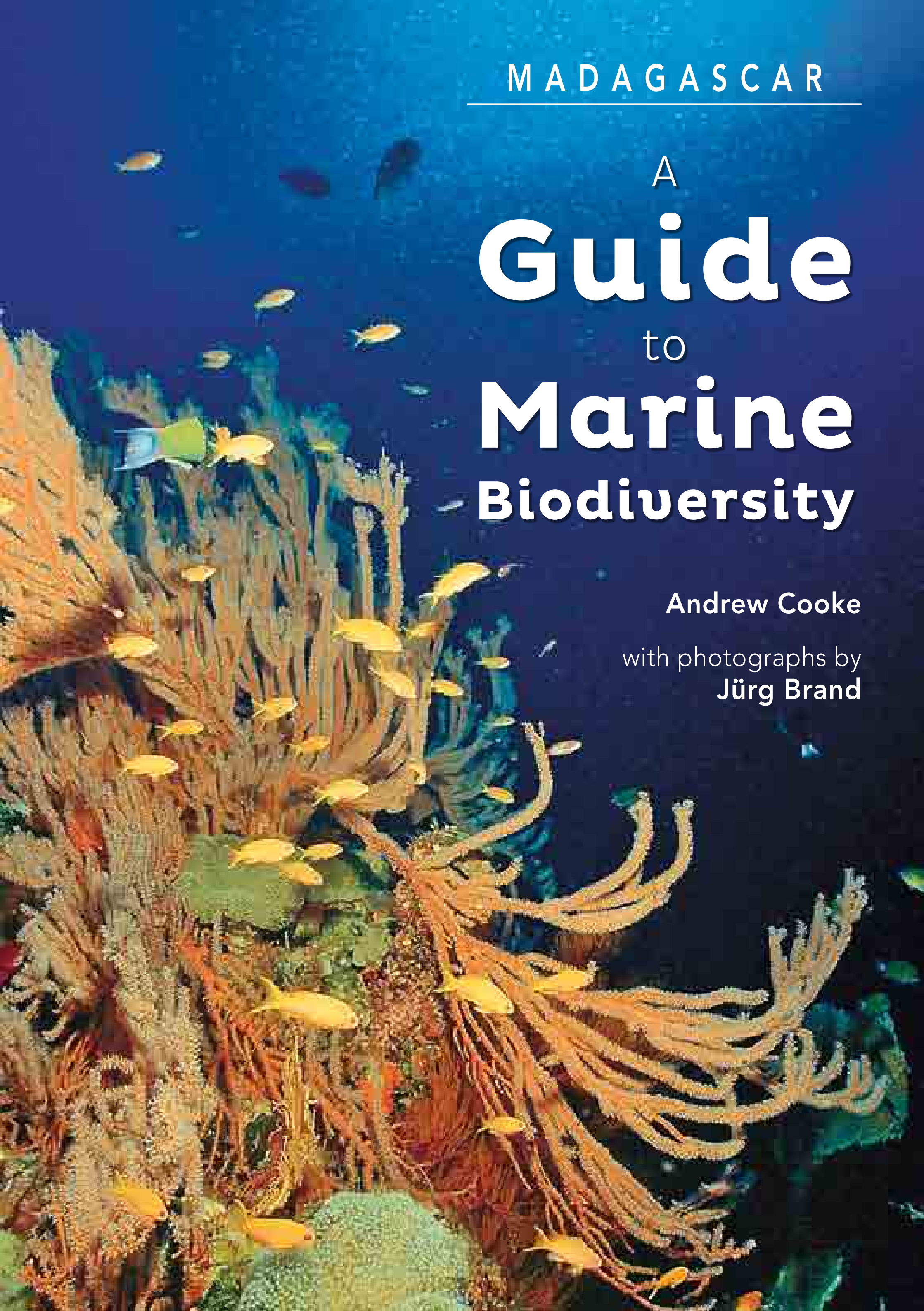
MADAGASCAR

A Guide to Marine Biodiversity

Andrew Cooke

with photographs by
Jürg Brand



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World Bank
Banque Mondiale

MacArthur
The John D. and Catherine T. MacArthur Foundation

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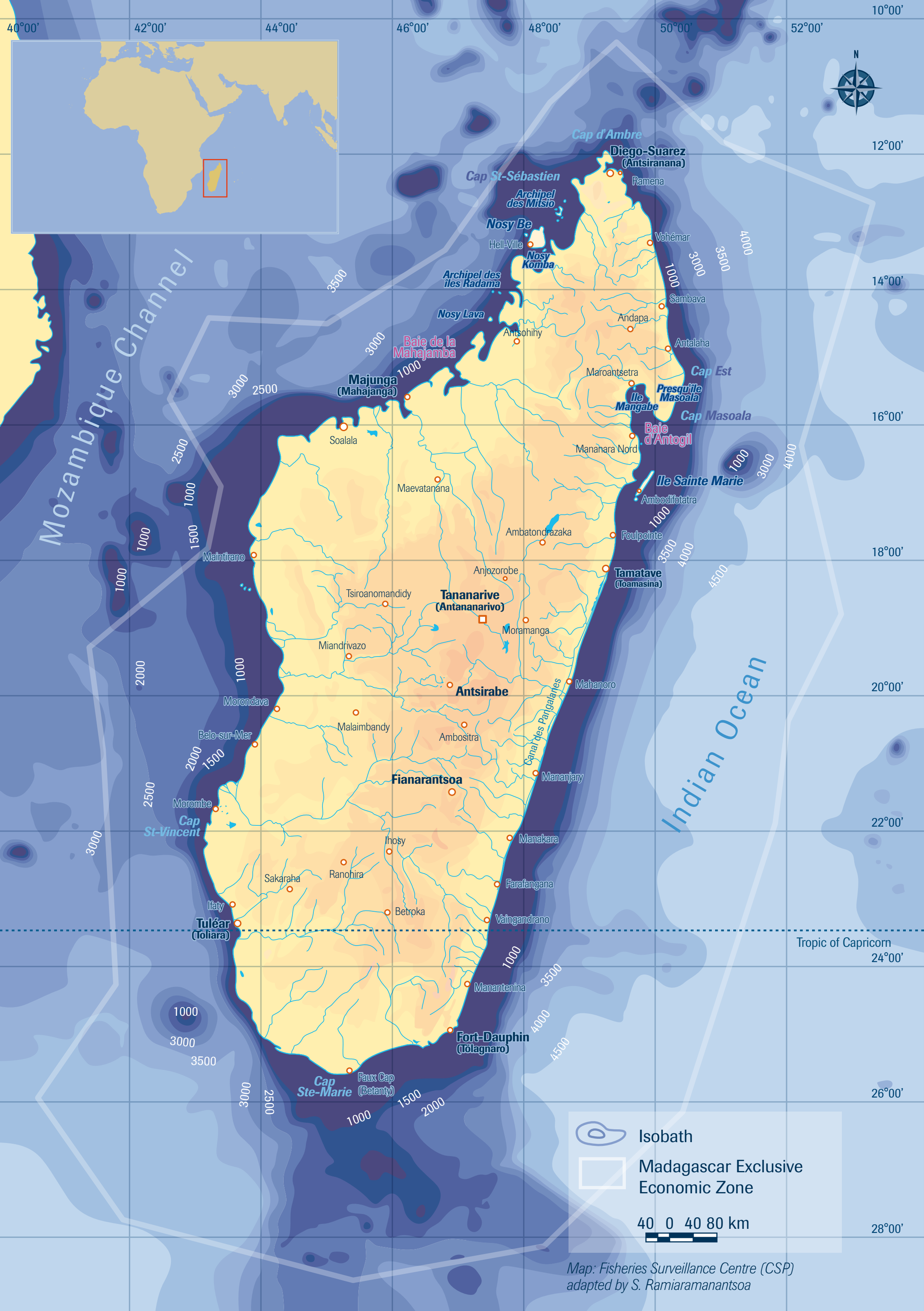

Mozambique Channel
Indian Ocean
Cap d'Ambre
Diego-Suarez (Antsiranana)
Ramena
Cap St-Sébastien
Archipel des Mitsio
Nosy Be
Hell-Ville
Nosy Komba
Vohémar
Archipel des îles Radama
Sambava
Andapa
Nosy Lava
Antsohihy
Antalaha
Baie de la Mahajamba
Majunga (Mahajanga)
Maroantsetra
Cap Est
Presqu'île Masoala
Ile Mangabe
Cap Masoala
Soalala
Baie d'Antogil
Mananara Nord
Maevatanana
Ile Sainte Marie
Ambodifotatra
Ambatondrazaka
Foulpointe
Maintirano
Anjozorobe
Tamatave (Toamasina)
Tsiroanomandidy
Tananarive (Antananarivo)
Moramanga
Miandrivazo
Antsirabe
Mahanoro
Morondava
Canal des Pangalanes
Malaimbandy
Ambositra
Belo-sur-Mer
Fianarantsoa
Mananjary
Morombe
Cap St-Vincent
Manakara
Ihosy
Ranohira
Sakaraha
Farafangana
Ifaty
Betroka
Vaingandrano
Tuléar (Toliara)
Tropic of Capricorn
Manantenina
Fort-Dauphin (Tolagnaro)
Cap Ste-Marie
Faux Cap (Betanty)
Isobath
Madagascar Exclusive Economic Zone
40 0 40 80 km
Map: Fisheries Surveillance Centre (CSP) adapted by S. Ramiaramanantsoa

Dedication

This book is dedicated to the memory of Jean-Louis Acquier, anthropologist and diver *extraordinaire*, who first introduced the author to the Grand Récif of Toliara in 1991 and whose enthusiasm provided the original inspiration for this guide.

Jean-louis Acquier inspecting corals in a reef gulley – Grand Récif, Toliara, 1992

Preface

This guide is the first output of a longstanding project. Originally conceived as a guide for scuba divers, the project grew into a broader work on maritime Madagascar encompassing history, people, ecosystems, economic activities, environmental management, conservation and a series of regional directories. While a place remains for such a comprehensive work, constraints of time and funding, imperatives from sponsors and a perception of immediate need resulted in the decision to publish an introductory guide focused on marine ecosystems, biodiversity and species of concern.

The last 10 years has seen a major upturn in interest in marine conservation around the world, including Madagascar. Terrestrial biodiversity conservation in Madagascar has benefited from a long history of research and exploration and the publication of various guides to the fauna and flora, many of which have been published in French or Malagasy as well as English. Apart from some brief guides on whales and dolphins and one coffee-table book on Nosy Be, no general guide has been published on the marine biodiversity of Madagascar.

The guide is intended to introduce the reader to the marine biodiversity of Madagascar, building on scientific research from the 1960s to the present day. The guide also takes account of new understanding about marine ecosystems and the effects of climate change. This will be the first time that such knowledge has been synthesized into a single, accessible, volume. We sincerely hope that the guide will provide a useful common foundation of knowledge for all those interested in marine biodiversity conservation in Madagascar.

The guide is presented in an easily readable, informative and generously illustrated format designed for a wide ranging audience, including marine scientists seeking an overview of Madagascar's marine ecosystems, marine conservationists, development specialists, researchers, students, visitors to Madagascar and the general reader. While all information in the guide is based on scientific publications or reports, sources are not quoted in the main text. However, a comprehensive bibliography is provided at the end of the book for the benefit of specialized readers.

Helen Crowley

Lisa Gaylord

Christopher Holmes

Andrew Cooke

Jürg Brand

Acknowledgements

The idea for a Madagascar marine guide first arose during visits to the library of the Natural History Museum, London, in the summer of 1991, while studying the work of French scientists of the Station Marine d'Endoume on the reefs of Toliara during the 60s and 70s. Since that time, the project has been through several transformations involving various collaborators, contributors and sponsors.

Profound gratitude is due to my late friend and collaborator, Jean-Louis Acquier, geographer and diver, who introduced me to the Grand Récif of Toliara and provided the initial inspiration for this guide. This book is dedicated to his memory. I thank Alan Hickling for introducing me to Jean-Louis and making the first link in the chain.

Having secured sponsorship from *New Holland* Publishers and a free flight from Air Madagascar (whose support is gratefully acknowledged), further inspiration was provided by my late friend, George Van Schalkwyk, who helped me explore the coral reefs from Cap Est to Cap Masoala in 1995. I salute George's memory.

Major thanks are due to Jürg Brand, geographer and diving photographer who joined the project in 1999 bringing his extensive knowledge of Madagascar's coral reefs and his excellent photographs. Jürg contributed much useful information and helped develop the vision for a more comprehensive work which we hope to produce in the future. Thanks also to Claudia Townsend, who joined us later and planned the tourism component of the future book.

Pivotal to the guide's realization was the project of the MacArthur Foundation, implemented by the World Bank, to support the production of local language field guides in developing countries. While this guide has been published much later than the sponsors would have wished, the seed funding and WCS's agreement to adopt the project made its final achievement possible. I thank the MacArthur Foundation, Kathy McKinnon of the World Bank and Helen Crowley of WCS for their support.

At this point grateful thanks go to my partner Blaise, for providing the impetus to restart the project and research and write large sections of text, and Rupert Cook for his journalistic flair and enthusiasm that helped take us to a first manuscript. Valuable contributions were provided by Peter Metcalf (historical context), Simon Peers (pirates), Charlotte Defontaubert (marine protected areas), Chloë Webster (southern coastal region), Alasdair Harris (on the Velondriake project), Philippe Jean of SOGREAH (EIAs for offshore oil & gas) and Pierre Van de Bogaarde (shipwrecks) – their work should bear fruit in a more comprehensive volume.

A final push was provided by Lisa Gaylord, WCS, who saw the possibility of achieving the publication of an introductory guide focusing on marine biodiversity. Thanks to her and to her successor, Christopher Holmes, for helping the project to completion. During this last phase Faratiana Ratsifandrihamanana (WCS) and Minosoa Ravololoharinjara (Resolve) helped with additional text, maps, graphics and the bibliography and Lalatiana Razafimahatratra (Phyto-Logic) helped with layout. I sincerely thank Jackie Lamoure for her careful translations into French and Chloë Webster and Marine Rousseau for helpful editing.

Many writers, researchers, scientists and specialists have helped with information or advice along the way – in approximate chronological order I thank Hilary Bradt, Man-Wai Rabenevanana, Christian Ralijaona, Dr H.D. Rabesandratana, Berthin Rakotonirina, Edouard Mara Remanevy, the researchers at UFSH (now IHSM), Toliara, during the 90s, Pierre Vasseur, Sue Wells, Catherine Gabrié, Jean-Michel Lebigre, Olivier Langrand, Sheila O'Connor, Paul Siegel, Meg Gawler, Martin Nicoll, Steve Goodman, Frank Hawkins, Joanna Durbin, Vic Cockroft, Marcel Kroese, François Odendaal, the members of the 1993 Toliara Coral Reef Expedition, Nick Polunin, Ivor Williams, Matt Richmond, Guy Andriamirado Rabarison, Malcolm Smale, David Obura, Jean-Pascal Quod, Heritiana Randriamiarana, Onesime Ratomahenina, Haja Razafindrainibe, Eulalie Ranaisovon, Zbigniew Kasprzyk, Jean Maharavo, Pierre Laboute, Jessica Metcalf, Jean-Louis Lauzières, Georges Rafomanana, Harimandimby Rasolonjatovo, Gerry Allen, Charles Veron, the late Johann Lutjeharms, Monica Tombolahy, Todd Romaine, Jina Sagar, Terrence Gosliner, Phillip Hockey, Jason Clay, Gilles Gaultier, Damon Stanwell-Smith, Robert Fricke, Bertrand Guytart, Tony Ribbink, Lucy Scott, James Stapley, Catherine Muir, Zo Razanamaharo, Olivier Behra, Christine Lippai, Bernard Séret, Mathieu Le Corre, Leonard Compagno, David Barnes, Roger Safford, Tim Healy, Alasdair Harris, Garth Cripps, Jérôme Bourjea, Peter Best and Justin Cooke.

To the above list I must add the experts and scientists of WCS who have helped with information and in other ways, in particular Matthew Hatchwell, Tim McClanahan, Ramon Bonfil, Herilala Randriamahazo, Bemahafaly Randriamanantsoa, Howard Rosenbaum, Salvatore Cerchio, Rachel Graham, Yvette Razafindrakoto and Tiana Rakotosamimanana.

Of the dive masters, boat and hotel owners who have helped I thank the late Jacques Ducaud, Denis Guillaumat, Tony Adkins, Richard Paper, Patrice Eryeh, Philippe Lenel, Alain Bos, Monique Vachaud, Eric Hoffman, Max Felici, Christian Solterer, Richard Walker and Fred Lucas.

Very special thanks are due to the talented Stève Ramiaramanantsoa for his creative and intensive work on the lay-out which made the guide come alive to spur us on and win credence with the sponsors.

To conclude, while acknowledging so many contributions, I must nevertheless accept full responsibility for any errors or omissions that have been made.

Above all, I thank my partner, Blaise, for her constant support and encouragement over the years even while she, in the same time span, managed to write and publish several guides of her own!

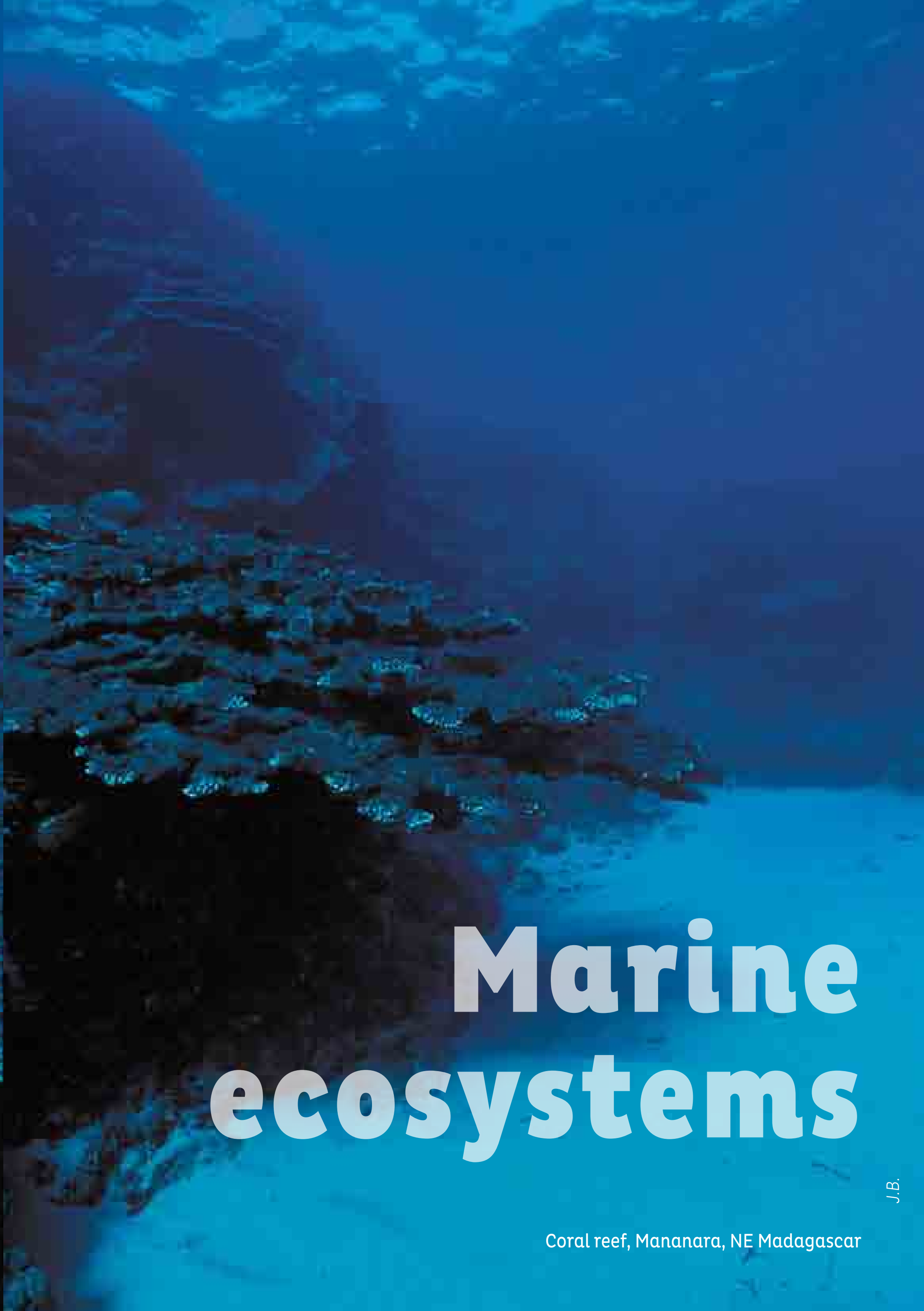
Summary

Protected species 124

Table corals, Salary Bay, SW Madagascar

J.B.

