathidae – Pipefish & Seahorses**

Pipefish and seahorses typically have long, tubular snouts, elongate bodies and feed on tiny crustaceans. Seahorses are rarely seen on dives due to their cryptic nature whereas pipefish are more commonly seen on sand and rubble substrate. The have an unusual method of reproduction that involves the male fertilizing and incubating the eggs once they have been deposited in his brood pouch by the female.

- Long, elongate bodies
- Cryptic, hide amongst seagrasses, corals and other invertebrates
- 5 – 15cm

**Monocanthidae – Filefish**

Filefish are very similar to triggerfish but have only one long, prominent dorsal spine compared to the three shorter dorsal spines on the triggerfish. Filefish also have more compressed, thinner bodies. They are normally seen solitary or in pairs swimming close to the reef.
• Similar to triggerfish but with one, long dorsal spine
• 10 – 40cm (max 100cm)

Cantherines pardalis (Wirenet Filefish)

Ostraciidae – Trunkfish/Boxfish

Trunkfish derive their common name from their distinct box-like bodies. Their mouth is low with thick lips, and are slow-moving diurnal predators of small sessile invertebrates and algae. They swim using the small dorsal and anal fins and are seen on dives closely associated to the reef. When under stress they can secrete a toxin (ostracitoxin) which is lethal to other fishes.

• Box-like bodies
• 10 – 30cm

Tetradontidae – Pufferfish and Tobies

Pufferfish are named for their ability to inflate themselves by drawing water into specialized organs near the stomach. They have a rounded body shape even when not inflated with a small dorsal fin and no pelvic fin. The mouth is small and pointed, especially in the tobies, and their teeth are fused into a beak which can be clearly seen on some of the larger species. Pufferfish also harbor one of nature's most powerful toxins, tetrodotoxin. The pufferfish are generally quite shy fish and will hide in the nearest hole when divers approach. Tobies are smaller than pufferfish but share a similar body shape. They are often seen in pairs on the reef and are more inquisitive of divers.
**Arothron immaculatus** (Immaculate Puffer)  
**Canthigaster solandri** (Spotted Toby)

- Bulbous body and scaleless
- Teeth fused to form beak
- Small, single dorsal fin
- 10 – 40 cm (max 120 cm)

**Diodontidae – Porcupinefish**

Porcupinefish are very similar to pufferfish but they are differentiated by the prominent spines covering their body. The spines lay flat on the body unless the fish is threatened and inflates itself. Their teeth are also fused into beak that is used to crush prey.

- Bulbous body similar to pufferfish
- Body covered in large spines
- Small single dorsal fin and no pelvic fin
- 30 – 60 cm

**Synodontidae – Lizardfish**

Lizardfish are long, slender, cylindrical bodied fish that perch on rocks and coral heads resting on their pelvic fins. They have large mouths and are well-camouflaged for ambushing prey. They are easily confused with sandperches but have a straight back and a smaller dorsal fin.

- Small to medium sized fish
- Lie perched on rocks and coral resting on their pelvic fins

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Sandperches also have an elongate body and are normally seen perching on sand and rubble substrate, resting on their pelvic fins. They can be distinguished from lizardfish by their curved body shape and prominent, lizard-like eyes. They are generally benthic carnivores of small invertebrates and fishes.

- Small to medium sized fish that normally lie perched on sand
- Curved bodies and lizard-like eyes
- 10 – 20cm

Zanclidae – Moorish Idol

This family contains a single species, the Moorish Idol. It has a rounded, compressed body, tubular snout and a dorsal fin that elongates into a long, whip-like filament. It is most closely related to the surgeonfish family, but is most often confused with the Longfin Bannerfish, a species of butterflyfish, due to the long, filamentous dorsal fin they both possess. The Moorish Idol can be easily distinguished from the Longfin Bannerfish by the prominent orange saddle on its nose. The Moorish Idol is omnivorous but feeds primarily on sponges and algae.
Antennariidae – Frogfish

Frogfish are particularly strange looking fish that are difficult to find on the reef due to their excellent camouflage abilities. They have round, bulbous bodies, jointed elbow-like pectoral fins that are used like arms, and large, upturned mouths. They sit motionless on the reef camouflaged with their background (often sponges) waiting for prey. Frogfish entice prey with a first dorsal spine that has been modified into a fishing pole (illicium) tipped with a lure (esca). Frogfish have incredibly fast reflexes and can suck up prey in milliseconds.

- Round body with small eyes and large upturned mouth
- Limb like pectoral fins with elbow like joint
- Have a highly modified first dorsal spine into a fishing lure
- Very well camouflaged
- 10 – 30cm

Scorpaenidae – Lionfish and Scorpionfish

Scorpionfish and lionfish both have venomous fin spines. Scorpionfish are well-camouflaged fish that are covered in appendages and tassels, and remain motionless resting on coral heads, rocks or the substrate waiting for prey. Scorpionfish will dart away from their resting place if a diver approaches too close and are often not observed until this point. Some have brightly coloured undersides or parts of their pectoral fins, which may be flashed as a warning to potential predators.