Marine ecosystems



J.B.

Coral reef, Mananara, NE Madagascar

Physical context

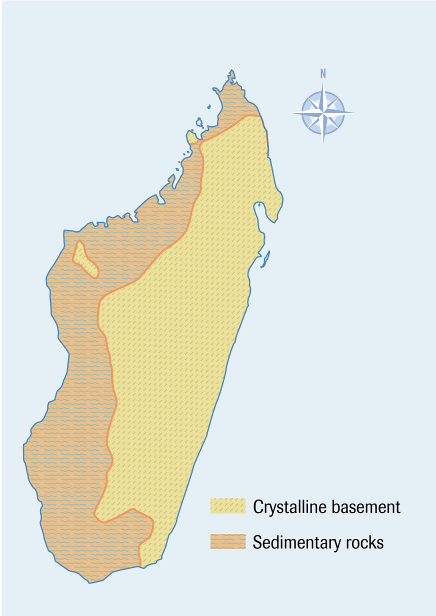
Geophysical setting

Madagascar's geophysical setting determines many of the factors that shape its marine and coastal environment including seabed topography, climate, winds, ocean currents, water temperature, dissolved nutrients, primary productivity, salinity, tides and sea level change.

View from Cap Sainte Marie, southernmost point of Madagascar

R.C.

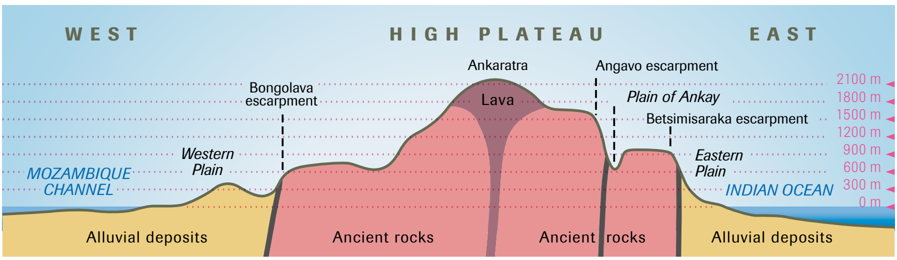
Madagascar lies on a relatively stable part of the earth's crust. The most recent volcanic activity was the creation of the many volcanic islands of the Nosy Be area and the Comoros island chain (which occurred from about 15 to 5 million years ago) while the last major tectonic movements are more ancient, associated with the separation of Madagascar from India (around 55 million years ago).



Simplified geological map of Madagascar
(after H. Bésairie)

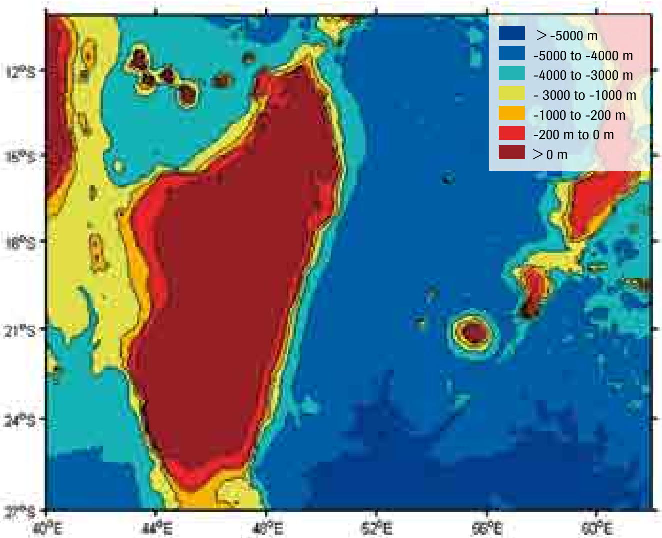
Processes of weathering and deposition over millions of years have led to the erosion of Madagascar's highlands and seaward extension of Madagascar's western coast and continental shelf (the larger protrusions corresponding to the major river deltas), with the important exception of the Toliara coastline (SW Madagascar), where the continental shelf is narrow due to geological faulting. On the east coast, wave action and the shearing effect of the Eastern Madagascar Current (EMC) have limited coastal extension, resulting in a narrow coastal plain and steep continental shelf.

The length of Madagascar's coast is officially set by the national geographic institute *Foibe Taosarintanin'i Madagasikara* (FTM) at 5,603 km, including the coastlines of the larger inhabited islands (Nosy Be, Ile Ste Marie etc.). The principal shallow water marine and coastal habitats are mangroves, estuarine mud flats, rocky foreshores, beaches, coral reefs, and seagrass meadows. Coral reefs, mangroves, seagrass meadows, and mud flats are the dominant habitats along the shallow sloping west coast, whereas steeply shelving beach and rocky shoreline predominate on the east coast.



Geophysical relief of Madagascar viewed in cross-section
(after Bastian & Groison, 1958)

Bathymetry



Bathymetric map of Madagascar by Prof. J. Lutjeharms

The bathymetry of waters around Madagascar is known from a long accumulation of data over more than 100 years, including naval surveys, scientific expeditions, fisheries investigations and oil & gas exploration. Naval surveys have provided generalised bathymetric data for the entire area with detailed soundings around features of importance to navigation, such as offshore banks, islands, straits, ports and harbours. Scientific expeditions have tended to focus on major oceanographic features such as mid-ocean ridges while fisheries surveys have provided bathymetric data on areas of mid to shallow depths suitable for trawling. Oil and gas exploration is now generating very detailed bathymetric data within allocated concessions but the data are privately owned and likely to remain unpublished for some years to come. Along the coast of Madagascar, only the Nosy Be region has been the subject of a detailed bathymetric study (by French oceanographers).

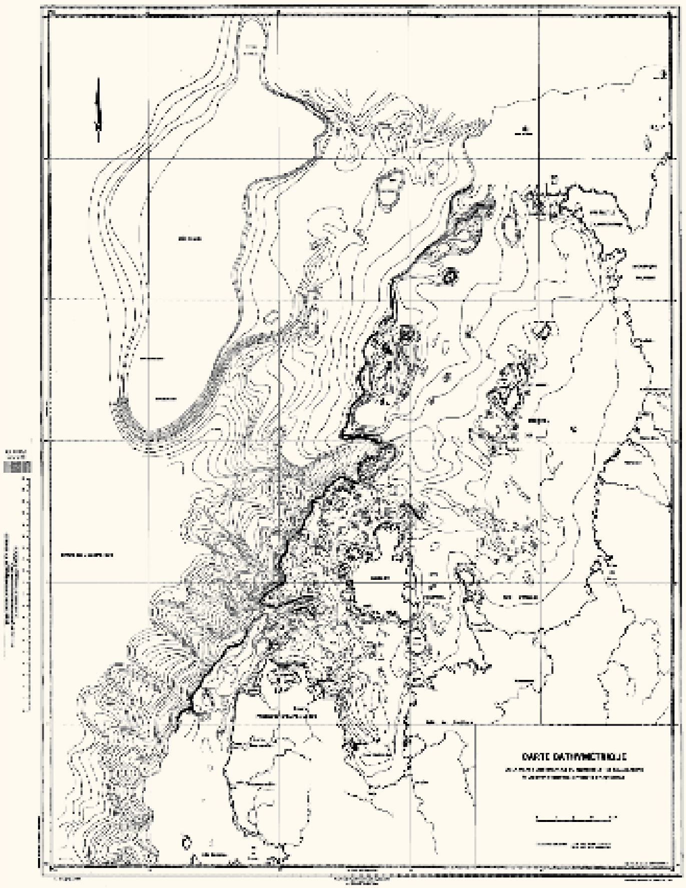
The available data have been compiled for the purposes of this book to generate a bathymetric portrayal of the seas around Madagascar extending West to East from the Mozambique coast to the Seychelles ridge and north to south from Aldabra Atoll to the northern part of the Madagascar ridge.

The major features to note from this bathymetric portrayal are:

- A marked asymmetry between E and W Madagascar, with a narrow, steep continental slope in the east and a wide, gently sloping shelf in the west (with the exception of the Toliara region, SW Madagascar, where geological faulting has resulted in a zone of steep shelf);
- The dominating feature of the Seychelles ridge, a granitic ridge to the east of Madagascar which rises to depths of 100 m or less and which has a major influence on oceanic circulation in the region;

- The existence of a ridge to the south of Madagascar – while not fully shown on this map the ridge extends more than 1000 km to the south of Madagascar and is a major regional oceanographic feature supporting rich deep sea biological resources;
- Associated with the Madagascar ridge, a marked widening of the continental shelf in SE Madagascar which contributes to unusual oceanographic circulation in this area;
- The narrowness and relative shallowness of the central Mozambique channel which has a marked effect on tides and oceanic circulation, creating a partial ecological barrier between north and south;
- The distribution of sea mounts and oceanic islands, corresponding to fracture lines in the earth's crust or hot spots in the earth's mantle (e.g. the Comoros island chain) and which serve as ecological "stepping stones" for migratory species.

Familiarity with the bathymetry of the seas around Madagascar is fundamental to an understanding of Madagascar's place in the larger marine ecosystem and of the variations within Madagascar's own marine environments.



Bathymetric map of Nosy Be by Daniel et al. 1973

Landmass and sea level changes

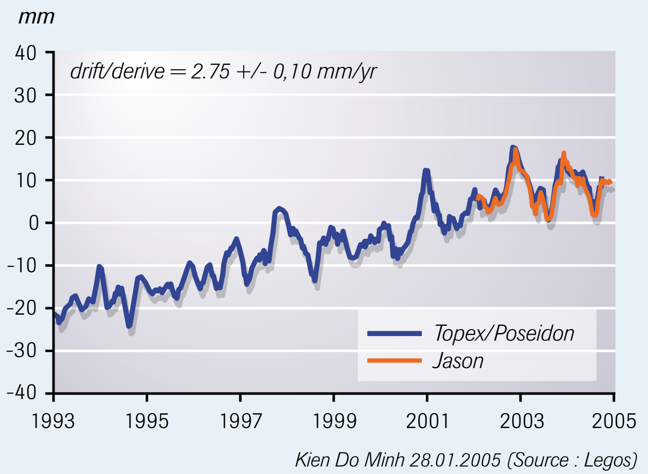
Since separation from Africa in the early Triassic period (220 million years ago), the western coast of Madagascar has risen and fallen in relation to mean sea level, resulting in episodes of marine deposition. The evidence for these is the extensive series of Mesozoic (195-100 million years ago) and Tertiary (from 65 to 7 million years ago) marine limestones which make up the Isalo massif, the Bemaraha *tsingy* and the Mahafaly plateau. These limestone deposits were laid down in warm seas during periods when Madagascar's western plains were below sea level.

Over more recent geological time (Quaternary, 1.5 million years ago to the present day) there have been further variations in sea level. While the net trend over the Quaternary has been a drop in sea level of about 15 m, more recently sea levels have risen, including a dramatic rise of about 6 meters around 6,000 years ago associated with the melting of polar ice caps after the last Ice Age.

Tidal gauge records indicate a significant increase in mean sea level of about 1.8 mm per year, which is attributed to melting of the ice caps as a result of global warming.

GLOBAL WARMING AND SEA LEVELS

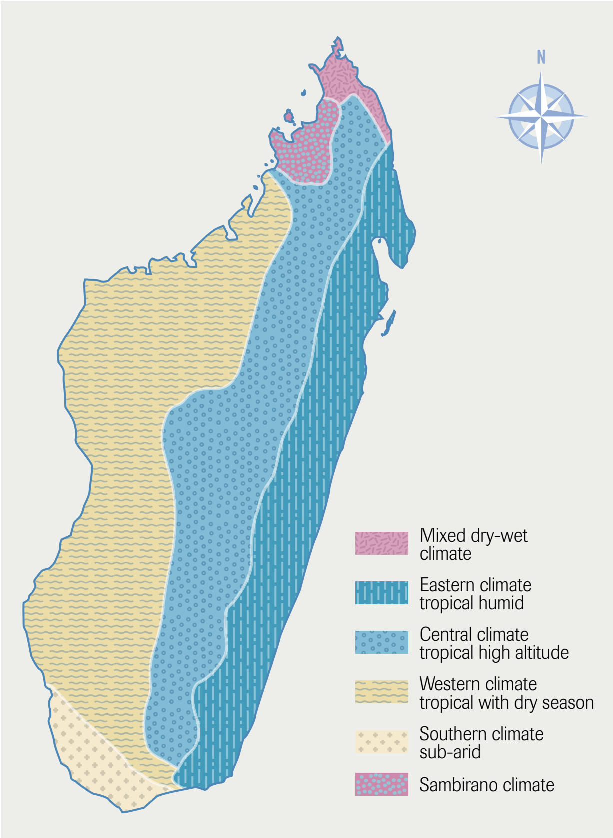
Additional sea level rise is predicted as a result of global warming. Recent estimates indicate that sea levels rose by about 20 cm between 1870 and 2004 - but that accelerated melting of the ice sheets could result in a rise of as much as 1 metre between now and 2100. Such a rise would have significant impacts on Madagascar's marine and coastal ecosystems such as coral reefs and mangroves.



Graph of mean sea-level variation for the periods 1993-2004
(Sources: Topex/Poseidon 1993-2002; Jason-1 2002-2004)

Climate

Madagascar lies mostly within the Indo-Pacific Tropical zone, while the extreme south of the island is sub-tropical. The principal features of Madagascar's climate have been more or less constant since the Paleocene (65-58 million years ago), with humid conditions in the east and dry conditions in the west. The highest annual rainfall (3300 mm) is recorded in the town of Maroantsetra in the north east and the lowest, less than 330 mm, to the south of Toliara. The current climatic trend, in keeping with the predicted effects of global warming, is a slight warming (average temperatures rose by 1°C between 1900 and 2000). Total rainfall remains unchanged but is becoming concentrated into briefer more intense rainy periods and more polarized towards the North East.



Principal climatic regions of Madagascar
(Creyot & Denizet, 1969)

Madagascar's western coasts enjoy a warm, dry and sunny climate most of the year. By contrast, the east coast is permanently humid and receives high rainfall from March to September when air temperatures can become cool. Exceptions to the general pattern include the far north-western region (including Nosy Be), which enjoys a mixed dry-wet climate (known as the *Sambirano*), and the extreme south east (around Tolagnaro), which has a later and briefer rainy season.

Winds & cyclones

In general, winds along the east and southern coasts are strong and southerly, while along the west and north west coasts winds are variable and less strong. Antsiranana, in the extreme north, and Tolagnaro in the south east, are the windiest coastal locations in Madagascar while Nosy Be, protected by the highlands of the Tsaratanana Massif, is the least windy.

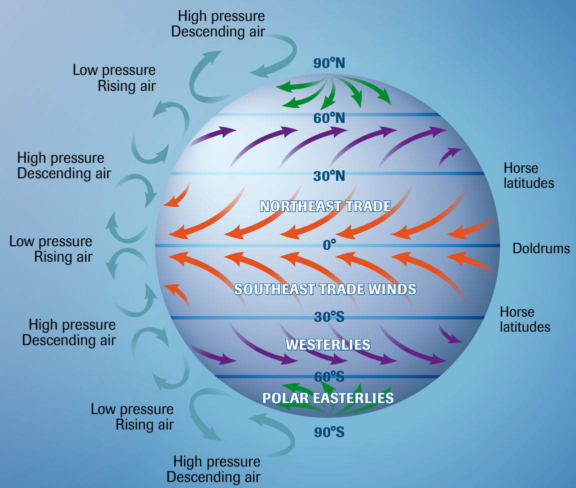
Cyclone approaching Madagascar – note the visible trace of its trajectory

CYCLONES

Cyclones affect the region from February to April, and spin westwards, across the Indian Ocean along what is known as 'the cyclone belt'. Madagascar is at particular risk because the turning point of many cyclone trajectories lies over the Mozambique Channel, meaning that a single cyclone can cross Madagascar twice and strike the coast on four or even more occasions. The coastal areas at highest risk from cyclones are NE, NW, SE and SW. In the last decade, the NE coast has been more severely affected by intense cyclones than other regions. A predicted effect of global warming is that cyclones will become more frequent and more intense.

PREVAILING WINDS

Prevailing winds around Madagascar are determined by the alternating influence of permanent zones of high pressure centered over the Mozambique Channel and the Mascarenes (Seychelles, Mauritius, Reunion). Throughout the cooler months (April to October), the Mascarene anticyclone dominates, reinforced by the low pressure over the Mozambique Channel, bringing south-easterly trade winds to all of Madagascar's coasts. In the summer months (November to March), the northern monsoon system shifts southwards, resulting in northerly winds in the northern part of the island, which become variable further south.



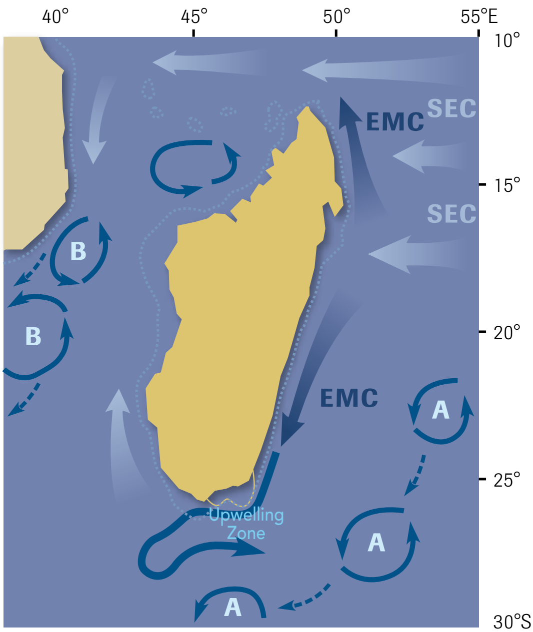
World wind circulation

Super-imposed on the general wind pattern is the daily cycle of offshore and onshore breezes that may dominate in the morning and evening, particularly in the south and west. In the morning, cooler air over the land displaces warmer air over the sea (creating an offshore breeze), with the opposite effect in the evening (leading to an onshore breeze).

Currents

The sea surface circulation in the southern half of the Indian Ocean is wind-driven and anti-clockwise. Madagascar lies in the path of the westward flowing surface current known as the South Equatorial Current (SEC) which strikes the east coast at a latitude of about 17º S (off Toamasina) and splits into two branches, one north-bound, the other south-bound. These branches make up the Eastern Madagascar Current (EMC). The south-bound EMC is swift-flowing, intense and narrow (80 km); it hugs the coast until it reaches Tolagnaro where it ends in a zone of turbulent flow, associated with cold, deep water upwelling between Tolagnaro and Cap Ste. Marie. Sometimes the current bounces back eastwards into the Indian Ocean, in a process known as "retroflection".

Oceanic circulation to the west of Madagascar is markedly different and the Mozambique Channel may be considered to lie in the "shadow" of the Madagascar landmass. The northern flow of the westbound South Equatorial Current flows past the northern tip of Madagascar and passes by the Comoros Islands. Surface water passes southward, from



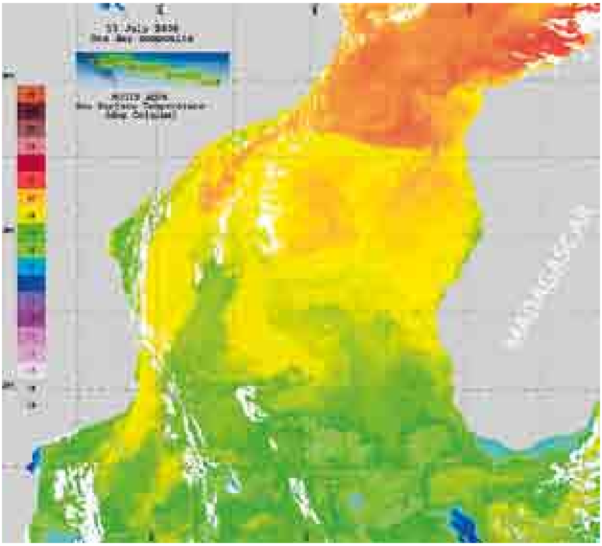
Oceanic circulation around Madagascar
by Prof. J. Lutjeharms

STABILITY OF CURRENT REGIMES AND THEIR INFLUENCE ON CLIMATE

The main features of the movement of ocean currents affecting Madagascar have probably existed since the Paleocene (65 to 58 million years ago), although they have been affected by occasional periods of change. The current pattern of prevailing currents has persisted for at least the last two million years. Droughts in the south-east of the island are possibly related to changes in surface currents off the South-East of Madagascar.

this flow, into the northern half of the Mozambique Channel. The surface water is then trapped in a slow, anti-clockwise rotation, or *gyre* centered on the Comoros which exhibits a zone of high temperature at its centre, suggesting there is limited horizontal or vertical mixing. Migratory tunas use this zone as a "safe haven" for spawning. The central portion of the Mozambique Channel features eddies drifting slowly southwards. The circulation of water along the western coast of Madagascar is poorly known but there is evidence for both northward and southward flow. There is a semi-permanent area of deep water upwelling off the Madagascar coast near Cap St. André and the island of Juan de Nova, corresponding with the zone of convergence between the warmer waters of the northern part of the channel, and the cooler waters of the southern part of the channel.

Temperature



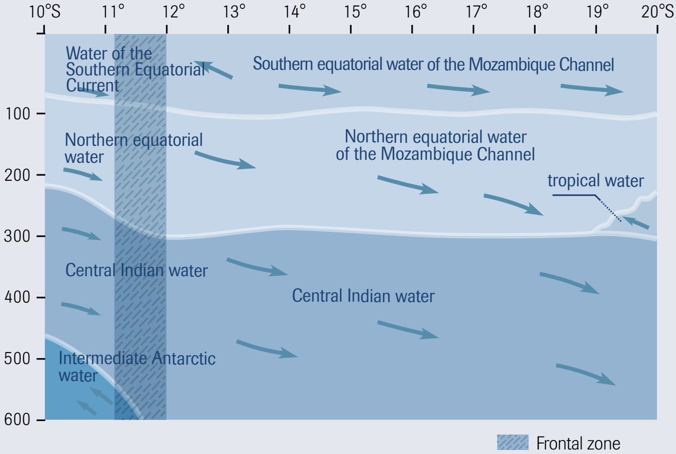
Sea surface temperature in the Mozambique Channel

Sea temperatures around Madagascar are higher and less varied than would be expected for its partly sub-tropical position - the high temperatures are due to the warm waters of the South Equatorial Current which surround all of Madagascar. Offshore, the average annual surface temperature ranges from 22°C in the south to 28° C in the north, with local seasonal extremes from 19° to 33°C in shallow areas. Anomalously high sea temperatures have occurred in 1998 and 2001, which appear to have been associated with 'El Niño Southern Oscillation (ENSO)' events in the eastern Pacific (when warm surface water extends further westward than usual from Central America) and when warm surface waters also persist in the Western Indian Ocean.

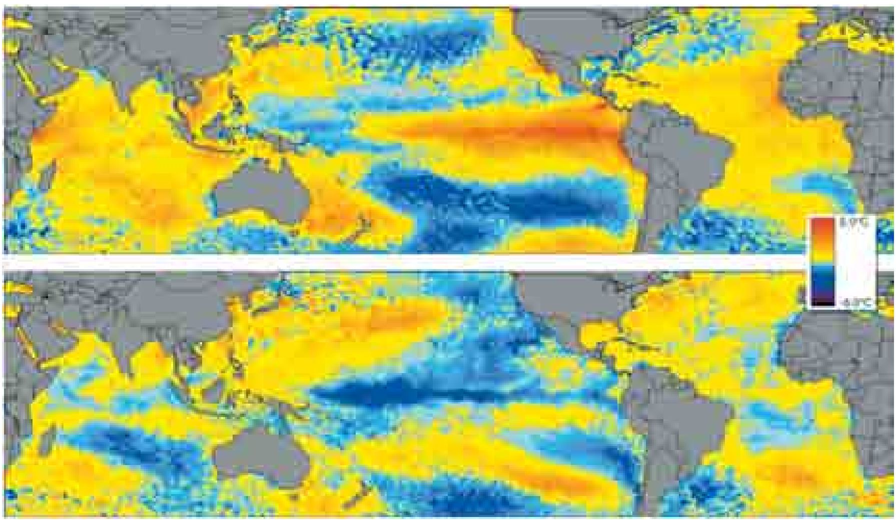
Madagascar's warm and stable sea temperatures provide ideal conditions for the development of coral reefs and the maintenance of an essentially tropical marine ecosystem. Sub-tropical and near-tropical temperature conditions are only encountered in the extreme south, particularly between Tolagnaro and Cap Ste Marie, associated with cold water upwelling.

THERMOCLINES

On the east coast there is a marked transition from warm to cold water at a depth of 100 m (known as a "thermocline"). The presence of a thermocline reflects the stability of the current and the low degree of intermixing between surface water and deeper waters. On the west coast, where the northern surface waters meet and overlie southern surface waters, the thermocline is found at 300 m. The convergence of southern and northern waters is visible in satellite images which show an abrupt change in surface water temperature at about the latitude of Cap St. André.

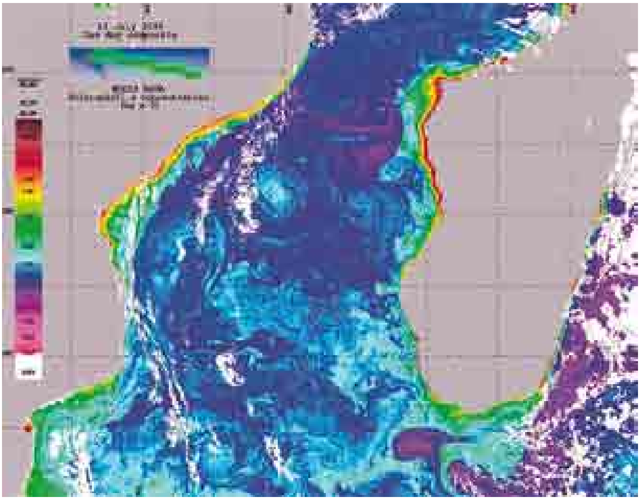


Thermoclines and water masses in the Mozambique Channel
(Magnier & Piton, 1973)



Global effect of El Niño (Source: SeaWiFS)
Top: El Niño years - Bottom: normal years

Nutrients & productivity

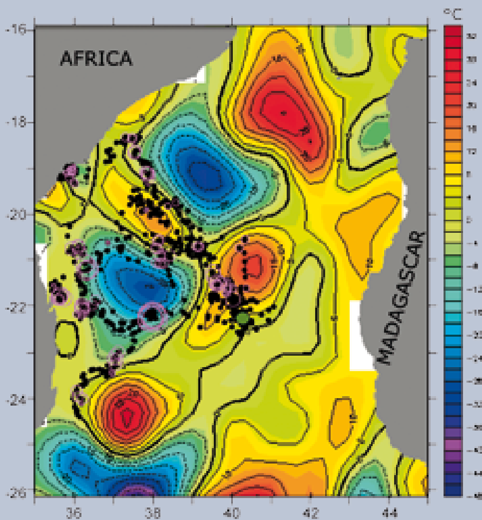


Concentration of chlorophyll A in sea surface waters around Madagascar

The biological productivity of surface waters is a result of the balance between several competing processes. In warm, sunny, conditions mineral nutrients in the surface water (nitrogen, phosphorous) become depleted through uptake into algae, plankton and the higher food chain. Most of the nutrients are lost to the ecosystem when organisms die off and fall to the sea

SEABIRDS AS INDICATORS OF PRODUCTIVITY HOTSPOTS

Since the beginning of history, fishers have recognized the role of seabirds as indicators of the presence of fish. In the Mozambique channel, the eddies draw cold waters up from the sea bed, creating zones of high productivity on their perimeters, attracting pelagic fishes. Frigate birds, capable of remaining aloft for long periods, exploit these zones of productivity in order to feed on small pelagic fishes. By attaching transmitters to the birds and tracking them by satellite, scientists have been able to demonstrate that the birds travel between fishing zones associated with the eddies.



Primary productivity and bird migration in the Mozambique Channel (Source: Le Corre et al, 2005).

floor as “marine snow”, creating a “marine desert” in the surface waters. Nutrients can be replenished by “upwelling” when cool deep water is drawn up to the surface(such as occurs along the eastward margins of the oceans), vertical mixing (as occurs around oceanic eddies) or by rivers draining into the sea.

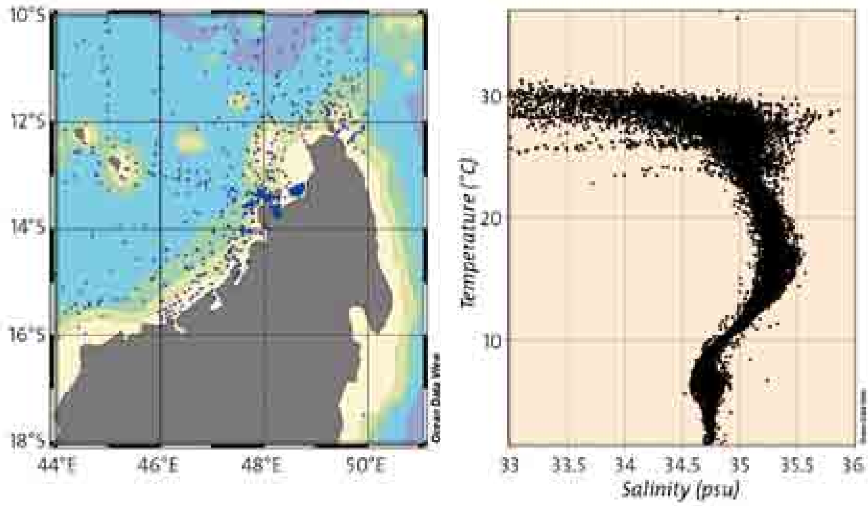
The seawater swept westwards across the Indian Ocean by the South Equatorial Current is deficient in nutrients, resulting in generally low levels of biological productivity in the seas around Madagascar. Exceptions to this pattern are the areas of upwelling (off SE Madagascar and around Juan de Nova), around eddies in the Mozambique Channel and along the west coast due to the inputs of rivers. There is also some evidence of “hotspots” off Toliara in the southwest and the Masoala peninsular in the northeast. Nutrient levels are substantially higher in the Mozambique Channel than in the waters off east Madagascar, due to greater vertical mixing and the inputs of rivers along the coasts of Madagascar and Mozambique.

For the most part, high marine biological productivity is confined to shallow coastal waters. The highest levels of nutrients are found off Madagascar’s western river deltas, which support large shrimp fisheries. The rivers of the eastern escarpment contain much lower levels of nutrients than those of the western plains, compounding the low natural productivity of eastern waters. The largest marine fishery on the east coast is in the Bay of Antongil, a semi-enclosed bay fed by numerous rivers and nutrient inputs associated with human settlements.

Marine plankton (Photo: Projet BCLME - PNUD/GEF)

Salinity

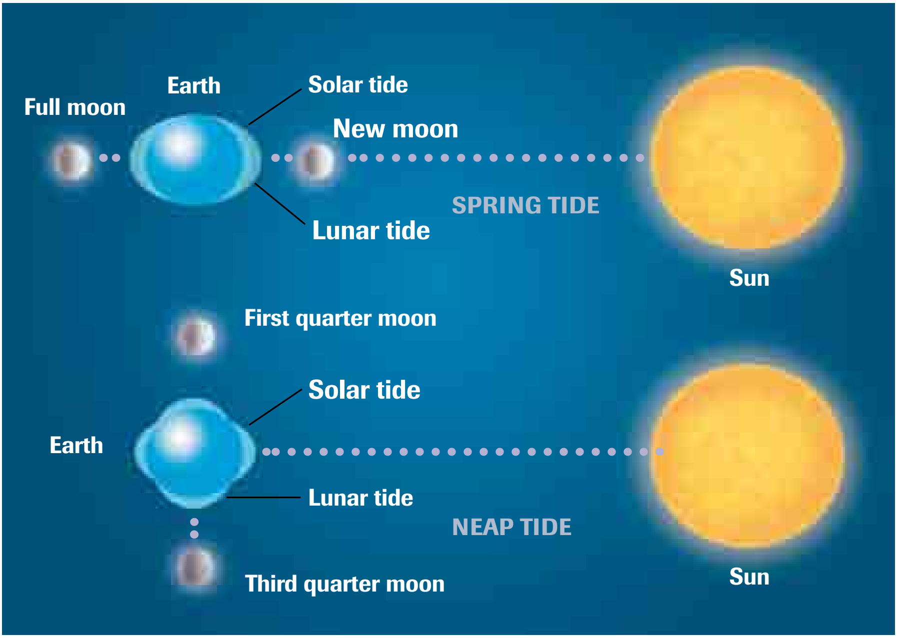
Tropical surface waters are generally less salty than sub-tropical surface waters, due to the greater freshwater input from tropical rain and rivers near the equator. The increased biological activity in the warmer, wetter, tropical latitudes further depletes the mineral content. Madagascar is surrounded by waters of the South Equatorial Current which have an average salinity of 35 ppt (parts per thousand). At 200 m below the surface, the water is marginally saltier (35.7 ppt). Salinity is substantially reduced in the vicinity of river mouths where only species tolerant of varying salinity (euryhaline species) can thrive, such as shrimps.



Temperature and salinity profile – North West Madagascar during the rainy season – note the low salinity of warm surface water due to inputs of rain and rivers (Projet ACEP)

Tides

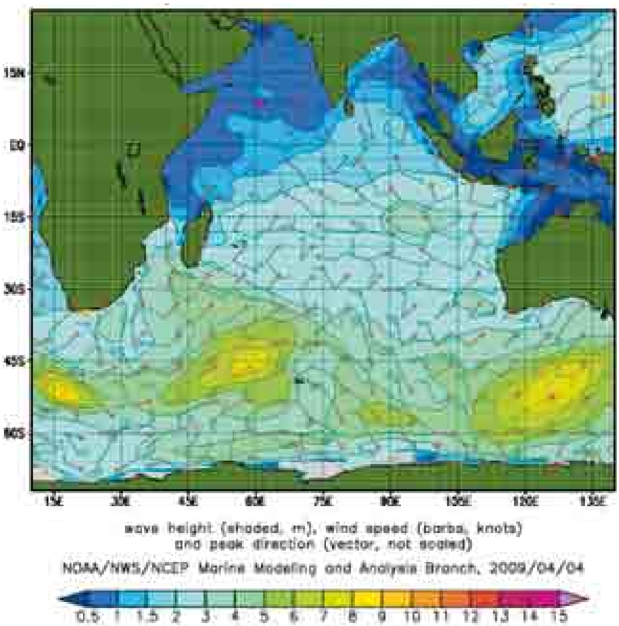
Due to the narrowing of the Mozambique Channel and the reduced depth at its northern end (from 5000 m to around 1300 m), the west coast of Madagascar has some of the largest tidal ranges of the western Indian Ocean. The average range over a spring tide is 3.8 m at Mahajanga and 2.6 m at Toliara. The eastern coast tidal range is much smaller - about 1 m in the northeast, dropping to about 0.5 m in the southeast. Consequently, coral reefs and mangroves cover much larger areas on the west coast than on the east coast (over 90% of all reefs and about 98% of all mangroves are on the west coast).



Tides and the lunar cycle

WAVE HEIGHT

Wave height is mainly determined by wind speed. Madagascar is located in an area in which average wave height varies between 4 meters in the south to 0.5 meters in the north. Greater wave heights occur during tropical storms or cyclones, which can generate very violent sea conditions.



Wave height and wind speed (4th april 2009) (Source: NOAA)

Oceanic domain

J.B.

Fish shoal, Petit Castor, Nosy Mitsio, NW Madagascar

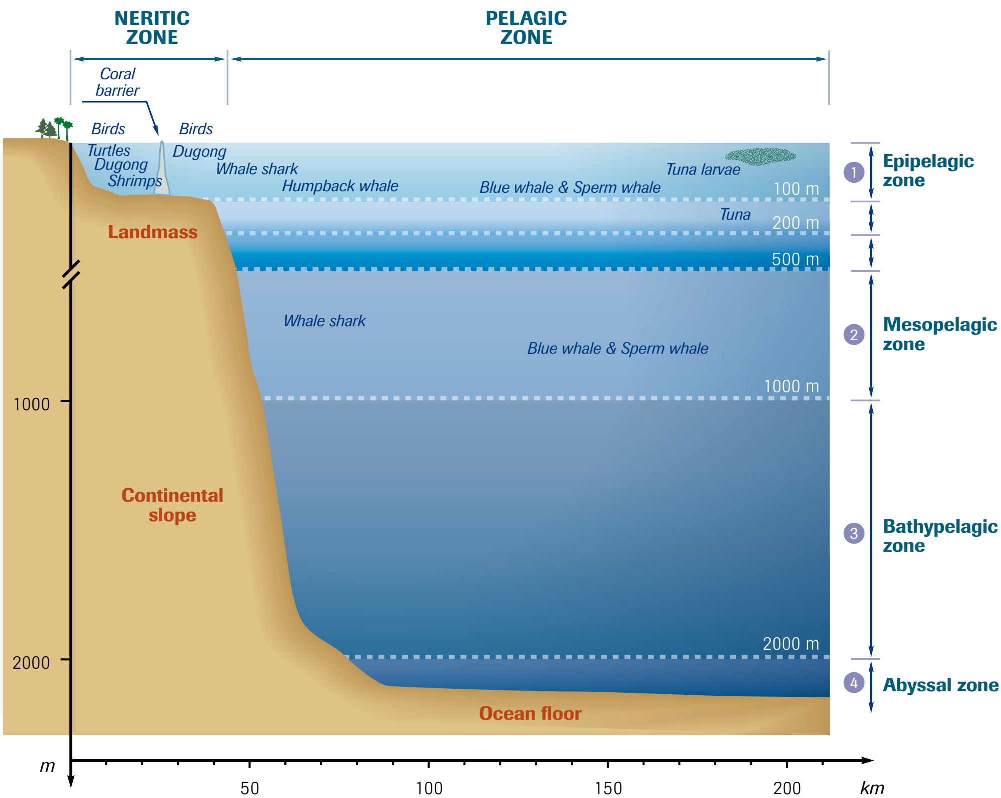
The oceanic domain comprises ecosystems of the open ocean, including oceanic surface or *epipelagic waters* (0-200 m), mid depth or *mesopelagic waters* (200-1000 m), deep or *bathypelagic waters* (1000-4000 m), and the *abyssal plain itself* (typically 4000-5000 m). In some places seamounts rise from the abyssal plain towards the surface. Life in these systems is generally sparse (with the exception of seamounts and mid-ocean vents), but the vast area and volume of these domains means that they contain an enormous biomass of living matter and thousands of plant and animal species, many of which are still unknown to science.

Ocean surface waters (0-200 m)

Open ocean surface waters of the Agulhas Current Large Marine Ecosystem are clear, warm and nutrient-depleted (*oligotrophic*). They can be considered a 'marine desert', comprising relatively sparse densities of plankton and other species although, because of high light penetration, surface-associated life extends to considerable depths (at 200 m light is 1% of the surface intensity, just enough to support photosynthesis).

Ocean mid-water zone (200-1.000 m)

The mid-water (mesopelagic) domain (200-1000 m) is a dark zone whose productivity depends entirely on the 'rain' of dead organisms from the surface. Larger inhabitants of this zone include thresher sharks that typically migrate closer to the surface at night to feed, using their acute night vision to detect prey in silhouette above them and then stunning them by threshing their tail. Visitors to this twilight zone include leatherback turtles *(Dermochelys coriacea)* and the Ocean sunfish *(Mola mola)* which descend to up to 1000 m to feed on jellyfish, and the whale shark *Rhincodon typus* which feed at night on the plankton-rich "scattering" layer.



Zones of the marine environment (Source: SOMEAH, adapted by S. Ramiaramanantsoa)

Deep water (1.000-4.000 m) and abyssal zone (4.000-5.000 m)

The bathypelagic (1000-4000 m) zone and abyssal plain (4000-5000 m) are completely black, and of constant cold temperature (4ºC), representing one of the most uniform marine environments across the globe. Madagascar's deep waters are virtually unexplored. Larger inhabitants of this zone include giant squid (and its main predator, the sperm whale *Physeter macrocephalus*) and angler fish. Deep ocean currents flow in the opposite direction from those on the surface. Certain species, such as freshwater eels (*Anguilla* spp.), exploit this effect to return to deep water spawning grounds near the Seychelles, from which the fertilised eggs float to the surface and return, carried by surface currents, to the rivers of the east coast of Madagascar.