Lionfish are instantly recognizable by the long, protruding spines that radiate from their dorsal and pectoral fins. They are normally seen under overhangs during the day or swimming slowly near the substrate.
Scorpionfish are well-camouflaged and rest on substrate

Lionfish have long spines on dorsal and pectoral fins

Large spiny head, bony ridge cheek

Well developed pectoral fins

Fin spines venomous

5 – 30cm

Cirrhitidae – Hawkfish

Hawkfish are small, grouper-like fishes that are generally seen perching on coral heads. Many species have dorsal fins with numerous short filaments (cirri) on the end of each of the spines. They eat small crustaceans and fish, that they ambush with quick bursts of speed.

Small grouper-like fish

Perch on coral heads

Often small mass of cirri on dorsal fin spines

10 – 15cm (max 30cm)

Aulostomidae – Trumpetfish

Trumpetfish are represented by a single species in the Indo-Pacific basin. The trumpet fish has a long, tubular body with a flaring snout through which prey are sucked. They are sometimes seen hanging vertically amongst coral, seagrass, or schools of larger herbivorous fishes in order to approach unsuspecting prey.

Distinct long tubular body and nose

Up to 80cm

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**Fistularidae – Cornetfishes**

Cornetfish are similar to trumpet fish but are characterized by a long, vertically flattened (rather than laterally) body and long and a whip-like tail filament.

- Long body that is vertically flattened
- Whip-like tail filament
- Up to 150cm

![Fistularia commersonii (Cornetfish)](image)

**Centriscidae – Shrimpfishes**

Shrimpfish are small fish that swim in small groups in a distinct vertical head-down position. They are related to the seahorse and have a similar tubular snout. The body of the shrimpfish is long and transparent and they have a long spine that extends from their body, which is an extension of their dorsal spine. Shrimpfish can often be found hiding among seagrass, the spines of Diadema, staghorn corals or gorgonians. If threatened their posture becomes increasingly horizontal as they swim faster.

- Swim vertically in head down position
- Seen in small groups, often hiding amongst Seagrasses and corals.
- 10 - 15cm

![Shrimpfish swimming](image)

**Muraenidae – Moray Eels**

Moray eels are elongate snake-like fish with large mouths with numerous sharp teeth. They can be distinguished from sea snakes by their long, continuous dorsal fin, which is not seen on sea snakes. During
the day they are normally seen hiding in crevices and caves with only their heads showing. Moray eels repeatedly open and shut their mouths to force water over the surface of their gills. Their reputation for being dangerous is unfounded and will only bite if severely provoked.

- Extremely elongated body
- Long, continuous dorsal fin
- No pectoral or pelvic fins
- Hide in crevices with often only the head showing
- 60 – 90 cm (max 300 cm)

Carangidae – Jacks and Trevallys

Jacks and trevallys are medium to large silvery fish. They are fast-swimming pelagic fish so are generally observed swimming in the deeper water off the reef. They have two dorsal fins, a long pectoral fin and a highly forked tail fin. They are normally seen in schools and are economically important food fishes.

- Large, silvery pelagic fish
- Two dorsal fins
- Highly forked tail
- Often seen in schools
- 30 – 100cm (max 120cm)

Sphyraenidae – Barracuda

Barracudas are elongate fish with silvery bodies. They have long, pointed heads with large down-turned mouths with numerous sharp teeth. Barracudas also have two widely spaced dorsal fins. They are often seen solitary but more often they are seen in schools. They very rarely attack divers but it is reported that they may sometimes be attracted to shiny, silvery objects in the water.
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‣ Elongate and silvery
‣ Two widely spaced dorsal fins
‣ Pointed head
‣ Large mouth and big teeth
‣ 70-100cm (max 190cm)

*Sphyraena barracuda* (Great Barracuda)

### 8. INTRODUCTION TO INVERTEBRATES

#### 8.1 Introduction

Invertebrates account for 95% of species in the Animal Kingdom (Fig. 8.1). The Animal Kingdom has just over a million scientifically described species categorised into thirty-two phyla. The phylum Chordata, which includes all fish, birds, and mammals, only contains around 45,000 (3%) species, of which only 4,000 (0.03%) are mammals. The remaining phyla are comprised of invertebrate groups.

*Fig. 8.1 Diagram to show the percentage of animals that fall within the different phyla*

[Figure showing the percentage of animals within different phyla]

E.O. Wilson
Some invertebrates are "keystone species" playing particularly important roles in the maintenance of biotic communities. Coral reefs are perhaps the most dramatic example, providing a wide range of niches for a diversity of plants and perhaps one-third of all fish species.

Here we will take a brief look at some of the most commonly seen reef invertebrates.

8.2 Phylum Porifera (Sponges)

Sponges are the oldest living group of metazoan (multi-cellular organisms) with over 9000 described species to date. They first appear in the fossil record over 600 million years ago during the Late Precambrian period. Sponges have simple body plans that function at the cellular level. They have neither organs nor a digestive cavity or mouth and lack both muscles and nerves. Sponges are sessile filter feeders and they have tiny inhalant pores, called ostia, in their outer walls through which water is drawn (Fig. 8.2). Cells in the sponge walls, called choanocytes, filter bacteria and food particles from the water. Water flowing through sponges therefore provides food and oxygen and acts as a means for waste removal. These cells also have whip-like flagellum which drives the flow of water into the sponge. The flow of water through the sponge is unidirectional and is pumped out of the body through exhalent holes. The volume of water passing through a sponge can be enormous, up to 20,000 times its volume in a single 24 hour period.