Giant squid photographed from a fishing vessel (authenticity uncertain)

The abyssal plain is typically covered in soft silts, mud and carbonate "ooze" rich in nutrients. The abyssal zone may support quite rich assemblages of organisms, including sponges, sea pens, gorgonians, soft corals and anemones. More mobile organisms, such as fish, brittlestars, crustaceans, molluscs and various worms may also be abundant.

The abyssal community essentially relies on the input of nutrients from the surface waters, with organic materials slowly drifting down through the water column and settling as "marine snow" on the ocean floor. Occasionally, exceptional nutrient inputs may take place, such as a dead whale sinking to the sea floor, or when plankton blooms in the surface waters die off and sink. A single 40t whale carcass supplies a sudden nutrient input equivalent to 2000 years of normal fallout from the surface.

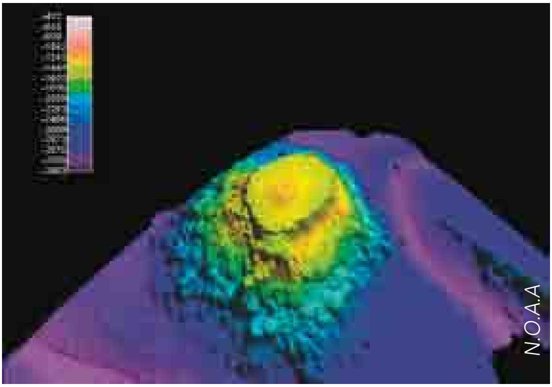
Seamounts

Seamounts are sub-marine volcanoes formed next to spreading oceanic ridges or above 'hotspots' in the earths' magma whose peaks may rise 1000 m or more above the sea floor, often approaching the ocean surface, when they are known as a 'guyot'.

The different categories of seamounts are defined as follows:

- **Seamount**: an isolated elevation rising 1000 m (1 km) or more from the abyssal plainwith a wide upper surface;
- **Mounticule**: an isolated elevation of less than 1,000 m above the sea bottom with a wideupper surface;
- **Needle**: a small column rising from the seabed.

Most of the major seamounts around Madagascar are in waters around oceanic islands belonging to France, such as Iles Glorieuses, Tromelin, Juan de Nova, Europa and Bassas de India.



Denson seamount, Pacific Ocean

In contrast to the surrounding ocean, seamounts support complex communities of deep water corals, sponges and rich concentrations of marine life including deep water demersal fishes such as orange roughy *(Hoplostethus atlanticus)* or alfonsino *(Boryx splendens)*, long-lived fishes that occur in massive, stationary, aggrega-tions, rendering them an easy target for industrial deep sea trawlers.

Seamount marine life

Seamounts are mostly isola-ted by considerable distances from the nearest seamounts or land masses and thus each seamount is unique, with many endemic species.

Seamounts are threatened by deep water industrial trawling using immensely strong trawling gear capable of dislodging rocks weighing a ton or more, causing wholesale devastation of the ecosystem that has taken millions of years to develop. A global movement has been initiated to catalogue all seamounts, as well as assess their importance for biodiversity and establish protected areas for their conservation.

Oceanic banks

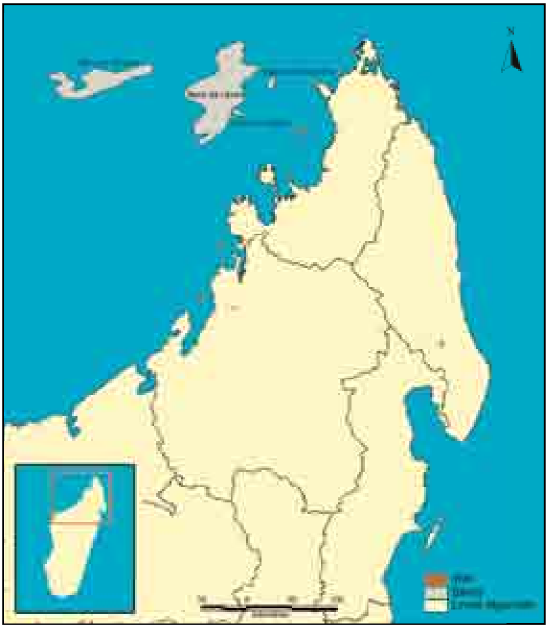
A number of oceanic banks occur close to the edge of Madagascar's continental shelf. The largest of these is the Banc de Leven (with the associated Banc de Castor), some 40 km west-northwest of the Mitsio Island group, which covers an area of about 2500 km^2 and effectively constitutes an extension of Madagascar's continental shelf. To the west of Leven lies the Banc de Geyser, which may be considered part of the Comoros Islands volcanic chain.

Marine life on Banc de Castor, North West Madagascar

J.B.

The continental margin of North West Madagascar, which includes the Banc St Leven, is one of the few to have been mapped in detail, demonstrating the mountainous nature of the undersea landscape around this part of Madagascar.

About 150 km due west of Cap St. André is a pair of seamounts, former atolls, rising to within 30 m of the surface. Ile Juan da Nova (17º03'S, 42º43'E) is the only fully exposed atoll, with an extensive coral reef. To the south of Juan de Nova are three smaller mounts or banks (Taunton Castle, Estaign, and Vines). Oceanic banks are absent along the southwest coast. About 80 km south of Cap Ste Marie lies the Banc de Tabinta, separated from the continental shelf by a small gap. South of Tabinta the ocean floor, at around 2000 m, includes a number of mounts rising to within 500 m of the surface and several holes descending to over 3 km. Important deepwater fisheries of alfonsino *(Boryx splendens)* were discovered here in 2007. A few isolated oceanic banks also occur along the east coast of Madagascar (Banc de Gabrielle, Banc de Antehirondro).



Banc de Leuen and Banc de Geyser
in the North West

Continental shelf seas

Also known as the 'neritic' province (derived from *nerites* (Gr) meaning sea snail), the shelf seas, descending to an average depth of 200 m, are relatively productive because of the high concentrations of nutrients from rivers and vertical mixing of bottom sediments into the water column. It is here that 95% of marine fisheries production is concentrated. Again, productivity levels are much higher in the western than eastern coastal seas of Madagascar. The waters of Madagascar's western rivers, fed by wide river basins over long distances, are strongly mineralized and loaded with sediment by the time they arrive at the coast. By contrast, eastern rivers drain off the rocky eastern escarpment over short distances and are deficient in minerals. Scientists have reported that the mineral content of some eastern rivers may be less than that of distilled water from a laboratory!

Submarine canyons

During the ice ages of the Pleistocene period (12 million years ago up to 12,000 years before the present), due to locking up of water in the ice caps, sea levels dropped by 100 m or more, causing rivers to cut canyons into coastal margins. Upon melting of the ice caps, sea levels recovered, leaving submarine canyons close to the shore.

The largest submarine canyon of Madagascar is the Onilahy River submarine canyon, off St. Augustin in SW Madagascar, which also happens to be associated with a geological fault that has caused a sharp drop in the level of the sea-floor, resulting in extremely deep water (2000 m) close to the river mouth. The near vertical walls of the canyon and continental slope provide suitable habitat for the coelacanth *(Latimeria chalumnae)* which was first captured by fishermen at St. Augustin in 1994 and is presumed to dwell in caves in submarine cliffs at depths of about 300 to 400 m.

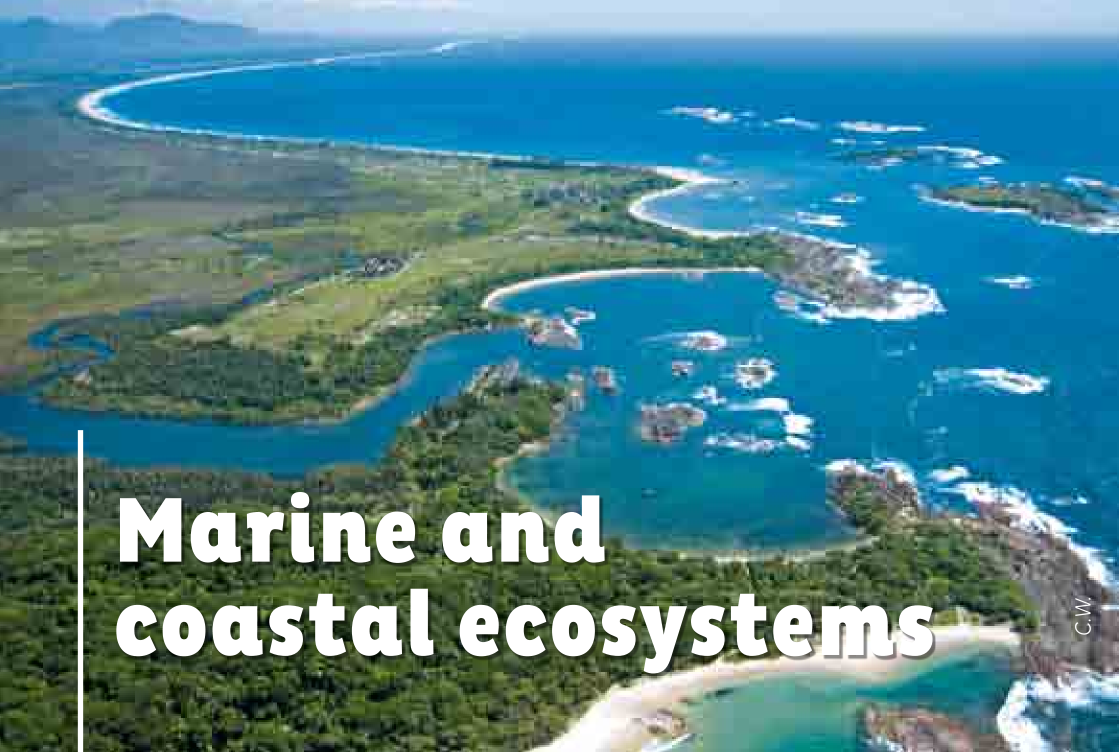
Other examples of marine canyons have been discovered by divers in the Nosy Hara area of NW Madagascar, in much shallower water and providing spectacular undersea scenery for divers.

Map of South West Madagascar showing the location of the Onilahy River marine canyon

Map showing the location of the Maningory marine canyon south of Ile Ste Marie

Reef gulley, Nosy Ve, South West Madagascar

Marine and coastal ecosystems

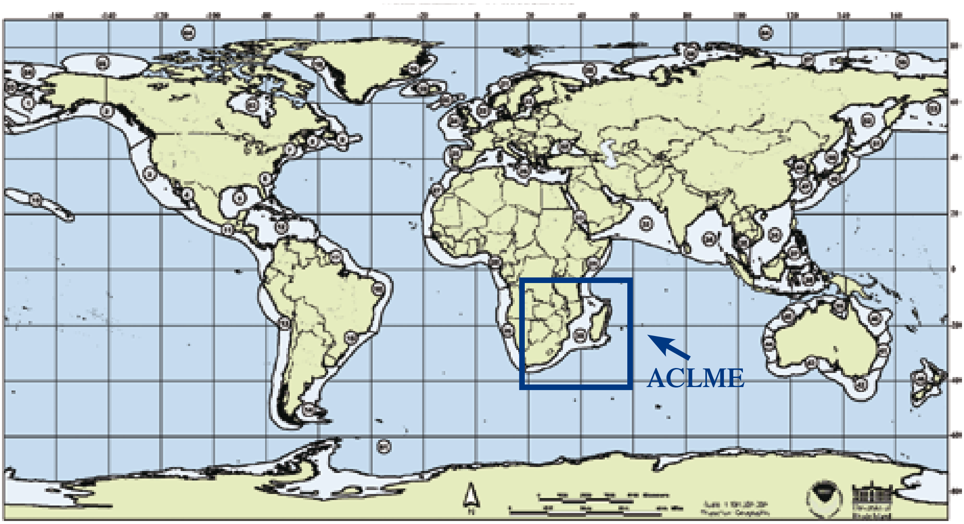


Aerial view of Bay of Sainte Luce, SE Madagascar

Agulhas Current Large Marine Ecosystem

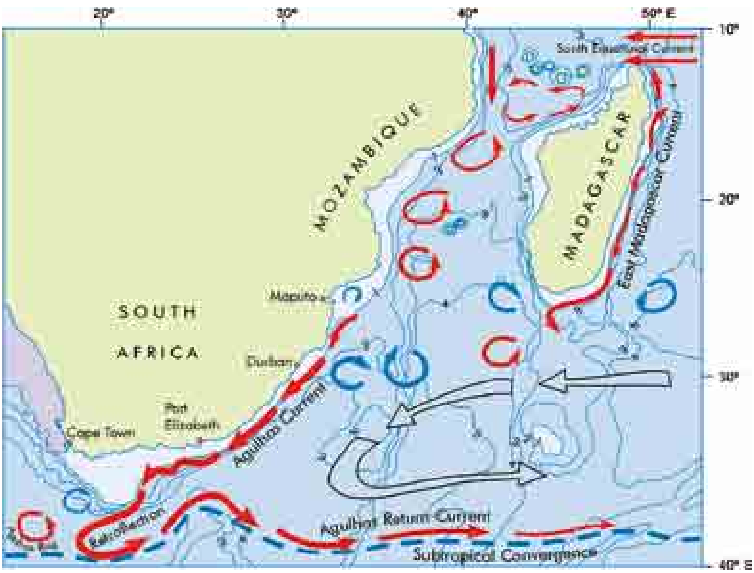
Large Marine Ecosystems (LME's) are regions of the ocean generally 200,000 km^2 or greater in area, encompassing coastal areas from river basins and estuaries to the seaward boundaries of continental shelves and the outer margins of the major current systems. They are characterized by distinct bathymetry, hydrology and productivity and dependent human populations. Some 64 LME's are identified around the world, covering 95% of the world's capture fisheries. LME's are enjoying increasing recognition among international agencies, countries and inter-governmental organisations as manageable ecological units at a multi-country scale. Five LME's are recognised around Africa – the Somali Current LME, Agulhas Current LME, Benguela Current LME, Guinea Current LME and Canary Current LME.

According to the LME scheme, Madagascar occupies an *upstream* position in the Agulhas Current Large Marine Ecosystem, or ACLME. The ACLME is characterised generally by warm water temperatures (20-30ºC) and low primary productivity, with the exception of a few 'hotspots' associated with small upwelling areas (notably off SE Madagascar and Ile Juan de Nova off NW Madagascar), oceanic



Large Marine Ecosystems of the World
showing the Agulhas Current Large Marine Ecosystem (ACLME) (Source: N.O.A.A.)

eddies drifting southwards in the Mozambique Channel and close to major estuaries. However, the ACLME is important for marine biodiversity, since it includes the majority of the coral reefs of the western Indian Ocean. Well over 10,000 shallow marine animal species are known for the western Indian Ocean, including over 2000 fish species and over 300 reef-building corals.



Surface Currents of the Agulhas Current Large Marine Ecosystem (ACLME) (Source: Prof J Lutjeharms)

To the north of the ACLME lies the Somali Current LME (SCLME), which is dominated by an intense seasonal cold water upwelling system along the Somali coast driven by the north east Monsoon (from November to March), and is highly productive although less species-rich. To the east of the ACLME and SCLME lies the Mascarene Plateau, a distinctive granitic ridge of continental origin extending from latitude 2º to 22º S, with an average sea depth of just 100 m. The Mascarene Plateau links the islands of Seychelles, Mauritius and Reunion and has been proposed as a distinct LME. The proposed Mascarene Plateau Large Marine Ecosystem is also characterised by low productivity but high biodiversity.

Coral reefs

Coral reefs are three-dimensional calcareous structures produced by living organisms, growing in shallow, clear, nutrient-poor, tropical seawater. Coral reefs are almost entirely confined to a zone between latitudes 30º N and 30º S of the equator, and to water less than 30 m deep. The main reef structure is composed of the skeletons of stony or hard reef-building corals cemented together by limestone generated by various kinds of algae. The limestone cement comprises over 70% of the reef's essential structure, enabling it to withstand wave action and grow with time. As the reef grows, it also accumulates the debris of wave-smashed corals and other organisms.

Coral reef growth is dependent upon sunlight and adequate flushing with clean seawater to provide oxygen, fresh supplies of nutrients and the removal of sediment and metabolic waste products. Coral organisms can only maintain growth with limited exposure to open air with the result that reef flats are created as the reef reaches the surface. Conversely, reef development is hindered or prevented by turbidity, excessive wave action and the presence of fresh water.


Coral reef slope, Salary Bay, SW Madagascar

J.B.

Coral reef flat at Nosy Atafana, Mananara, NE Madagascar

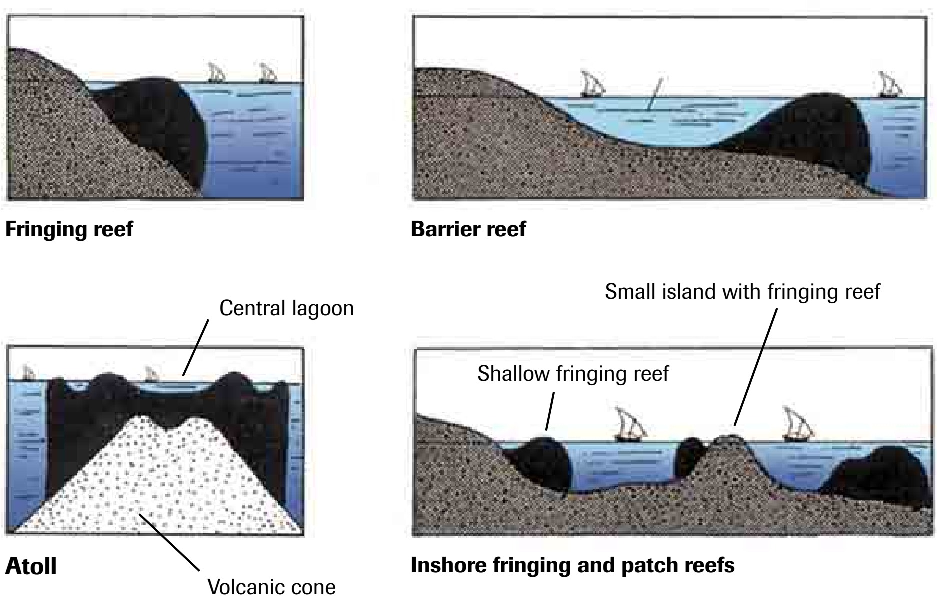
The complex three dimensional structure of a coral reef provides habitat for numerous plant and animal species, resulting in the development of complex communities of plants and animals. In tropical, nutrient-depleted seas, coral reefs act to concentrate nutrients and biological productivity into a tiny area, resulting in intensive competition for space on the reef. Organisms have developed myriad strategies for coping in such a competitive environment, including chemical warfare (used by coral colonies to kill or repel neighbours), adopting a minute size (many coral reef fishes are tiny) or switching to a nocturnal existence (many fish are active at night, surrendering their shelters to daylight species at dawn and dusk, resulting in a 'rush hour' at change-over time). Dawn and dusk are exciting times to dive on a coral reef.

Map showing distribution of coral reefs along Madagascar's coast (Source : Cooke et al 2003)

Reef types

Coral reefs may be classified into four main types: fringing, barrier, patch and atolls.

- **Fringing reefs** grow in shallow water fringing the shore - the coral forms narrow platforms which grow outwards towards the open ocean.
- **Barrier reefs** may develop from fringing reefs, growing outwards from the shore and eventually enclosing a lagoon of deeper water behind them.
- **Patch reefs** grow in shallow, sheltered waters, usually close to the shore but also offshore where conditions allow. They develop a flat top and may grow as a circular structure, sometimes enclosing a small lagoon.
- **Atolls** are a ring-shaped ribbon reef with a lagoon in the centre, usually surrounding the submerged peak of a seamount. The term *atoll* comes from the Dhivehi (an Indo-Aryan language spoken on the Maldive Islands) word *atholhu*. The word was first popularised by Charles Darwin who explained the genesis of an atoll. He reasoned that a fringing coral reef surrounding a volcanic island in the tropical sea will grow upwards as the island sinks, leaving behind a ring of reefs surrounding a lagoon where reefs do not grow because conditions are unfavourable (absence of flushing or wave action, high temperatures etc.). Examples of atolls around Madagascar include the coral banks of Petit Castor and Grand Castor, northwest of Nosy Be, the Iles Glorieuses, north west of Diego (which belong to France) and, further north, the internationally famous Aldabra Atoll (part of the Seychelles).



Different types of coral reefs (Source: Richmond, 2002)

Coral reefs in Madagascar

The coral reefs of Madagascar occur predominantly as emergent fringing and barrier reefs, patch reefs and as submerged coral banks and shoals. They are best developed along the relatively protected west coast at locations close to deep water and away from river mouths; they are least well developed along the wave battered east coast. Several estimates have been made regarding the length of coral reefs in Madagascar. Inspection of marine charts indicates 1130 km of fringing reef, 557 km of reef around islets and islands or patch reefs, 52 km of true barrier reef (all in the Toliara region), and 1711 km of submerged coral banks and shoals, making a total of 3450 km of coral formations.

Also occurring in Madagascar, especially on the east coast, are rocky reefs in which coral colonies grow on boulders and other rocky substrate without developing into a true coral reef. Examples can be seen at Tampolo marine park in the Bay of Antongil and at Nosy Atafana marine park, part of the Mananara Biosphere reserve. Another structure allied to coral reefs although lacking corals, are algal or 'grey' reefs. Algal reefs are found particularly in the far south, for example at Lavanono.

The most developed reef structure in Madagascar is the Grand Récif of Toliara, which is perched at the edge of the continental shelf and benefits from clear oceanic water and excellent flushing from an almost constant oceanic swell. This has caused the reef to grow seawards in the form of a series of spurs and grooves

CORAL BLEACHING

Coral bleaching occurs when the close relationship, or symbiosis, between the coral polyp and algae living in the polyp's tissues (zooxanthellae), breaks down and the zooxanthellae desert the polyp, giving rise to bleaching. Bleaching also affects soft corals and anemones. Bleaching tends to occur when the polyps are stressed, such as by high water temperatures or excessive sunlight. In freshly bleached corals, the polyps are still alive and you can usually find small patches of colour on shaded parts of the colony. Provided that normal temperature conditions are rapidly restored, the *zooxanthellae* will recolonise the polyps and the colony will recover. However, if stress conditions are prolonged, the polyps die and the coral colony will rapidly be overgrown by algae. Major coral bleaching events have occurred in the Western Indian Ocean, including Madagascar, in 1998 and 2004, associated with El Niño years. Bleaching events are becoming more frequent as a result of global warming, although they did sometimes occur in the past (for example, they were observed in the Seychelles in the 1950s).

Normal coral Bleached coral

with living coral to a depth of some 35 metres at the base of the reef slope. The best developed reefs along the east coast are in the north east, in a region known as the ‘blue triangle’ encompassing the Masoala Peninsular, Mananara, Foulpointe and Ile Sainte Marie and corresponding to zone of relatively slack water between the north and southbound branches of the Eastern Madagascar Current (EMC).

The predominant type and structure of coral reefs varies according to the regional marine environment. Well developed coral reefs are virtually absent along the coast between Toamasina and Tolagnaro where intensive wave action and coarse sediments have combined to prevent the growth of large coral structures. However, various sources confirm that a band of coral growth at depths of 10-20 meters exists along most of the coast. Exceptions also occur such as in the protected bays of Lokaro. However, coral and fish species diversity appear very reduced compared with the principal coral reef regions.

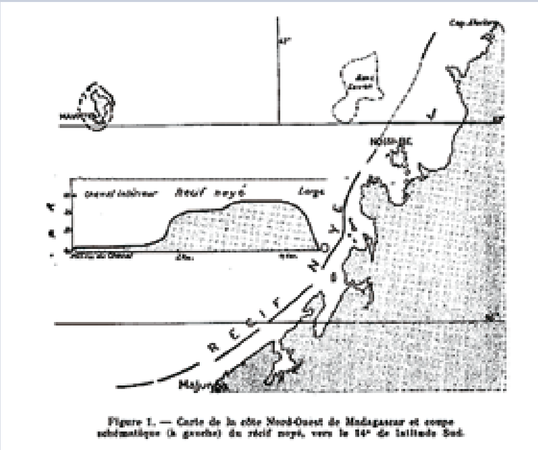
CHARACTERISTICS OF REEF STRUCTURE IN THE DIFFERENT CORAL REEF REGIONS OF MADAGASCAR

Region	Environmental conditions	Dominant reef type	Max. depth of reef corals
NE	Narrow continental shelf, intensive swell and wave action, seasonal cyclones, winds generally strong from E, few islands, swift currents, high rainfall, numerous small rivers, waters often turbid	Fringing	15 m
NW	Wide continental shelf, low wave action, cyclones rare, winds weak and variable, numerous islands, weak currents, moderate rainfall, moderate number of rivers, waters rarely turbid	Patch and fringing	50 m
SW	Narrow continental shelf, high oceanic swell, cyclones rare, southerly winds seasonally strong from SE, moderate number of islands, weak and variable currents, low rainfall and few rivers, waters turbid only during and after rainy season when rivers full	Barrier and fringing	35 m

THE ANCIENT OR 'DROWNED' REEF OF WEST MADAGASCAR

While Madagascar is particularly known for the spectacular barrier reefs of the Toliara region, equally impressive is the existence of an ancient submerged barrier reef parallel to the western and north-western continental shelf which stretches over 1000 km from opposite the Bay of Narinda to just north of the Mangoky delta. The ancient reef survives today as a string of submerged banks and shoals, sometimes broken by passes, at a general depth of 15 to 30 m with frequent peaks rising to 10 m or less and occasional troughs corresponding with ancient river canyons such as the fosse du *Tsiribihina* where the reef probably never existed. When the ice caps melted at the end of the last Ice Age about 6,000 years ago, sea levels rose rapidly by about 20 m, 'drowning' many of the world's coral reefs. Where conditions were favourable for reef development, such as at Toliara, reef growth was able to keep up with sea level rise, but in other areas only parts of the reef have managed to stay close to the surface. The 'drowned' reef was probably emergent along much of its length 6,000 years ago, almost matching the Great Barrier Reef of Australia in length. The drowned reef therefore provides a model for how coral reefs around Madagascar may cope if sea levels rise as predicted as a result of global warming.

The drowned reef is made up of sandy coral banks supporting about 10% live coral cover and attracts rich concentrations of fishes associated with the continental edge, such as snappers, breams, emperors, groupers and trevallies. Fish are most abundant between November and April, corresponding with the peak fishing season and the peak abundance of sharks.



Map showing the ancient drowned reef of Madagascar (Source: Fourmanoir, 1963)

Sea grass meadows

Sea grasses are aquatic flowering plants that flourish in protected shallow marine waters such as lagoons behind coral reefs. Seagrass beds are found intertidally as well as subtidally, sometimes down to about 40 m, and often occur in close association with coral reefs and mangroves. Seagrasses stabilise bottom sediments against the effects of wave and tidal action and provide habitat for numerous free living and sedentary organisms, including many that attach themselves to the plants. Biologically, seagrasses perform an essential cycling of nutrients by absorbing phosphorous (P) through the roots and leaves and returning both Nitrogen (N) and P to the water column from sediments via the plant.

The full extent of Madagascar's sea grass meadows is unknown, since they have never been mapped and are difficult to distinguish in aerial photographs or satellite images. Based on the surface area of clear and protected shallow marine waters the area of sea grasses in Madagascar is likely to exceed that of coral reefs, estimated at 3000 km^2.

Dugong dugon

According to published literature, 12 sea grass species are known for Madagascar. Seagrass beds in Nosy Be often occur in mixed stands of two or three species, most commonly *Syringodium isoetifilium* and *Thalassia hemprichii*. Only *Thalassodendron ciliatum* forms monospecific stands. Some habitat preference is observed – *Thalassodendron ciliatum* (formerly *Cymodocea ciliata*) tends to colonize coral rubble, while *Syringodium* and *Halophila* prefer silty substrate.

The sea grass habitats in Madagascar support many species of fish and invertebrates. Resident fauna of seagrass beds include various fishes, mud lobsters (*Callianissidae*), echinoderms

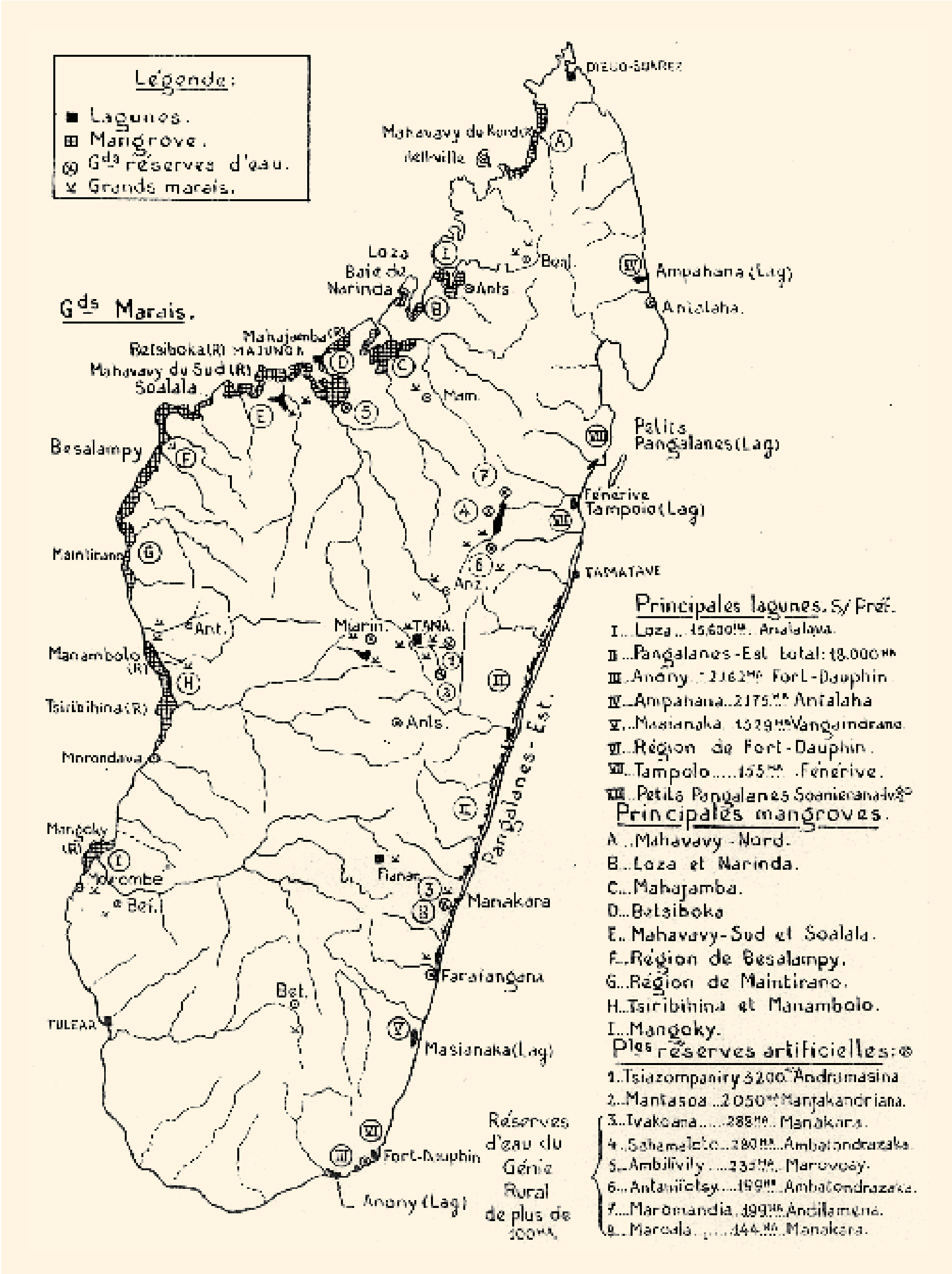
Sea grass meadow, Nosy Atafana, Mananara, NE Madagascar (edible urchin *Tripneustes gratilla*, black urchin *Echinothrix calamaris*, two conspicuous starfish (*Protoreaster lincki* and *Pentaceraster tuberculatus*) and various sea cucumbers, notably the snake-like *Synapta maculata)*, hermit crabs and gastropod molluscs, including cowries. Sea grass beds are also important as feeding grounds for dugong and sea turtles, particularly the green turtle *Chelonia mydas*.

Mangroves

Mangrove prop-roots *(Rhizophora mucronata)*, Nosy Atafana

Mangroves are communities of trees which grow in tropical intertidal marshes. Their characteristic features are tolerance to salt water and low-oxygen (anoxic) soils. Most mangrove tree species have aerial roots (*pneumatophores*) enabling them to absorb oxygen from the air or surrounding water. With these key adaptations, mangroves are able to benefit from the hot, wet and nutrient rich environment offered by tropical tidal mudflats. The productivity of mangrove forests is among the highest of all forests; healthy mangroves, if well managed, can yield large supplies of wood for construction and fuel and other useful products such as tannins.

Madagascar possesses over 425,000 ha of tidal marshes, of which about 327,000 ha are covered in mangroves, amounting to 20% of all African mangroves and 2% of the world's mangroves. Three types of mangrove are recognised - estuarine, lagoonal and littoral. About 98% of all Madagascar's mangroves are on the west coast. The shallow slope of the western coastal plain, the many estuaries and deltas, large tidal range and relatively protected sea conditions all combine to provide ideal conditions for mangrove development. The largest stands (> 25,000 ha) of mangroves are found in the deltas of Madagascar's major western rivers - Mahajamba, Betsiboka (including the Bombetoka mangrove), Mahavavy, Besalampy, Tsiribihinina and Mangoky - which account for over 75% of all of Madagascar's mangroves.



First map of Madagascar's mangroves by Kiener (1963)

Mangroves are an important component of the coastal ecosystem. They provide habitat for numerous species, including nursery and feeding grounds for fishes, shrimps, crabs and birds. They also act as sediment traps, promoting the development of coral reefs and seagrass meadows which depend on clear water for their growth. Mangroves underpin shrimp fisheries and provide suitable environment for the establishment of shrimp farms. Mangroves provide a range of valuable goods and services including wood for fuel and construction and coastal defence. For these reasons, mangroves are considered to be among the most economically valuable ecosystems.

With just eight tree species, the mangroves of Madagascar are relatively poor in species compared with the mangroves of South-East Asia (40 species). Most of the Madagascar mangrove stands contain six species from four families: Rhizophoracae (*Rhizopora mucronata*, *Bruguiera gymnorrhiza* and *Ceriops tagal*), Avicenniaceae (*Avicennia marina*), Sonneratiaceae (*Sonneratia alba*) and Combretaceae (*Lumnitzera racemosa*).The primary colonizers located

Mangroves at Nosy Atafana, Mananara, NE Madagascar

Mangrove vegetation – typical progression from seaward to landward side
(Source : Lebigre et al, 1990)

Th = Grasses, **TV** = Salt flat
a : *Avicennia marina*, **b** : *Bruguiera gymnorrhiza*, **c** : *Ceriops tagal*, **h** : *Hibiscus tiliaceus*, **1** : *Lumnitzera racemosa*, **r** : *Rhizophora mucronata*, **s** : *Sonneratia alba*.

along the mangrove's seaward fringe are *Sonneratia* and *Avicennia*. *Rhizopora* and *Bruguiera* are found behind the colonizer species or along creeks. Finally, *Bruguiera*, *Ceriops tagal* and *Xylocarpus granatum* tend to occupy the areas flooded only at high tide. *Heritiera* occurs in the landward fringe and is not always considered a true mangrove.

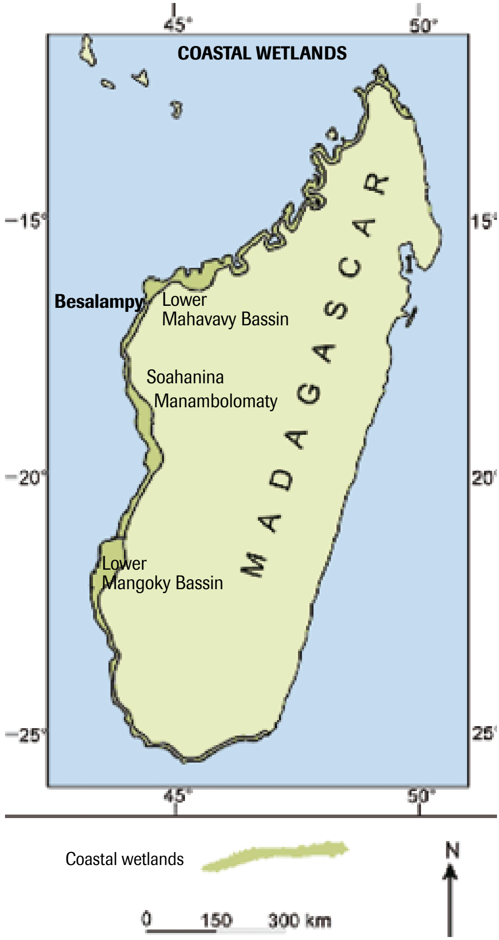
SPECIES OF TREES OCCURRING IN MADAGASCAR'S MANGROVES

Species	Malagasy name	Location
Avicennia marina	Afiafy	Seaward fringe
Sonneratia alba	Songery	Seaward fringe
Rhizophora mucronata	Tangandahy	Mid mangrove & creeks
Lumnitzera racemosa	Rogno	Mid mangrove & creeks
Xylocarpus granatum	Fobo	Back mangrove
Brugeria gymnorrhiza	Tangampoly	Back mangrove
Ceriops tagal	Tangambavy	Back mangrove
Heritiera littoralis	Reneho	Landward fringe

Coastal wetlands

Coastal wetlands are areas of permanently or periodically flooded land on the coastal fringe. They include marshes, lakes and lagoons of fresh, brackish or salty water. Tropical coastal wetlands provide habitat for many species, such as crocodiles, fish and water birds. They also provide valuable environmental good & services such as fisheries, water for agriculture, reeds for roofing and waterways for transport.

Madagascar possesses approximately 2 million hectares of coastal wetlands (including mangroves), over 90% of which are along the west coast where the broad coastal plain and numerous rivers generate large areas of wetland. Most of the Western wetlands are located between Sahamalaza and Morombe. The largest wetlands are associated with the major river deltas of Mahajamba, Betsiboka, Manambao, Manombolo, Tsiribihinina and the Mangoky. There are a few important coastal wetlands along the east coast, notably Laka Sahaka (NE), the Pangalanes canal system and occasional lagoons (from North to South-Ampahana, Petits Pangalanes, Tampolo, Masianaka, Tolagnaro and Anony).



Map of coastal wetlands in Madagascar
(Source : BirdLife International)

Malagasy coastal wetlands provide habitat for a characteristic flora, including the lesser reedmace or cattail *Typha angustifolia*, rushes *Juncus* sp., reeds *Phragmites* spp., papyrus *Cyperus* spp., water lilies *Nymphea stellata* and free floating species such as *Eichinochloa stagnis*. All these species are pantropical in their distribution.

Malagasy coastal wetlands provide habitat for numerous threatened animal species including crocodiles *Crocodilus niloticus*, 11 endangered or near-threatened species of wetland bird, including the critically endangered Madagascar Fish Eagle. Madagascar's coastal wetlands still support one or more species of sawfish (Pristidae), categorized as Critically Endangered.

Bay in North West Madagascar

Bays in Madagascar

Madagascar's coast features numerous bays which are important for natural resources and biodiversity. The larger bays of Madagascar are mostly of tectonic origin i.e. they are the result of geological faulting. The greatest number of bays is found along the West Coast, although the largest bay of all, Antongil, is on the North East coast. South of Toamasina, the East coast is virtually free of bays until the Fort Dauphin area (Sainte Luce, Evatraha, Tolagnaro, Italy etc.).

In many ways, bays can be considered as partially self-contained ecosystems. They tend to have their own micro-climate and wind regime, water circulation and relatively high water temperatures. Often they are fed by rivers, resulting in reduced salinity and high primary productivity, accentuated where human populations are significant due to effluents and other waste. Bays are particularly vulnerable to the phenomenon of "red tides", where the surface water becomes dominated by a particular form of toxic dinoflagellate plankton. Bays are often fringed by mangroves or other types of coastal wetlands and may contain a diversity of ecosystems within a relatively small area. Bays serve as critical habitat for many species, including shrimps (Ambaro, Ampasindava, Narinda, Mahajamba, Boina, Baly), water birds (all the western bays) and even humpback whales (Antongil).

In addition to their biological interest, bays have historically served as staging posts for shipping, leading to the establishment of coastal communities and high human populations today, posing particular challenges for environmental management. The Bay of Antongil, for example, has been the subject of a science-based integrated management process.