Sponges can trap roughly 90 percent of all bacteria in the water they filter. Some sponges also harbour symbionts such as green algae, dinoflagellates, or cyanobacteria, from which they also derive nutrients. Sponges can develop into diverse life forms, ranging from encrusting sheets to large barrels. Their structure is supported by a skeleton composed of an organic substance called spongin, or they may have calcareous or siliceous skeletons composed of chambers, or more commonly rod-like branched elements called spicules.

There are 3 main classes of Porifera:

a) Calcarea – Sponges with calcium carbonate spicules.

b) Hexactinellida – Deepwater sponges with siliceous spicules.
c) Demospongiae – Includes the vast majority of shallow water tropical species and up to 90% of presently described sponges. They have siliceous spicules and/or spongin fibres.

Sponges can reproduce asexually and sexually. Most sponges that reproduce by sexual means are hermaphroditic and produce eggs and sperm at different times. Sperm are frequently "broadcast" into the water column and are subsequently captured by female sponges of the same species. Once the larvae are in the water column they settle and develop into juvenile sponges. Asexual reproduction is through budding or fragmentation.

Sponges on the reef provide homes for a large diversity of other organisms, including shrimps, crabs, barnacles, worms, brittlestars, sea cucumbers, other sponges, cyanobacteria, and light-loving microbes. Sponges appear to suffer little predation, only being fed on by nudibranchs and certain species of fish and turtle. This is thought to be due to the complex protective compounds produced by sponges as a by-product of their daily metabolism. Several of these sponge compounds are shown to be active against certain tumor cell types and highlights the possible medicinal resource of the Porifera.

Fig. 8.2 The ostia (inhalant pores) of a sponge, through which water is filtered, are clearly visible.

8.3 Phylum Cnidaria (Corals, Anemones, Hydroids, Jellyfish)

The Cnidaria are a large and diverse phylum which include hard and soft corals, anemones and jellyfish. There are more than 10,000 described species of Cnidaria and they form the basis of many tropical and colder water marine ecosystems.
This diverse group is united by the fact that all members are armed with stinging cells called nematocysts and the name Cnidaria comes from the Greek meaning ‘stinging creature’. The nematocysts are barbed, harpoon-like darts tipped with poison that are discharged on contact with prey or predators.

Cnidarians are radially symmetrical (the body is symmetrical around a central axis). Cnidarians can have one of two basic body plans, a polyp, with the tentacles and mouth facing upwards, or a medusa, with the tentacles and mouth facing down (Fig. 8.3). Some Cnidarians may pass through both life forms during their life cycle, whilst others only pass through one of the two.

Some cnidarian species consist of a single polyp, such as sea anemones and mushroom corals, whilst other species comprise colonies of polyps, such as most hard and soft corals. The basic body plan of the polyp is a cylindrical column with a ring of tentacles surrounding the only opening. The main column of the body consists of an outer layer, the epidermis, a middle layer, the mesoglea and an inner layer, the gastrodermis. There are no respiratory, circulatory or excretory organs and only a hydrostatic (water based) skeleton.

Cnidarians not only rely on their stinging cells to catch prey but also use suspension feeding to capture food. Many cnidarian species also harbor symbiotic single-celled algae, called zooxanthellae, which contribute

**Fig. 8.3 Diagram of a cnidarian polyp (NOAA photo)**
nutrients to the cnidarian. In some hard coral species it is estimated that the algae can contribute up to 80% of the daily food requirements of the coral.

There are 4 important classes of this Phylum:

1) **Hydrozoa** ‘Hydrozoans’

The Hydrozoa are a diverse group of organisms with about 2700 species. Most hydrozoans are colonial and can form a variety of life forms from small, feather-like branched colonies, to large colonies with a calcareous skeleton. Most hydrozoans alternate between a polyp and a medusa stage, when they can be difficult to distinguish from a true jellyfish. Floating colonies of hydrozoans, such as the "Portuguese man-o’war" are also often confused with jellyfish but are actually made up of many individuals. Individual polyps often have specialised functions, such as for feeding or for reproduction.

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**Macrorhynchia spp.**

**Millepora spp. (Fire Coral)**

One of the most common and obvious groups of hydrozoan species is the family Milleporidae. They are often called ‘Fire Corals’ due to fact that they secrete a calcareous skeleton similar to the hard corals and can cause a painful sting to those who accidentally touch their surface.

2) **Cubozoa** ‘Box Jellyfish’

The Cubozoa is a small group in which the bell of the medusa is cuboid in shape with 4 tentacles, or groups of tentacles, on each corner. They are generally small in size, between 1cm and 30cm, but have highly toxic stings, many of which are fatal to humans. Box jellies are known to eat fish, worms, and arthropods. They are unusually strong swimmers and also have surprisingly complex eyes for an animal with no brain. Their eyes are sensitive to light and box jellyfish have been reported to maneuver around peer legs and to flee human collectors.
3) Scyphozoa ‘True Jellyfish’

The Scyphozoa consist of over 200 species of pelagic, free-swimming organisms that can range in size from twelve millimeters to more than two meters across. Their life cycle involves an alternation between sessile polyp phase and a free-swimming medusa stage. The medusa stage is usually the dominate stage in the Scyphozoa, and some species, such as Aurelia aurita shown above, also travel in large groups that can number into the thousands.

The Scyphozoa have only one opening, like all cnidarians, through which food and waste must be passed out. Surrounding the ‘mouth’ are usually four oral arms or tentacles which contain the stinging cells that are used for paralyzing prey and defense. The larger jellyfish prey on fish and invertebrates whilst smaller jellyfish may feed on suspended organic particles in the water. One member of the jellyfish family, Cassiopeia, has evolved an unusual feeding style. It lies upside down on the seafloor in the shallows so that its tentacles face towards the surface. The body tissue of the jellyfish contains photosynthetic dinoflagellates, which manufacture their own food and provide food for the jellyfish.

4) Anthozoa (Sea Anemones, Hard and Soft Corals and Sea Pens)

The Anthozoa is the largest of the Cnidarian classes, with over 6000 described species. They are exclusively marine, sedentary and can occur as individual polyps or in colonies. They have no medusoid stage in their life cycle.

Diagram 8.4 on the next page shows the major orders in the Anthozoa. Details of each order in the diagram are listed below along with further information on other smaller orders.

Subclass Octocorallia (Octocorals):

The polyps have eight internal walls, and therefore have eight-fold radial symmetry, and feathered tentacles.

Most octocorals produce spicules within their body tissue to provide support. The majority of octocorals are filter feeders and may also house symbiotic zooxanthellae.

- Order Alcyonacea (soft corals); The soft corals are composed of about 28 families. They are characterised by the development of a fleshy outer layer into which the polyps can retract, and which makes the coral flexible. Species can form a wide variety of life forms including encrusting, massive or tree-like colonies.
• Order Gorgonacea (sea fans and sea whips); They are typically brightly coloured and form fan or branched shapes that align themselves perpendicular to the prevailing current. They are tougher than other members of the octocorals and have a firm internal skeleton composed of a proteinaceous material called gorgonin.

• Order Pennatulacea (sea pens); Sea pens are elongate, complex colonies which bury their base in soft substrates. Most seapens have a central, organic rod in the primary polyp that supports their colony.

• Order Helioporacea (blue corals); Unlike other octocorals, Heliopora lacks spicules, but has a solid, blue, aragonitic skeleton. Heliopora is an important reef forming coral throughout Micronesia. The live colonies look brownish blue due to the color added by zooxanthellae but the dead skeleton is blue in colour. They can be distinguished from hard corals underwater by the numerous small holes that cover their surface when their polyps are retracted.

• Order Stolonifera (stoloniferans); The polyps can retract into individual tubes which are connected to each other by runners, or stolon. Tubipora musica, the organ-pipe coral, is a conspicuous stoloniferan in that it builds substantial colonies supported by a red endoskeleton.

Subclass Hexacorallia (Anemones and Hard Corals):

The Hexacorallia is a diverse group and hexacoral polyps can vary greatly in form. They have six tentacles and internal walls, or a multiple thereof, and can have as few as 6 or as many as several hundred tentacles.

The size of polyps range from less than 1mm to greater than 1m in diameter, and may be solitary or colonial.

• Order Actinaria (sea anemones); Sea anemones mostly form distinctive solitary polyps, with an upwards facing mouth and a flattened “foot” for attachment. Their tentacles contain the stinging nematocysts and anemones are host to many animal symbionts taking advantage of this extra protection. Anemones are not only host to clownfish but also numerous other species of fish, copepods, shrimp and half crabs are adapted to use them for shelter.
Fig 8.4 Diagram of the main orders in the phylum Cnidaria
• Order Scleractinia (hard or stony corals); Hard corals are the most important reef-building animals and there are over 2,500 species exist worldwide. Although some species of hard coral can be easily identified there are several genera, such as the Acropora and Montipora, in which individual species can only be identified after examination of the skeleton under a microscope. This is partly because the morphology of coral colonies can alter depending on the environmental and biological conditions they are growing in. Hard corals were covered in detail in Chapter 3.

• Order Zoanthidea (zoanthids); Zoanthids are mainly colonial. They have relatively small polyps with short tentacles that arise around the edge of the polyp. Many species are able to incorporate sand into their mesoglea for support. Zoanthids can reproduce asexually to form colonies or clonal aggregates, or through free spawning. Zoanthids will close up when disturbed.