Littoral forests

'Littoral forest' refers to forest along the coastal fringe above the high water mark, and does not include mangroves (which are intertidal). Madagascar's coasts were once fringed with littoral forest, thicket or scrub of various types – evergreen littoral forests along the east coast and in the Sambirano region (around Nosy Be), dry deciduous forest along most of the west coast and dry thicket or scrub in the far south. Today, only fragments remain. Littoral forests are poorly protected and remain one of the most threatened ecosystems in Madagascar.

On the east coast, evergreen forest once covered the littoral zone from the humid region of Sambava southwards to Tolagnaro, extending inland to the lowland evergreen forests that covered the eastern hillsides. These east coast littoral forests can be divided into southern and northern types. Of the southern forests, there is again a division into forest on basalt (of which only the forest of Manombo remains – 100 km north of Tolagnaro) and forests on sand, small fragments of

Littoral forest in North East Madagascar (Masoala)

Littoral forest in South West Madagascar

which remain around Tolagnaro. The northern littoral forests are predominantly growing on sand. While they have been less heavily affected by deforestation than the forests of the south, they are nevertheless now reduced to fragments and localized stands. The largest remaining fragments are north of Foulpointe, in the region of Soanierana-Ivongo.

On the west coast, littoral forest comprises three main types – the distinctive, evergreen littoral forest of the Sambirano region (around Nosy Be), dry deciduous forest in the west and dry thicket or scrub in the far south.

Again, the precise forest type is determined by substrate. For example, in the south west littoral forests on red and white sands are quite distinct. The littoral zone of the far south west is characterised by dry thickets or scrub growing on sand dunes dominated by *Euphorbia stenoclada*, sometimes with *Didieracea madagascariensis*. Just inland, the forest growing on red sands is dominated by baobabs and is typified by the forests of Mikea and the site known as PK32, near Ifaty. These forests are especially rich in endemic genera and species but under intense threat from deforestation and grazing.

EASTERN LITTORAL FORESTS

The soils in the littoral zone are mostly shallow, supporting trees which root only into the upper 30 cm where organic matter holds the nutrients. The littoral forest trees form a low canopy (under 20 m tall), reflecting the impoverished conditions, and perhaps also reflecting frequent cyclone disturbances which uproot any taller trees.

High species and genus endemism are typical in the eastern littoral forests. At least four genera of plants are known to be endemic to the eastern littoral formations, and 360 plant species have been recorded from one eastern fragment (Tampolo) including 11 palm species. The most common strand genera are *Calophyllum*, *Faucherea*, *Mimosops*, *Pandanus* and *Terminalia*. Further inland the species composition includes broad-crowned *Instia* trees, slender *Diospyros* (Ebony) trees, *Uapaca* with stilt-roots protruding from the trunk, *Protorhus*, *Eugenia* and *Ocotea* trees. *Raphia* palms and *Ravenala* clumps with *Pandanus* and *Draceana* plants in the undergrowth are common in the swamps which often occur behind the beachfront. Exotic species such as *Casuarina* and *Melaleuca*, both from Australia, are invading and making inroads into some of these strand and swamp communities.

Eastern littoral forests are characterized by impoverished animal communities - especially in comparison to nearby lowland dense forest. However, they may hold a rich diversity of birdlife.

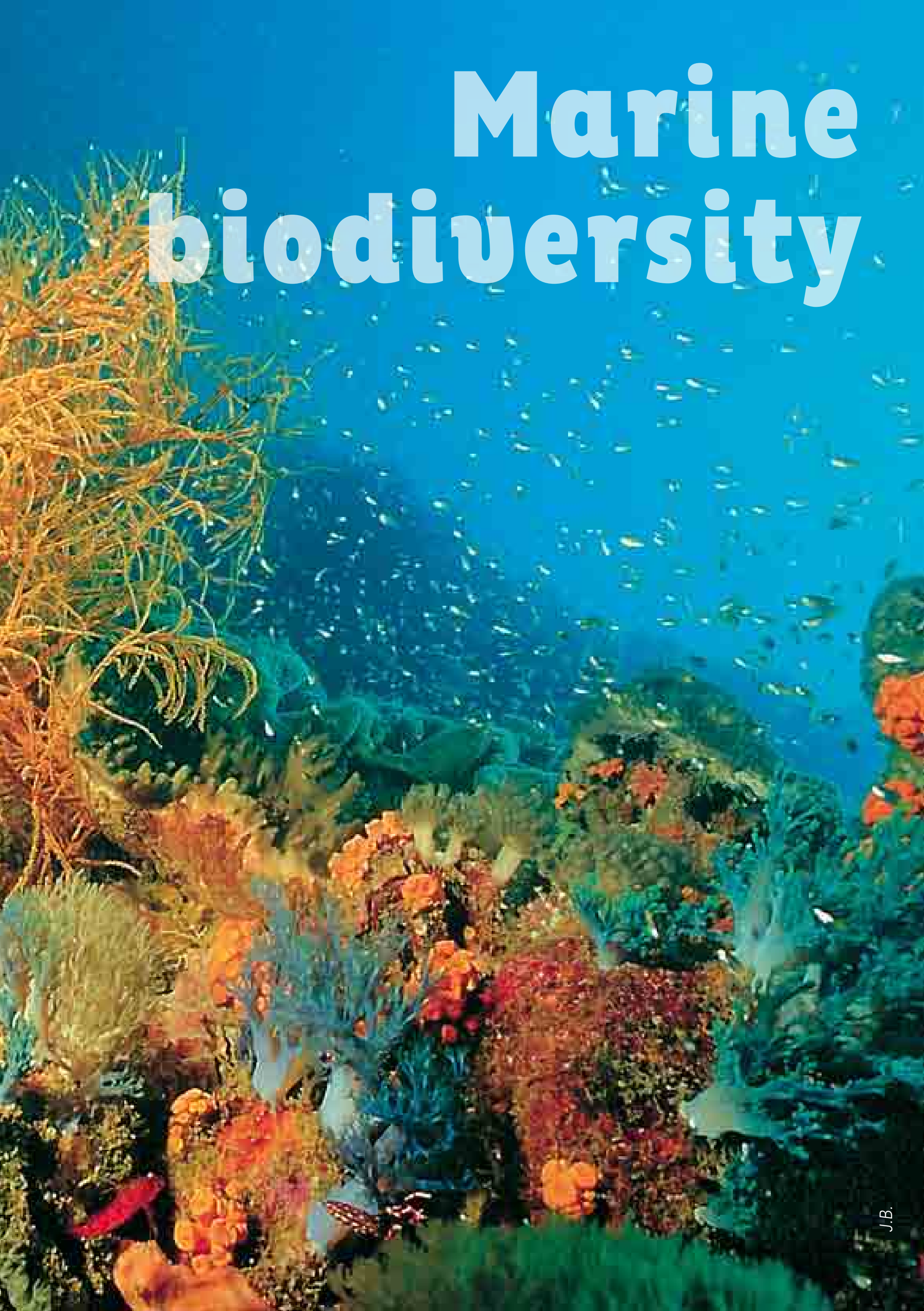
The human impact on eastern littoral forests has been recorded as early as the 16th century CE, with the harvesting of ebony (*Diospyros* spp.) and other valuable trees for house and ship construction (*Instia*, although not endemic, is heavily harvested for construction timber). Modern deforestation is marked in the southern regions, due to higher population densities and gentle, accessible terrain which suits grazing animals.

Littoral forest north of Fort Dauphin, South East Madagascar

C.W.

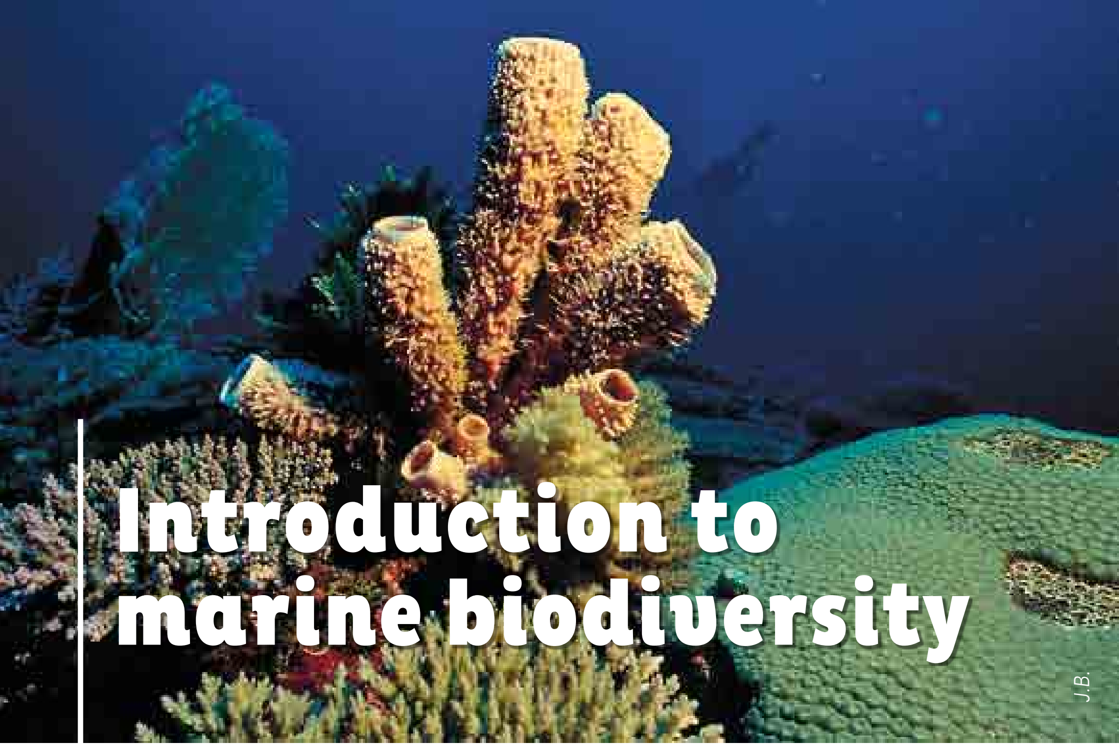
Marine biodiversity, Cap St Sebastien, NW Madagascar

Marine biodiversity



J.B.

Introduction to marine biodiversity



Sponges and corals, Nosy Mitsio, NW Madagascar

What is marine biodiversity?

«Biodiversity» is the shortened form of «biological diversity» which is defined internationally as the diversity of ecosystems, species and genes. Marine biodiversity is a major part of the world's biodiversity. Not only do the oceans cover 70% of the earth's surface, but life probably first evolved in the sea and most of the main taxonomic groups of organisms known to science (*phyla*) are exclusively or primarily marine (e.g. sponges, cnidaria, annelids, molluscs, echinoderms etc.).

The marine environment contains a diversity of *ecosystems* from the sea surface to the deepest ocean trenches. Examples of marine ecosystems include coral reefs, boundary-current upwelling systems, open ocean pelagic ecosystems, mid-ocean vent ecosystems, seamounts, seagrass beds, kelp forests and many others. Marine ecosystems harbour a vast diversity of *species*. An estimated 300,000 marine species are known to science, comprising mostly easily visible species found in shallow waters. The total number of marine species, including small and microscopic species, is much greater than this, possibly as many as several million species. Contained within these millions of species is an immeasurable *diversity of genetic materia*l (DNA and RNA), from the most ancient genes that underpin life itself to recent genetic “innovations” helping organisms to survive in a competitive and dangerous marine environment.

Contemporary human efforts to understand and manage the vast subject of marine biodiversity are various. At the ecosystem level, scientists endeavour to understand how ecosystems function at a range of scales from entire oceans to tiny patches of a coral reef. The global “Large Marine Ecosystem” (LME) framework has been developed to break down the world’s most productive marine ecosystems into 64 manageable regional blocks based on bathymetry, currents and trophodynamics (Madagascar, for example, lies within the Agulhas Current LME). At the level of species, the “The Census of Marine Life” is a global initiative of scientific institutions seeking to maximise knowledge of marine species. Marine conservation planning is typically supported by inventories which identify areas of greatest species diversity (several have been conducted in Madagascar). At the level of marine genetic diversity, there exist many international initiatives to document the genes and genomes of marine organisms, and to identify genes useful in medicine and other technologies. At the national level, private sector and public sector projects are being undertaken to identify bioactive compounds in marine organisms useful in medicine (several research projects have been undertaken in Madagascar).


Reef biodiversity at Cap St Sebastien, NW Madagascar – sponges, sea fans, soft corals, clams...

J.B.

Madagascar's marine biodiversity

"Madagascar's marine biodiversity" is made up of the marine ecosystems, marine species and marine genetic material lying within Madagascar's Exclusive Economic Zone (EEZ). The limits to EEZs defined by international law are not based on ecological criteria. In effect, Madagascar's marine biodiversity is an integral part of the marine biodiversity of the Western Indian Ocean and, ultimately, through ecosystem inter-linkages, the world's marine biodiversity. This is particularly so for the biodiversity of deep waters which are uniformly dark and cold around the globe (< 4°C). It is less true for the biodiversity of tropical surface waters, which is closely similar to the tropical waters of the Western Indian Ocean and similar, if less closely, to tropical marine biodiversity of the Indo-Pacific region. Because of the continuous nature of the marine environment, tropical marine species endemism does not occur at the country level, but at the level of marine "ecoregions" separated by natural barriers to the movement of tropical species such as areas of low temperature, antagonistic currents or physical

Reef biodiversity at Cap St Sebastien, NW Madagascar – sponges, octocorallians, soft corals, hard corals, fish...

barriers. Marine biodiversity thus differs from terrestrial biodiversity, which is specific to islands or continents. Whereas most terrestrial species of Madagascar are endemic to the country, most marine species are not. To date, only a dozen or so marine species endemic to Madagascar have been identified.

While Madagascar's marine biodiversity is mostly shared with other countries of the same marine ecoregion and beyond, Madagascar is important for the sheer amount of marine diversity within its jurisdiction. With over 5000 km of east and west facing coasts and a similar length of continental shelf edge and slope, 250 small islands, extensive deep water, pelagic, shallow marine, intertidal and estuarine habitats, spanning 14° of latitude from tropical to temperate zones, it is reasonable to hypothesize that Madagascar possesses greater total marine biodiversity than any other western Indian Ocean country. Reviews of the history of marine research and published literature tend to support this view.

History of marine biodiversity research in Madagascar

Madagascar's marine ecosystems have been the subject of a considerable amount of research effort, mainly by French scientists and institutions during the colonial and post-colonial period, and latterly by international research organisations and NGOs interested in marine conservation. By far the largest single body of data relates to the Grand Récif and other coastal ecosystems of the Toliara region (SW Madagascar), which was an important centre for marine biodiversity research for almost 15 years between 1960 and 1975, by scientists operating through the Marine Station of Toliara (now established as the Institut Halieutique et des Sciences Marines or IHSM). Also important, but less species focussed, was research in the Nosy Be region (NW Madagascar), conducted from the National Oceanographic Research Centre

Panels at entrance to IHSM, Toliara

"*Dr Fridtjof Nansen*" survey routes and stations in June 1983 (Source: FAO)

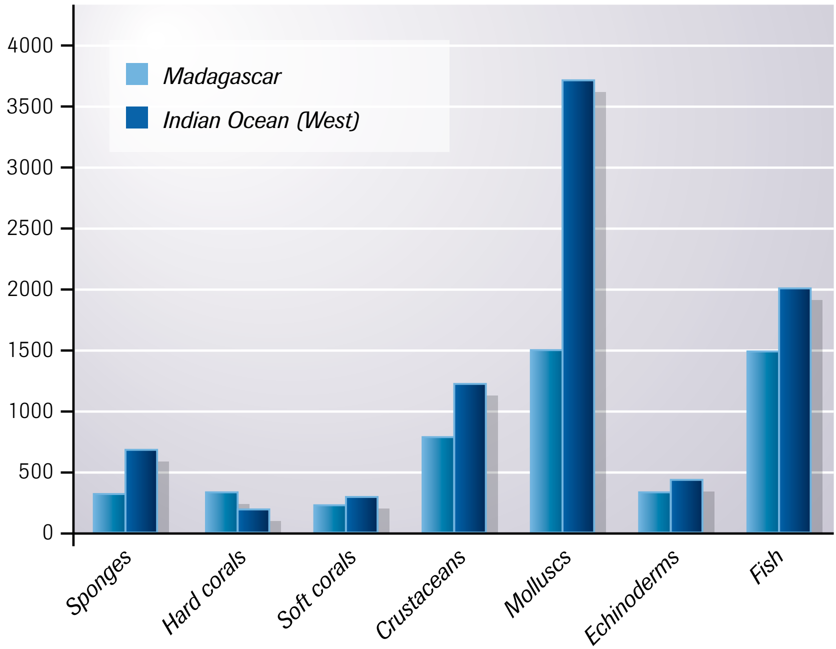
(CNRO). More recently, scientific studies and expeditions have considerably added to the amount of available data, particularly for sites identified as being of interest for marine conservation.

Recent studies and scientific surveys have added a considerable volume of new data, particularly in relation to sites identified as being of interest for marine conservation. Apart from the land-based research centres, significant scientific data have been collected by oceanographic research vessels such as the *R/V Fridtjof Nansen*, which undertook research cruises in Malagasy waters in 1983 and 2009.

Literature reviews for the Western Indian Ocean & Madagascar

Comparative studies of tropical marine biodiversity generally focus on shallow water marine *macrofauna* easily detectable without special methods or equipment. The most recent review for the western Indian Ocean (Richmond 2001) indicates that the region supports at least 8,627 species of shallow water invertebrate macrofauna. Analysis of data from the available literature for Madagascar (Cooke et al 2003) and a report from Conservation International (McKenna et al 2003) reveals 4792 species of marine invertebrate macrofauna, suggesting that Madagascar provides habitat for about 60% of the region's marine invertebrate macrofauna. For some taxonomic groups the number of species now recorded for Madagascar actually exceeds the number previously reported for the entire western Indian Ocean! These findings suggest that Madagascar's marine biodiversity is high in relation to the regional average but that the literature on Madagascar's marine biodiversity is not well known.

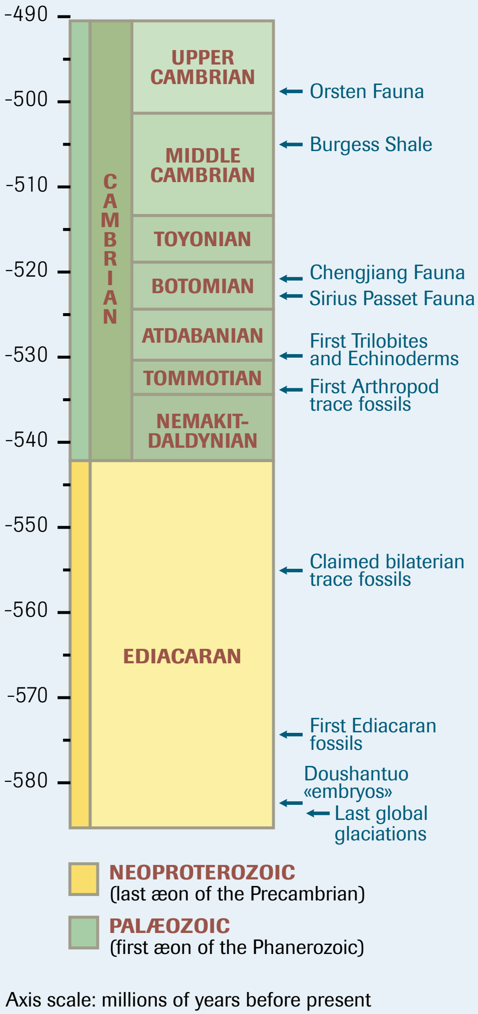
The hypothesis that Madagascar's shallow water marine species biodiversity is higher than the regional average was supported by rapid assessment surveys conducted in 2002 and 2006 by Conservation International, which confirmed that Madagascar supports more species of reef-building corals than reported for any other western Indian Ocean country and that diversity was also high for reef fish (830 species reported in the literature) and molluscs.



Number of marine species recorded around Madagascar and reported for the Western Indian Ocean by Richmond (2001)

Reef biodiversity at Nosy Be, NW Madagascar – sponges, cnidarians, hard corals, soft corals, fish...

Classifying marine fauna



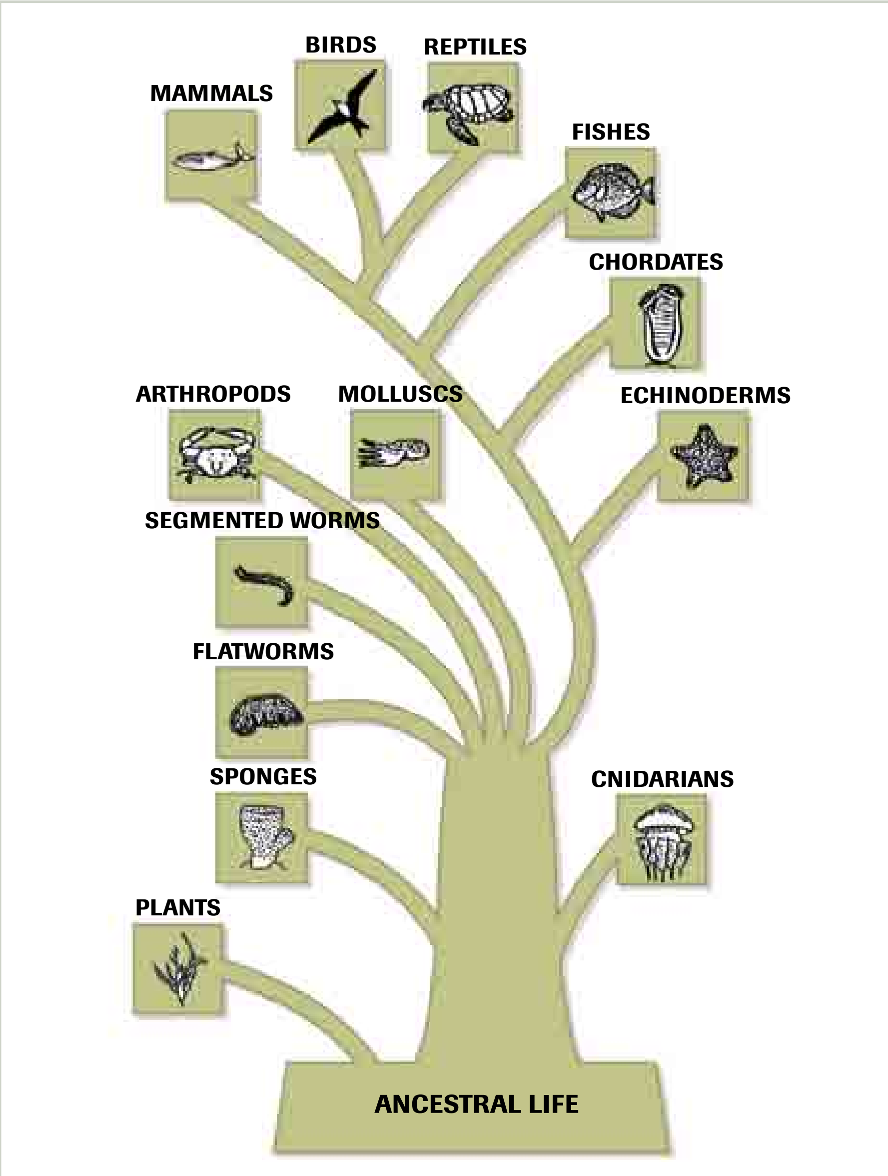
Chronology of the Cambrian explosion

Scientists currently recognise about 17 major groups (or phyla) of marine animals. Most of these first appeared in the oceans during the Cambrian 'expansion' (570-490 million years ago). The 'phylum' is

THE CAMBRIAN "EXPLOSION"

A seemingly rapid diversification of marine life occurred in the Cambrian period (570 - 490 million years ago) when most of the marine invertebrate groups known today first appeared on the fossil record – in particular sponges, cnidaria, various worms, arthropods, echinoderms and molluscs (including bivalves and gastropods). Numerous explanations have been offered to explain the sudden expansion, including changes in the environment (e.g. an increase in oxygen levels), a mass extinction in the preceding Ediacaran period (which would have made a whole range of ecological niches newly available), developmental explanations (e.g. evolution of eyes, advent of new genes involved in development etc.) or ecological explanations (such as accelerated co-evolution of species and the increasing complexity of ecosystems). Whatever may have caused the Cambrian expansion, it led to major opportunities for occupation of ecological niches which have never occurred on the same scale since. The result is that the main groups of marine fauna we recognise today have existed for around 500 million years!

the highest level of Linnean classification used by biologists to classify animals and is based on the general body plan of the animal. Several phyla are obscure, small or rarely seen. In this book we only consider the major phyla which can be observed without special searches or equipment.



Evolutionary tree of marine plants and animals (Steene & Allen, 1994)

Sponges (Porifera)

Sponges are simple filter feeders that gather micro-organisms and organic matter from the surrounding seawater. The water flowing through the sponge brings in oxygen and nutrients and carries out carbon dioxide and other waste products. The body of a sponge is a simply organised collection of individual cells bound together in a gelatinous matrix usually filled with mineral spicules of silica or calcite. The body is pierced by numerous narrow canals and interconnected chambers. Sponges exist in a range of forms, from simple spreading masses to elegantly shaped flasks, pipes, spheres and rosettes. Although sponges have no clearly defined organs, cells are specialised for different functions. Cells lining the chambers called *choanocytes* possess tiny whip-like hairs called *flagella* which beat

TOLIARA CORAL REEF SPONGES

The complex structure of a well developed barrier reef provides numerous different habitats for sponges. A study of 280 species of sponges found on the coral reefs of Toliara revealed the following groups:

- A small number of species of sponges grow in full light conditions on the rocky or sandy areas of the inner reef flat – these tend to be brightly or deeply coloured sponges growing in encrusting or spreading forms.
- A characteristic fauna of a few species of massive flask-shaped or smaller goblet-shaped sponges occurs on flat surfaces of the lower sloping platform of the outer slope in reduced light conditions between 20 and 55 m depth
- A large number of shade-loving species are found in cryptic habitats of the reef outer slope, the reef front, the outer and inner reef flat and the inner slope.
- The darker areas of the galleries in the reef front have a distinctive fauna of very hard sponges of special interest.

Source : Vasseur 1981


J.B.

Barrel sponge ***Xestospongia testudinaria*** (Pterosiidae) in unison, driving circulation of water through the sponge. Sponges reproduce both sexually and asexually, and have extraordinary regenerative powers - a sponge liquidised in a blender will slowly reorganise itself into a new sponge!

Siliceous sponge (Spirastrellidae)

Sponges are a major component of all marine ecosystems, from shallow waters to the abyssal depths. In Madagascar, they are abundant in coral reefs, seagrass beds, mangroves and on the sea floor of the continental shelf. Sponges also provide refuge for many other organisms, including crabs, shrimps, sea cucumbers, other invertebrates and small fish.

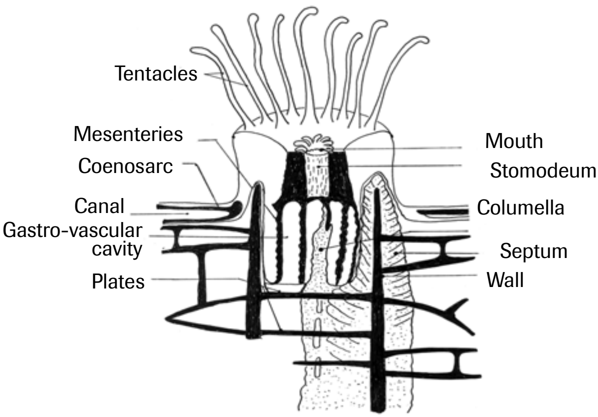
With at least 683 species in the Western Indian Ocean, sponges are probably one of the most species rich macro-invertebrate groups, outnumbering corals. The species composition of Madagascar's sponges overlaps substantially with that of East Africa; and it has more affinity with Indonesia than with India, probably as a result of larval dispersal across the Indian Ocean via the Southern Equatorial Current (SEC). There are, however, affinities with the sponge fauna of the Mediterranean, reflecting that the Mediterranean and the Western Indian Ocean were once part of a single large ocean, known as *Tethys*.

About 300 species of sponges have been reported for Madagascar (mostly from Toliara), but the true number is likely to be much higher. In shallow waters, species diversity is highest in coral reefs and lowest in mangroves, seagrass meadows or sandy and muddy habitats. In deeper waters, sponges are diverse and abundant – the sea floor of the continental shelf is carpeted with sponges that capture detritus raining down from the upper levels. When FAO conducted trawling experiments around southern Madagascar in 1983 in the Norwegian Research Vessel the *RV Dr Fridtjof Nansen*, it was found that the continental shelf off southern Madagascar was covered with vast fields of giant sponges, making trawling difficult or impossible. Industrial trawl operations off Mahajanga in the late 1990s also encountered high densities of large sponges.

Cnidaria (anemones, corals and their relatives)

Cnidarian polyps (Octcorallian)

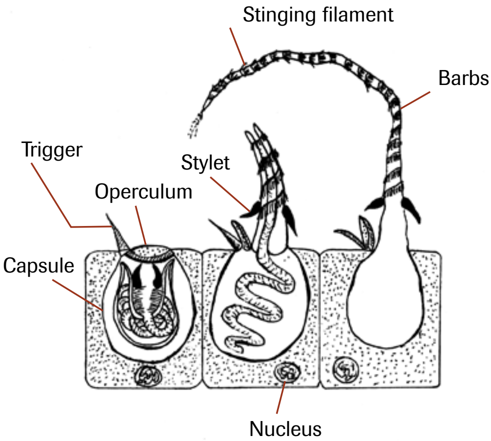
Sea anemones, soft corals, hard corals, sea fans, sea pens, hydroids and jellyfish are all grouped in the phylum *Cnidaria*. The Cnidaria is a group of exclusively aquatic animals sharing a common structure comprising a two-layered cylindrical body with mouth and tentacles armed with stinging cells, known as nematocysts. Cnidaria possess contractile tissue (muscle) and simple nervous systems. Many cnidaria live as tiny polyps in colonies, such as the corals, sea fans, sea pens and hydroids. Others are large solitary *polyps*, such as the anemones, jellyfish and mushroom corals. About 9,000 species of Cnidaria are known from the world's oceans, from the tropics to the poles, from surface waters to the abyssal depths. A smaller number of species are found in rivers and fresh water lakes and include the familiar *Hydra*. Cnidaria live either permanently attached to a substrate (to rocks, shells, boats, plants etc.), attached but also able to move slowly (such as anemones), as free swimming animals (such as the jellyfish) or as mobile colonies (such as the Portuguese Man of War).



Anatomy of a polyp
(graphic by Faratiana Ratsifandrihamanana)

POLYPS

Polyps are radially symmetrical, more or less cylindrical, and usually elongated along the axis of the body. The body comprises two layers separated by a layer of connecting tissue known as *mesoglea*. The base of the polyp may be attached either to a substrate by means of a disc-like holdfast if the polyp is solitary or connected to other polyps either directly or indirectly, if the polyp is part of a colony. The upper end of the polyp has an opening which acts as both mouth and anus, and is surrounded by a circlet of tentacles covered in stinging cells (cnidoblasts).



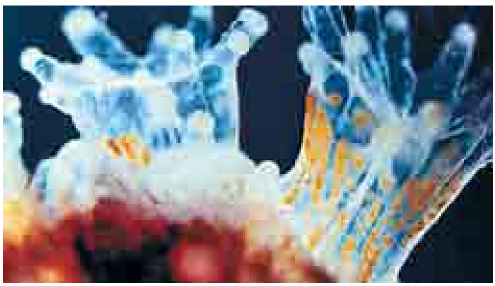
Nematocysts of polyps (after Steven Weinberg, graphic by Faratiana Ratsifandrihamanana)

STINGING CELLS

The name Cnidaria comes from the Greek word «cnidos», which means stinging nettle. Cnidaria have specialized cells – cnidoblasts – which contain stinging structures called *cnidae* or *nematocysts*, which shoot out barbed, twisted, threads containing toxins. The shooting of these nematocysts is one of the fastest known reactions in the animal kingdom, taking place in a few hundredths of a second. The twist in the thread causes the sting to drill into the tissue of the victim. The sting then breaks off, allowing the poison to do its lethal work. Jellyfish, 'fire corals' (*Millepora* spp.) and Portuguese Man-o-War *Physalia* spp. are the best-known stingers, although anemones and true corals will also discharge if you touch them even if you cannot feel it – one of the many reasons not to touch corals or anemones when diving is that you will force them unnecessarily to discharge their stings thereby wasting precious energy.

ZOOXANTHELLAE OR SYMBIOTIC ALGAE

Cnidaria are divided into two main groups – those that rely entirely on trapping prey to feed, and those that depend upon *symbiosis* with microscopic brown algae (zooxanthellae) living in their tissues. The symbiotic algae convert light into sugars and oxygen, about 95% of which 'leaks' out to feed the coral polyp. In return the zooxanthellae enjoy a protected, stable environment free from predators. The polyp may also contribute by catching plankton or other food particles in the water with the aid of its stinging cells, providing some additional nutrients (especially phosphorous and nitrogen) beneficial to both organisms. The polyps tend to be withdrawn during the day, and extended for feeding at night, or in



Zooxanthellae in polyps

conditions of low light. Some cnidarians are nearly completely dependent on zooxanthellae, while others trap prey but merely supplement their diet with sugars from zooxanthellae. Shallow reef building corals are highly dependent on symbiotic zooxanthellae; and can survive for only limited periods without their photosynthetic partners (as occurs in coral bleaching when the zooxanthellae leave the coral host).

Anthozoans

Reef building corals, Nosy Hara, Northern Madagascar

The most familiar cnidaria are the anthozoans (including corals that build tropical reefs, sea anemones, sea fans, and sea pens), which have a fossil record extending back at least 550 million years. The first known anthozoans were sea pen-like animals from the late Precambrian period. Later, in the Cambrian period, the first mineralized coral-like organisms appeared. The first coral reefs date from about 500 million years ago during the Cambrian period. True reef-building corals of the kind living today did not appear until the middle Triassic (251 to 199 million years ago), at about the same time as the first dinosaurs.

Corals are divided into two main groups – the 'soft' corals (which have tentacles in multiples of eight, also known as *octocorallians*) and the 'hard' corals (with tentacles in multiples of six, also known as *hexacorallians*). The inner body divisions reflect this difference in symmetry. There are exceptions to these general classifications – some octocorallians are actually hard and calcareous, such as the red organpipe coral *Tubipora musica*, while some hexacorallians are soft, such as the palythoans (*Palythoa* spp.). It should be noted that the so-called 'fire corals' (*Millepora* spp.) and 'blue corals' (*Heliopora* spp.), although having hard skeletons, are not true corals, but hydroids.

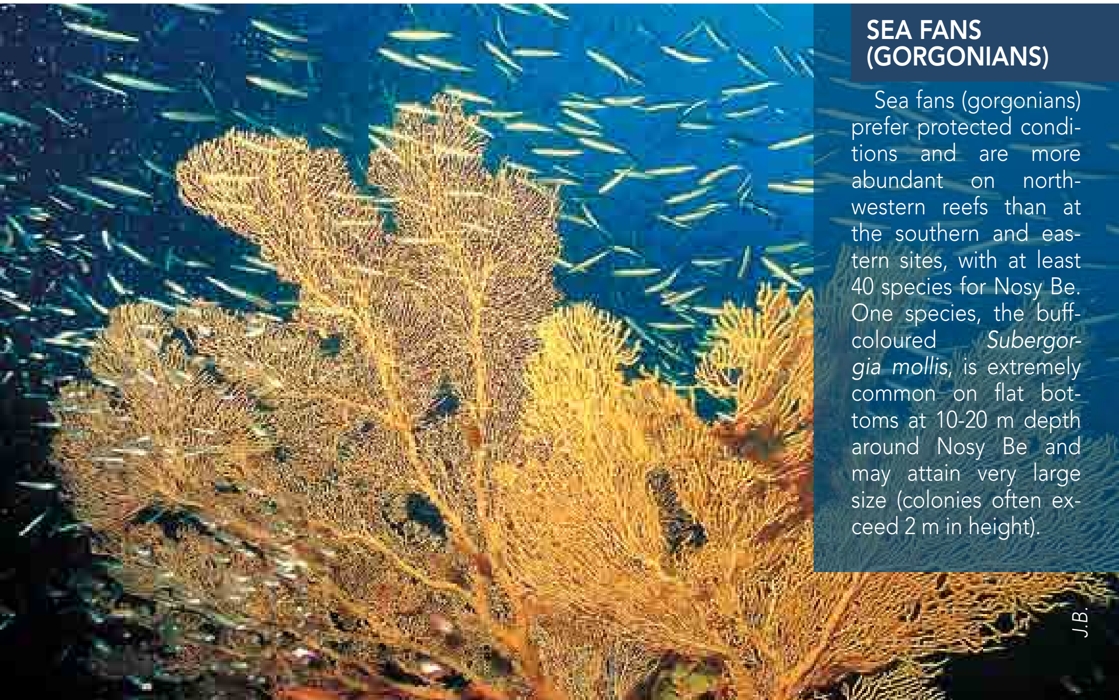
Sarcophyton sp. (soft coral)

SOFT CORALS

Soft corals include the sea fans (gorgonians), sea whips and alcyonarians (tree-like soft corals). Soft corals form an important part of the reef ecosystem, and they occur commonly in all reef habitats. Soft corals come in a wide variety of colony shapes (spreading, branching) and colours (pale or bright yellow, green, blue, red, orange and purple). Most soft corals contain zooxanthellae and are restricted to shallow waters (less than 100 m) but they also feed on plankton and detritus in the water, trapping food particles with their tentacles.

At least 300 species of soft corals have been described for the Western Indian Ocean. Approximately 222 species are known from the waters around Madagascar and neighbouring islands, most of which are common to the Indo-Pacific, with 62 considered endemic to the region. Soft corals are abundant on coral reefs, with at least 71 species for Toliara, and on rocky boulder substrate, as at Mananara-Nord.

Gorgonians (Subergorgiidea)



SEA FANS (GORGONIANS)

Sea fans (gorgonians) prefer protected conditions and are more abundant on northwestern reefs than at the southern and eastern sites, with at least 40 species for Nosy Be. One species, the buff-coloured *Subergorgia mollis*, is extremely common on flat bottoms at 10-20 m depth around Nosy Be and may attain very large size (colonies often exceed 2 m in height).

CORAL REPRODUCTION

Spawning coral (*Fungia* sp.)
(Photo: Blue Ventures Conservation)

Corals can reproduce asexuelly by budding, but most reproduce sexually at some point in their lives. Polyps can be male or female, but most are hermaphrodites, producing eggs and sperm. In sexual reproduction, males release sperm by the mouth which stimulates the females to release the eggs. During fertilization, the egg develops into a larva (planula), which floats freely for a few days or weeks before settling down on a suitable substrate. Often the larva carries a package of zooxanthellae (symbiotic algae) inherited from the female parent. *Goniopora* colonies are either all males or all females. The corals adopt two main strategies of reproduction. Mainly, coral polyps are «broadcasters» - they release sperm packets and eggs that fragment, followed by fertilization and larval development in the water column. On the Great Barrier Reef in Australia reproduction is synchronized precisely with lunar phases over a few nights each year, thus maximizing the chances of success and minimizing the rate of predation. Some reef-building corals (such as *Pocillopora* sp. and most species of deep water coral), are «brooders» - the sperm is released inside the polyp where fertilization of the egg and larval development occur. Sometimes packets of eggs or sperm can be observed in the mouth of the polyp and are usually pink or yellow in colour.

Rose coral *Montipora tuberculosum* (Acroporidae)

HARD CORALS

'Hard' corals are mostly colonial and *hermatypic* (that is they contain zooxanthellae in their tissues). The coral polyps excrete a hard, calcium carbonate (limestone) skeleton known as a *corallite*, which is fused

HARD CORAL DIVERSITY IN MADAGASCAR

Until the 1990s, only about 120 species of reef-building coral species (distributed between 62 genera) had been reported for Madagascar (based on research around Toliara), already placing it within a group of species-rich sites including Aldabra, Mauritius, Réunion, and Rodriguez. Surveys in the late 1990's indicated higher numbers of species at Masoala and Mananara in the north east, a region with less well developed coral reefs than Toliara, thus suggesting that the overall total would be much greater. In 2002, a rapid biodiversity assessment ('RAP') undertaken by Conservation International identified 323 species of hard coral for northwest Madagascar alone, more than doubling the number of species so far known for Madagascar and increasing by 30% the number of species known for the entire western Indian Ocean! Adding previously recorded species brought the total to 380 species, supporting the conclusion that "Madagascar has the highest recorded reef coral diversity of the Western Indian Ocean and the Red Sea". While no endemic genus is reported for Madagascar, *Horastrea* (Siderastreidae) is considered to be restricted to East Africa, Madagascar, and the Mascarenes. The same expedition identified at least seven new species to science and one new genus, which may include one or more species endemic to Madagascar or the sub-region (McKenna *et al*, 2003).

to its neighbours to form a continuous structure. Hard corals are the world's primary reef-building animals, and the Australian Great Barrier Reef is often referred to as the world's largest living structure. Hard corals reproduce both asexually, by splitting, and sexually, either by broadcasting or brooding.