• Order Coralliomorpharia (corallimorphs); Corallimorphs are anemone-like animals but are generally more fleshy than anemones. Most reef species harbour zooxanthellae. They can be found as solitary individuals or in small to large colonies. The largest corallimorph, Amplexidiscus fenestrafer, can reach 50cm wide and is capable of capturing small fish.
• Order Antipatharia (black corals); Black corals secrete an arborescent or whip-like scleroproteinaceous skeleton and superficially resemble gorgonians. Their name is derived from the colour of their inner skeleton which is used to make jewelry. In the water black corals normally form bushy or coiled whip-like structures which are brown, green or yellow. They can be clearly identified through the visible, fleshy polyps on the surface of the organism that can not pull into skeleton.

8.4 Phylum Mollusca (Snails, nudibranchs, oysters, clams, squid, octopus)

The molluscs are a diverse group of over 160,000 different species, of which about half are marine. The phylum Mollusca is divided into eight classes but there are three major classes, the gastropods, which comprise 80% of all living molluscs, the bivalves and the cephalopods.

Although the members of this phylum range in body shape from the gastropod snails to the giant squid there several key features which define the molluscs. The body is soft, unsegmented and bilaterally symmetrical usually with a definite head.

The ventral or lower part of the body wall is often specialized into muscular foot and used chiefly for locomotion. The dorsal body wall is typically surrounded by a thin mantle, which encloses the mantle cavity in which the gills are found, and secretes the shell material in shelled molluscs.

The phylum is comprised of three major classes:

1) Gastropoda

Gastropod literally means ‘stomach-foot’ and they are the most successful and most commonly seen class of molluscs. Gastropods have a single, often coiled, shell within which the body is protected. All gastropods have a toothed radula, a chitinous band in the mouth covered in horny teeth, used to scrape and rasp food. The majority of gastropods feed on algae, sponges, other molluscs and small invertebrates. The Triton trumpet, Charonia tritonis, is one of the few predators of the notorious Crown-of-Thorns starfish.
The Gastropods have two main subclasses:

Subclass Prosobranchia: Typically found with a spirally coiled shell into which the animal can retreat. Shells can also be domed or tubular shaped. This class includes abalones, limpets, nerites, turban and top shells, periwinkles, vermetids, conchs, cowries, helmet shells, whelks, olives and cones shells. It is important to note that the mantle can extend over the entire shell in some species making gastropods harder to identify.

Subclass Opistobranchia: Typically without shells the opistobranchs or sea slugs often have obvious, unprotected gills. However some species do have external or small internal shells. Several species also have 1 or 2 pairs of rhinophores for chemo-, tactile-, and photo-sensitivity. The sea slugs are hermaphroditic and lay distinct whorls of bright, ribbon-like eggs. The largest and most noticeable order within the opistobranchs are the colourful nudibranchs.
2) Bivalvia

Bivalves characteristically have a pair of hinged shells and tend to be laterally compressed in shape. The shells are opened and closed by an abductor muscle and are held together by ligaments. Bivalves include clams, oysters, mussels and scallops of which the giant clams can reach up to 250kg and 100 years old. Many species burrow in soft sediment using their muscular foot.

3) Cephalopoda

Cephalopod literally means ‘head-foot’ and members of this class have large heads and eight or more tentacles. The cephalopods include the squid, octopus and cuttlefish. They have large, complex eyes and a well developed nervous system, the most advanced in the invertebrate kingdom. Octopus have no hard internal or external skeleton, cuttlefish have a flat rigid bone (often found washed ashore) and squid have a gelatinous rod known as a pen. Squid and cuttlefish have a similar body plan but squids tend to be more elongate with two long non-retractable tentacles whereas cuttlefish have a larger body and smaller arms.

Cephalopods are rarely seen on dives due to their excellent camouflage and often the only indication that you are passing close to an octopus or squid is a plume of ink as the animal darts off. The ink acts as a diversion for predators and is ejected from a muscular siphon which is also used to propel the animal through the water. The cephalopods are capable of changing colour rapidly by using chromatophores, small muscles...
containing pigment that the cephalopod can contract to create a different colour, to act as a warning, camouflage or communication. Cuttlefish and some species of octopus can also change the texture of their skin to camouflage themselves more effectively with the substrate.

The most elusive and primitive cephalopod is the nautilus, which has a distinctive coiled shell and lives in deep waters during the daytime. The Giant Squid is the largest cephalopod and can reach lengths of 20m but has never been observed alive.

8.4 Phylum Echinodermata (Starfish, Brittledstars, Featherstars, Sea Urchins and Sea Cucumbers)

The Echinoderms constitute around 7000 described living species with another 13,000 known from fossil records dating back 600 million years ago. The name echinoderm literally means ‘spiny-skinned’ and refers to their endoskeleton of calcium carbonate plates usually baring spines which characterises this phylum. Also characterising this phylum is five-part radial symmetry and an internal water vascular system. This water vascular system is composed of an intake sieve plate and drawn into a series of canals which radiate through the body and end in tube feet. The tube feet can be expanded and contracted through the water vascular system and are used for locomotion, adhesion, feeding, respiration and sensory functions. There echinoderms have no excretory organs but usually a complete gut (mouth, stomach, intestines and anus) in one. The families are exclusively marine and the majority of species have separate sexes. The echinoderms are also renowned for their ability to regenerate lost body parts.

There are five major classes of echinoderms:

1) Asteroidea ‘Starfish’

The starfish usually have 5 arms radiating from a central disc-shaped body. However the number of arms can be over twenty and in some species the arms are not distinct and the animal appears almost circular in shape. The mouth is situated on the underside of the animal and many species are detritivores, eating the organic film covering the substrate, or predators, eating sponges, other starfish or coral polyps. Many species expel their stomach over the reef to feed thereby literally digesting the food before absorbing it into their bodies.
The most notorious member of this class is *Acanthaster planci*, the Crown-of-thorns starfish, eats coral polyps and unexplained population explosions have destroyed large areas of coral reef.

2) **Ophiuroidea** 'Brittle stars and Basket stars'

The brittle stars have a discrete circular body from which five arms radiate. Brittle star arms are highly flexible and are used mainly for locomotion. They are found in high densities on reef flats under rocks and in branching corals. When disturbed they can move very quickly and can shed arms if predators attack. The mouth is on the underside of the animal and they generally feed on detritus, but some are predators and suspension feeders.

Basket stars are nocturnal animals that remain curled up and hidden during the day and come out at night to extend their arms and suspension feed on plankton at night. Their body plan is similar to the brittle stars but each arm is intricately branched to help trap larvae and plankton in the water.

3) **Echinoidea** ‘Sea Urchins and Sand Dollars’

Sea Urchins are commonly seen on the reefs and are normally round-bodied with stiff and often sharp spines. Most species and nocturnal and are seen in caves and crevices during the day. They are major grazers
on the reef helping to turnover reef sediments and helping to release valuable nutrients. Sea urchins graze on algae and other organisms found on the substrate such as sponges and bryozoans. One of most commonly sighted sea urchin species is *Diadema* which can form dense aggregations in areas with an abundance of algae.

Sand dollars have oblong or flattened bodies, with short, relatively fine spines. They have a distinct flowershape symbol on the dorsal part of the body. The spines of several urchins contain mild venoms whist a few species have venomous pedicellariae (small beak-like structures on their outer surface) which can inflict a painful sting and is potentially lethal to humans.

4) **Holothuroidea** ‘Sea Cucumbers’

Sea cucumbers are elongate animals with a mouth surrounded by short tentacles at the anterior end of the body. They are normally seen lying on the sand floor where they feed by ingesting large amounts of sand and digesting the organic material. Sea cucumbers often leave a trail of sand as they feed as sand excreted from the anus.

The majority of sea cucumbers are large, solid, cylindrical-shaped animals with some species having long, branching tentacles surrounding their mouths. The synaptid sea cucumbers are long and skinny and have a very thin body wall, making them more delicate than other sea cucumbers. As a defence mechanism some species are able to eject cuvierian tubules (sticky, white tubules) if disturbed while others can eviscerate (expel internal organs by rupturing the body wall). However they are able to regenerate lost body organs in time.
5) **Crinoidea** ‘Feather stars and Sea Lilies’

Feather stars and sea lilies are filter feeders and feed on plankton from the surrounding water. Feather stars are abundant on the reef and distinguished by a large number of feathery arms joining at a central body. Feather stars can have between five to two hundred arms and each arm has numerous side branches, called pinnules, used for collecting food, reproduction and protection. Feather stars have special appendages, known as cirri, on the underside of their body to hold onto rocks whilst they extend their arms for filter feeding at night.

![Feather star, with arms extended, feeding at night](www.blueventures.org)

### 8.6 Phylum Chordata (Sea Squirts)

The sea squirts, also known as tunicates or ascidians, form part of the Urochordata, a subphylum of the Chordata. The Phylum Chordata includes the invertebrate sea squirts, fish, reptiles, birds and mammals. Although the ascidians are invertebrates they are included in the Chordates because their larvae have a notochord (which develops into a backbone in the vertebrates), which is lost in the adults. Therefore ascidians are the invertebrates most closely related to humans.

A**scidians are embedded in a gelatinous-looking ‘tunic’ and can occur as solitary or colonial individuals. Solitary individuals can range in size from 5mm – 25cm and normally have two noticeable openings. Colonial ascidians can comprise of large numbers of individual sea squirts or may form an encrusting mat with openings dotted over the surface of a continuous tunic. Ascidians are often mistaken for sponges but can be distinguished by their jelly-like body which will move when wafted.**

**Sea Squirts are sessile filter feeders, water is drawn into an inhalent siphon and then expelled through a separate exhalent siphon. The gill slits, or stigmata, of the branchial sac are covered in beating hair-like cilia and generate the water movement through the animal. Organic matter in the water is retained within the sea squirt by a layer of mucus lining the branchial sac.**
All ascidians are hermaphrodites and can reproduce asexually by budding or sexually. The larvae of sea squirts resembles a tadpole, and once the larvae has settled on the substrate it loses its tail and develops into an fixed ascidian.

Aiscidians are fierce competitors for space on the reef, and can rapidly overgrow corals, sponges and bivalve molluscs. Solitary species are often covered in dense assemblages of sponges, other tunicates and algae. The main predators of ascidians include starfish, polychaete worms, various fish species and flatworms. Some commensals and parasites of ascideans include shrimps, copepods, amphipods, molluscs, and protozoans.
9. INTEGRATED COASTAL ZONE MANAGEMENT AND MARINE PROTECTED AREAS

9.1 Introduction

Almost half a billion people live within 100km (60 miles) of coral reefs where they benefit from fisheries, wave and storm surge protection, and tourist income. With the worldwide coastal population expected to double by 2050, coral reefs will be facing increased pressure from unmanaged resource use and development along coasts. Unplanned coastal development and unmanaged use of the coastal zone is not only a serious threat to coral reefs, but it can also lead to long-term socioeconomic loss. Integrated Coastal Zone Management (ICZM) is an approach to develop and implement environmentally, culturally, and economically sustainable uses of the coastal zone. The goal of an ICZM strategy is to coordinate all coastal zone uses and activities, in both public and private sectors, according to an agreed upon set of resource management policies and practices.

Fig. 9.1 The coastal zone of the Andavadoakan coastal region

9.2 The principles of ICZM

ICZM has no fixed formula but is defined as “a continuous and dynamic process that unites government and the community, science and management, sectoral and public interests in preparing and implementing an integrated plan for the protection, sustainable exploitation and development of coastal ecosystems and resources” (GESAMP 1996).

ICZM takes into account that the coastal zone is a complex, dynamic place that supports a wide range of exploitative activities (including fishing, mining and tourism), and in order for coastal resources to be exploited.
in a sustainable way, the interaction between all these factors must be understood and taken into account when designing a management strategy. Traditionally, coastal activities have been managed by a variety of separate, single sector companies, such as fishery companies, tourism agencies and industry sectors. As a result of each sector having different agendas and priorities it can lead to over-exploitation of the coastal zone and conflict in management plans.

The aim of ICZM is to promote the idea that the coastal zone should be viewed and managed as a whole, in what is termed as a ‘holistic’ approach. Essentially, an ICZM plan is therefore a strategy that addresses socioeconomic problems, activities in the coastal zone, conservation of biodiversity, and habitat degradation associated with development. A successful management strategy should plan for future scenarios, and to achieve its goals, it must be backed by public support, political will and adequate funding.

Prior to developing an ICZM, there are 3 main requirements that must be satisfied:

• Resource/Habitat Assessment

The area must be surveyed to determine the distribution, abundance, and condition of coastal resources (Fig.9.2a). Physical and chemical processes of the coastal system must be understood along with how all living components (the biota) interact with these processes and each other. Functions (nursery/feeding grounds), goods (fish/curio), services (coastal protection) that coast provides should also be quantified.

• Stakeholder Assessment

Stakeholders are any group that can affect or will be affected by the management of the coastal zone and all human activities in the area (cultural and economic) must be evaluated (Fig 9.2b). This includes all matters relating to the exploitation of resources and traditional management methods. For example, in Andavadoaka, this represents fisherman, fish collecting companies (Copefrito, Murex), tourism industry (Coco Beach, Laguna Blu), local and national government, conservation and science groups (BV, WCS, WWF).

![Fig.9.2 Blue Ventures habitat and stakeholder assessment in Andavadoaka.](www.blueventures.org)
• Interaction and trends: past, present and future

Future projections of economic and demographic growth in the area must be evaluated.

Only after these three things are considered is it possible to determine what activities should be encouraged or discouraged, to identify potential areas of conflict, and to determine what alternative activities could be initiated. The level of exploitation that each resource can sustainably support must be considered; it can then form the basis for the management strategy of the ICZM.

The active participation of all resource users and local communities is a critical part of identifying important issues and potential conflicts. Local community perception of environmental problems and solutions must be incorporated into management schemes and local people must be involved in deciding what type of management system is appropriate. They can achieve this through discussions between local authorities, local communities and resource users, scientists/academics, and industrialists, and traditional and modern concepts can be incorporated into the development of an appropriate management scheme for the particular region.

Successful implementation of any management plan relies heavily on the sustained mutual interest and continued cooperative effort by all involved parties. This may require the dissemination of information among all involved parties through education and awareness programs, regular meetings and discussion, and frequent evaluation of objectives and resources.

9.3 Creating an ICZM strategy

Without an integrated approach, it can be difficult to effectively manage development. Governments often regulate development activities through several different laws, regulations and agencies. There may be one law and set of regulations for pollution from factories, one for fisheries, and one for coastal building permits, all administered by different agencies. This sector-by-sector approach focuses solely on one issue or constituency and could result in a loss of valuable resources. For example, if a government establishes a marine reserve, but does not use an ICZM approach to coordinate with other coastal zone activities, the reserve may be undermined by a large private development site that is planned within the next five years.

The key to successful ICZM implementation involves cooperation among the large number of regulatory agencies that oversee coastal development as well as private sector stakeholders.

The following strategies are useful for protecting coral reefs from unmanaged development. A model ICZM approach might incorporate many or all of the following:

1. Determine whether traditional principles or resource management measures exist and whether their appropriate implementation could enhance coastal resource management.

2. Engage local communities to extract anecdotal and traditional knowledge, to involve local stakeholders in policy planning and implementation, and to create local support for coastal management policies.

3. Inventory coastal environments, resources, and programs to learn about, improve the health, and better manage the coastal environment.
4. Determine short-term and long-term goals that call for coastal development consistent with the preservation of the environment and create a strategy for coastal zone management.

5. Create and enforce a strong legal and institutional framework, including economic incentives to reinforce desired behaviours and outcomes.

6. Develop a strong coastal management constituency and partnerships at the local, regional and national levels.

![The partners involved in the management decisions in the Andavadoaka region](Fig.9.3)

7. Establish Marine Protected Areas (MPAs), including no-take reserves, to protect, preserve and sustainably manage species and ecosystems of special value (this includes threatened species and habitats).

8. Perform Environmental Impact Assessments (EIAs) of all development projects in the terrestrial and aquatic sections of the coastal zone.

9. Assess and monitor pollutants in the water column and make a plan for pollution control.

**9.4 ICZM in Madagascar**

To date, marine and coastal ecosystems in Madagascar have not been the focus of large scale management plans. However, as the level and frequency of destructive practices occurring in the coastal zone increases, an ICZM is vital in terms of mediation between parties and for conservation.

The Malagasy government has begun to identify areas where ICZM would be a potentially useful tool, such as the Grand Recif near Tulear, one of the largest reef systems in the world and home to several endemic species of Madagascar.
An attempt in 1996 was made to create an ICZM with a large revision of law texts, the formation of new government bodies, such as the Ministry for Fishing and Marine Resources. An ICZM workshop was composed and held on the 18th October 1996 sponsored by the World Bank, IOC-UNESCO and Sida-SAREC.

In 1997, a 5 year marine and coastal environment program was initiated to promote ICZM. This included protecting areas, pollution prevention and monitoring as tools for ICZM. The current national ICZM plan in Madagascar is one in which empowerment is at a local level (recognises local laws or “dinas”), and management is decentralised parting responsibility to the stakeholders most directly involved.

9.5 Marine Protected Areas (MPAs)

Marine Protected Areas are one of the methods employed in ICZM and are created to manage marine resources. MPAs are defined as “any area inter-tidal or sub-tidal terrain, together with its overlying waters and associated flora, fauna, historical cultural features, which has been reserved by legislation or other affective means to protect part or all of the enclosed environment” (IMO 1991).

MPAs serve many different purposes and are established for a variety of reasons, but the three main aims of an MPA will be to (1) conserve biodiversity, (2) maintain the productivity of the marine ecosystem and (3) contribute to the economic and social welfare of the local communities. MPAs can include marine parks, marine reserves and locally managed marine areas that protect reefs, seagrass beds, shipwrecks, archaeological sites, tidal lagoons, mudflats, saltmarshes, mangroves, rock platforms, underwater areas on the coast and the seabed in deep water, as well as open water.

Marine protected areas with core ‘no-take’ reserves can play an important role in arresting and possibly reversing a decline in fish populations and productivity through:

• support for stock management, including:
  - protection of specific life stages (such as nursery grounds)
  - protection of critical functions (feeding grounds, spawning grounds)
  - provision of spillover of an exploited species
  - provision of dispersion centres for supply of larvae to a fishery

• improved socioeconomic outcomes for local communities

• support for fishery stability
There is a substantial weight of evidence in favour of the beneficial role of MPAs in a range of different types of fisheries, in different global localities, and within different fisheries management regimes. MPAs on their own are not usually sufficient as a single management tool, except possibly in small-scale subsistence fisheries where other management systems may not be very effective.

**Designing marine reserves**

In designing Marine Reserves with the goals of conservation and fisheries enhancement, the following criteria should be considered:

- **Spatial representation**: should include areas throughout the region.
- **Habitat representation**: should include considerable portions of all habitat types.
- **Size**: whether reserve size, or number of reserves in a network, can be expected to meet its goals.
- **Connectivity**: whether the reserve is connected to other reserves in the network or other areas in the ecosystem.
- **Vulnerable habitats and habitats important to life stages of protected species**: are these included and are there corridors of protected area between each important habitat.
- **Species present**: whether exploited or threatened species are present in the boundaries.
- **Ecological or economic services/potential**: whether the reserve area provides substantial ecological services and economic opportunities.
- **Natural and human threats**: is a reserve subject to severe natural or anthropogenic threats (for example, storms, pollution).
Conclusions

Marine reserve systems intended to conserve coral reef ecosystems and enhance the sustainability of local fisheries must include all habitats present in the ecosystem. It is also important that all management decisions have support from the local stakeholders, as well as sufficient enforcement and monitoring. Research and development based around the implementation of a marine reserve should also consider social and economic effects of the reserve and well as its impact on the ecosystem at the regional scale.

At the Durban vision 2003 the president of Madagascar pledged to triple the amount of protected areas in Madagascar in five years (1.7 - 6 million hectares). Although this figure may be a slightly unrealistic aim, it shows willing to the ever increasing pressure to protect the unique marine and terrestrial habitats present throughout Madagascar. Figure 9.5 shows a map of the potential sites for MPAs throughout Madagascar.

![Map showing sites of potential MPAs in Madagascar.](www.blueventures.org)