BLACK CORALS

Black corals (antipatharians) are non-zooxanthellate corals that live by feeding on plankton in the water column. About 10 species are known for the western Indian Ocean, with at least eight species reported for Madagascar, from the reefs of Toliara, Nosy Be and Mananara. Often golden colored when living, they possess a hard, flexible, ebony-like skeleton that is used for making jewelry. Black corals prefer calm waters and are much more abundant in the northwest of Madagascar than in the more exposed coral reefs of the southwest and northeast coast. Both branching black corals (*Antipathes* sp.) and single-stranded spiral black corals (*Cirripathes* sp.) are abundant at below 10 m around Nosy Tanikely and Nosy Be.

Black corals (Antipatharians) **and their polyps**

CORAL COMMUNITIES

Coral communities can appear bewilderingly complex. The first thing to bear in mind is that on any one coral reef in Madagascar there may be as many as 100 species of corals, all competing for light, food and space. Tiny coral larvae float in their millions above the reef and settle wherever they can and start to grow. Only a tiny proportion of these develop into colonies, either because they are eaten by predators, or because conditions are unsuitable and they simply perish. Corals employ a range of techniques to compete with neighbours including emitting toxins, stinging, digesting, smothering or simply outgrowing their competitors. Coral aggression plays a major role in forging the coral community structure. Fishes may also influence the community structure - in shallow water damsel fish may kill corals to make space for their algal gardens, while on the reef slope triggerfish and parrotfish substantially reduce growth of some corals by grazing. To complicate the picture further, herbivorous fish may actually enhance coral growth by feeding on algae which would otherwise smother the coral.

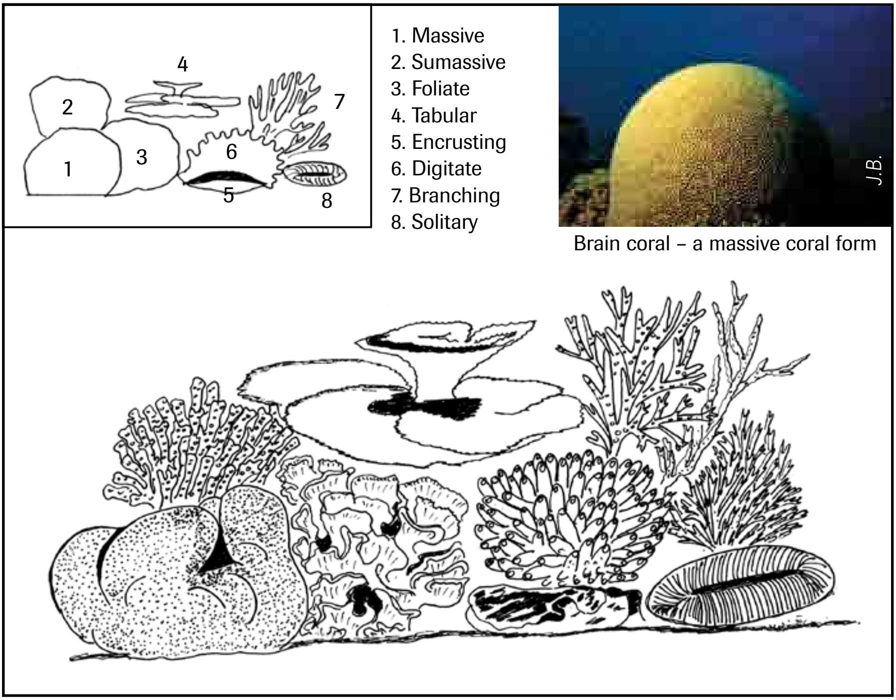
Coral community (Acroporidae, Pocilloporidae, Poritidae, Mussidae, Faviidae)

SPECIES DIVERSITY OF CORAL COMMUNITIES

The greatest diversity of corals is found in parts of the reef where conditions are suitable for the greatest number of coral species. Generally this is half way down the reef outer slope, where the swell is reduced but light intensity still high. Well flushed, shallow, lagoons also support rich coral communities. In extreme conditions, such as on the reef flat where waves break and corals are exposed at low tide, only a few species flourish. Conversely, at depth, the forms which survive are those which are efficient at extracting food from the water or which are adapted to low light conditions.

CORAL MORPHOLOGY

Corals on the reef occur in an astonishing variety of form and colour. Corals can be classified as encrusting, massive, submassive, columnar, digitate, branching or foliose (leaf-like). In areas of high wave action, robust or encrusting forms are favoured whereas in calm, well illuminated and well flushed waters, delicate fast growing branching forms (notably *Acropora* spp.) do best. Still lagoon waters favour the smooth dome-like colonies of *Porites* spp. and *Pavona* spp., well adapted to shedding the fine sediments that would clog other forms. *Porites* spp. are also adapted to tolerate wide ranges of temperature and salinity. Where the colonies are exposed at low tide, Porites colonies take on the form of 'micro-atolls' with a central pool.



Brain coral – a massive coral form

Different coral growth forms (Source: Richmond 2002)

Sea anemones (Actinians)

Sea anemones are solitary polyps. The mouth is surrounded by one or more rows of tentacles, covered with cnidoblasts, armed with poison-tipped nematocysts that function as a defence as well as a means to capture prey. The poison is a mix of toxins, including neurotoxins, which serve to paralyze and capture the prey, which is then moved by the tentacles to the mouth for digestion. Anemones have been reported as highly toxic to fish and to some crustaceans, which may be the natural prey of sea anemones. Clownfish that shelter among the tentacles of large anemones (of the family Amphiprioninae) protect themselves with a layer of mucus over their skin.

Anemone (Actiniidae)

Anemones tend to stay in the same spot unless conditions become unsuitable (prolonged tidal exposure during low spring tides, for example), or a predator is attacking them. In the case of an attack, anemones can release themselves from the substrate and swim slowly away to a new location using flexing motions. Certain anemones undergo bleaching during coral bleaching events, indicating the existence of a symbiosis with zooxanthellae similar to reef building corals.

Heteractis magnifica (Sticodactylidae)

Arthropods

The arthropods are a very diverse phylum of animals, including the spiders & scorpions, millipedes, centipedes, insects and crustaceans, characterised by segmented bodies and legs and an external jointed skeleton of chitin. In the marine environment, the crustaceans are by far the best represented group and are the only one treated in this guide.

Crustaceans (Crustacea)

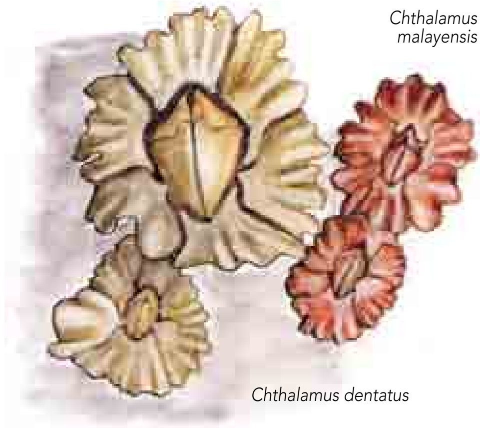
The crustaceans include barnacles, amphipods, sea lice, mantis shrimps, shrimps & prawns, lobsters, hermit crabs, true crabs and various lesser known groups. The majority of crustaceans are aquatic, living in either fresh water or marine environments, but a few groups have adapted to terrestrial life, such as terrestrial crabs, terrestrial hermit and coconut crabs and woodlice. Most crustaceans are covered by a jointed shell (exoskeleton) composed of a tough, flexible substance called chitin.

Rhynchocinetes durbanensis (Rhyncocinetidae)

In general the Crustacea are widely distributed, with few species particular to the western Indian Ocean. 779 species of crustacean have been reported from the coral reefs of Toliara, many of these being tiny, almost invisible, burrowing species found in sandy substrate that the typical observer is unlikely to see or even to look for. The total known for the western Indian Ocean is just 780 species, indicating that Madagascar's fauna is among the best studied.

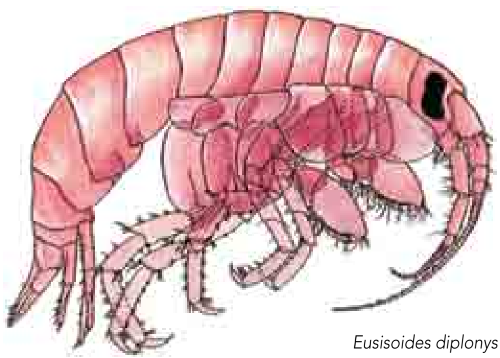
BARNACLES (CIRRIPEDIA)

Many people express surprise when told for the first time that barnacles are crustaceans, because of their limpet-like appearance. In fact, barnacles are sedentary crustaceans that use their modified brush-like limbs (*cirri*) to filter food from the surrounding water. About 1200 species are known worldwide but the barnacles of the Indian Ocean and Madagascar are virtually unstudied and the number of species is unknown.



Barnacles

There are two basic types of barnacle - stalked barnacles (Pedunculata) and acorn barnacles (Balanomorpha). Acorn barnacles are the more familiar type which encrust rocks, mangrove roots, the skin of whales and the shells of sea turtles.



Sea flea

AMPHIPODS

The Amphipods embrace a large number of tiny, flea-like crutaceans that abound in all marine environments. They are most familiar as the tiny crustaceans that attach themselves to swimmers in the surf and cause itching. However, they are abundant throughout the ecosystem and important as detritus feeders. Many species live in sponges, corals and other hosts. About 1000 species are known for the Indian Ocean region. Identification of most species requires a microscope and special expertise. Readers interested in amphipod identification should consult specialist works. The important point to retain is that amphipods exist in vast numbers and play an important role in all marine ecosystems.

Odontodactylus scyllarus

Mantis shrimp
(Odontodactylidae)

STOMATHOPODA (MANTIS SHRIMPS)

Among the most visually striking species of crustacean are the 'mantis shrimps', crustaceans which are neither shrimps nor mantids, but physically resemble both the praying mantis and the shrimp. Mantis shrimps are predatory crustaceans that live in the shallow waters of tropical and subtropical seas, growing to around 30 cm long. Called "sea locusts" by the ancient Assyrians, mantis shrimp have powerful claws, formed like jackknives, which they use to attack and kill prey by spearing, stunning or dismemberment. Some pet mantis shrimps have managed to break through their double-paned aquarium glass with a single strike from their claws!

Mantis shrimps are used as a measure of the health of coral reefs, as their abundance, diversity and recruitment are very negatively correlated with concentrations of petroleum hydrocarbons and certain heavy metals in

MANTIS SHRIMP EYES

Mantis shrimps have a sophisticated visual system, enabling them to capture prey effectively. The mantis shrimp eyes contain 16 different types of photoreceptors (12 for colour analysis, compared to only three in the human eye). Mantis shrimps can see polarized light and 4 colours of ultraviolet light, and they may also be able to distinguish up to 100,000 colours (compared to the 10,000 seen by human beings).

Mantis shrimp (Odontodactylidae)

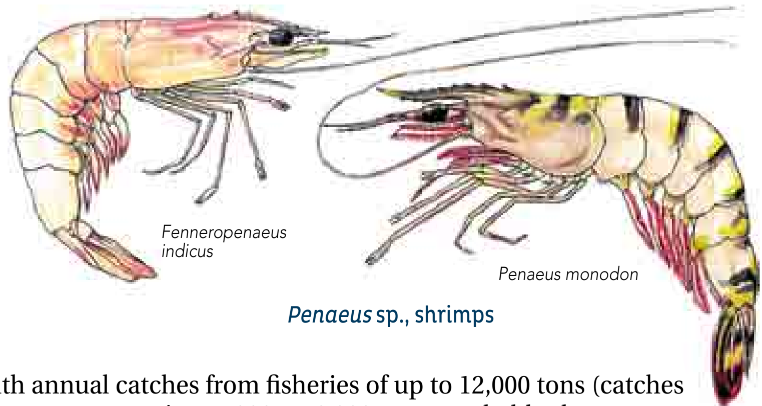
sediments, and with sewage and agrochemical run-off contamination. They are most likely to be seen in the more pristine coral lagoons.

In Madagascar, the colourful *Odontodactylarus scyllarus* is commonly seen in shallow coral lagoons, for example at Masoala and at Nosy Be, where the distinctive purple-barred *Lysosquilla maculata* also occurs. Three species are reported from around Anakao (*L. maculata*, *O. scyllarus*, and *Gonodactylus smithii*).

DECAPODS (MACROURA)

The decapods are a large order of Crustaceans which includes prawns, shrimps, lobsters, mudlobsters, hermit crabs and the true crabs. As the name suggests, their common feature is to have 10 legs (*deca* = ten, *podos* = leg or foot).

Shrimps (Penaeidae)



Penaeus sp., shrimps

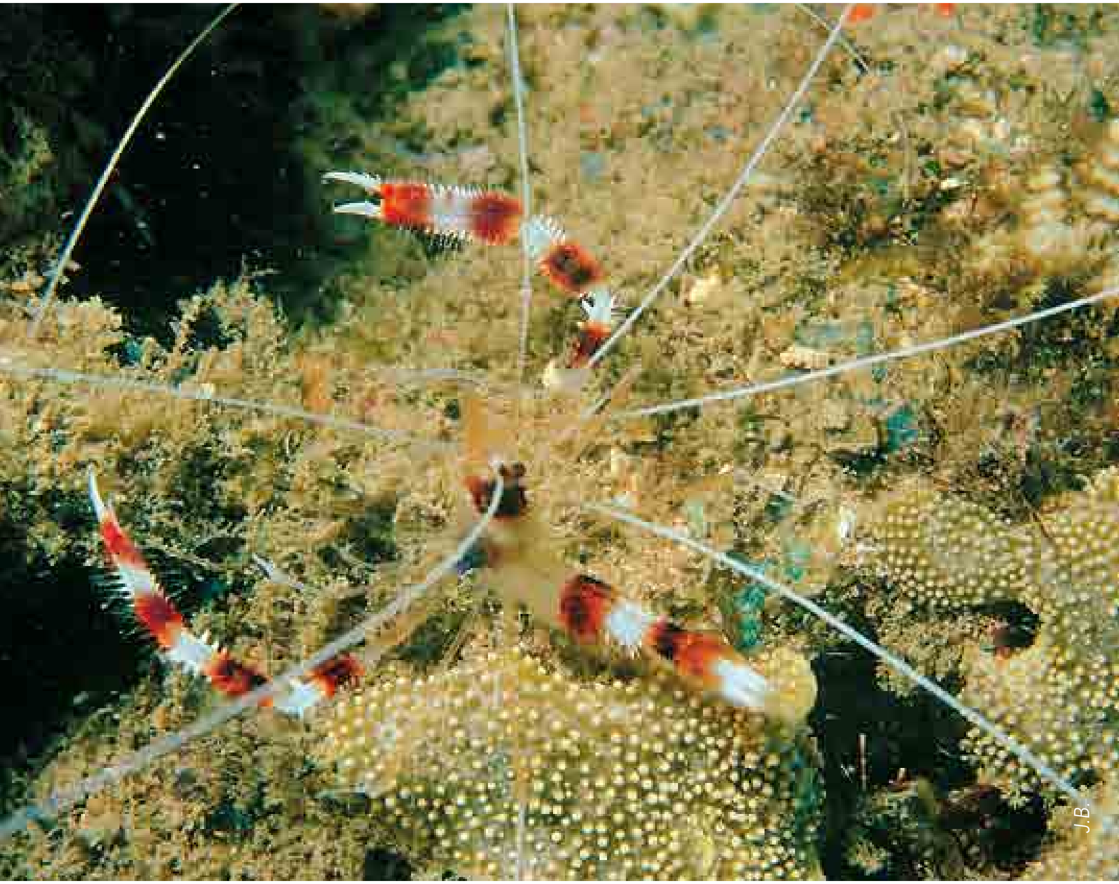
Penaeidae is a family of prawns containing many species of economic importance. Penaeid prawns (often known as penaeid shrimps) constitute Madagascar's single most important fisheries export, with annual catches from fisheries of up to 12,000 tons (catches have declined in recent years to just 5,000 or 6,000 tons, probably due to ecosystem damage by trawling) and about 5,000 tons from shrimp farms. The major wild species are *Penaeus indicus* (white prawn, which makes up about 70% of the catch in most years), *Metapenaeus monoceros* (pink prawn, about 20%), *P. semisulcatus* (brown prawn, about 10%), and *P. monodon* (tiger prawn, < 5%). *P. indicus*, the white prawn, is a daytime species, while the others are more abundant in night-time hauls. *P. monodon*, the tiger prawn, is the preferred species in shrimp farming.

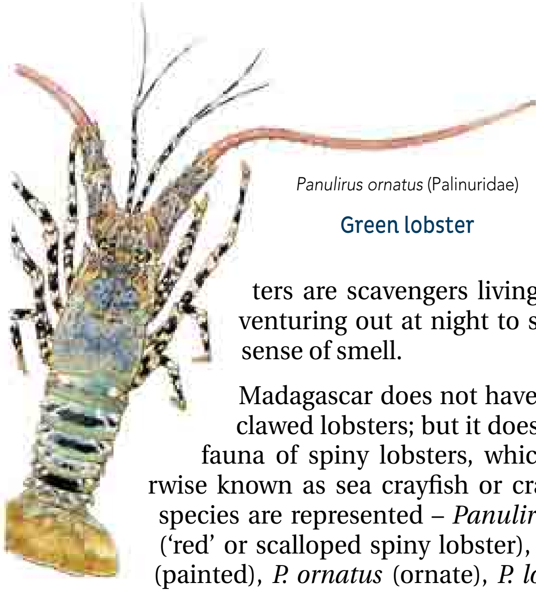
Penaeid prawns share a common life cycle in which juveniles enter estuaries to support the fastest growth phase before returning to deeper water to breed as adults. Captures are generally higher opposite mangrove areas, and at periods of peak river flow, when the stocks are swept seawards. Recent mark-recapture experiments on *Penaeus indicus* and *Penaeus monoceros* show that prawns have an average foraging range of about 10 km on the west coast (maximum of 100 km) while average range on the east coast is only 4 km (maximum 40 km). Adult females grow faster than males.

Prawn reproduction and recruitment into the population appears to occur year-round for at least some of the species, with reproductive peaks at the beginning and especially at the end of the dry season. Larval growth and settlement proceeds in October and November and is essentially completed by the beginning of December. The closed season for prawn fisheries in Madagascar runs from November to January, which corresponds to the rapid growth period of newly-settled juvenile prawns.

Less information is available on the many, often cryptic, shrimp (*Caridea*) species found on coral reefs or in seagrasses. Several shrimps live in close 'mutualistic' association with other organisms, such as the ubiquitous, orange and white, banded cleaner shrimp *Stenopus hispidus* (which picks parasites off fish), the distinctive red and white anemone shrimp *Periclimenes* cf. *brevicarpalis*, the purplish *P. imperator* (found on nudibranchs or echinoderms) and *Saron* sp. living in corals or amongst the spines of urchins.

Stenopus hispidus (Stenopodidae) – Banded cleaner shrimp





Panulirus ornatus (Palinuridae)

Green lobster

Lobsters

Lobsters are crustaceans of the infraorder Palinura, which include the true lobsters, spiny lobsters, furry lobsters and the slipper lobsters (*cigale de mer*). The infraorder Thalassinidae includes the mud lobsters. Lobsters are scavengers living in crevices of rock and coral reefs, venturing out at night to seek food using their well-developed sense of smell.

Madagascar does not have true, large-clawed lobsters; but it does have a rich fauna of spiny lobsters, which are otherwise known as sea crayfish or crawfish. Five species are represented – *Panulirus homarus* ('red' or scalloped spiny lobster), *P. versicolor* (painted), *P. ornatus* (ornate), *P. longipes longipes* (long-legged), and *P. penicillatus* (pronghorn). The principal species represented in fisheries are the red or scalloped spiny lobster *P. homarus*, mainly fished in the south and southeast from rocky habitats, and the painted spiny lobster *P. versicolor*, from the northwest and northeast, preferring coral reef habitats. It is only in the southeast that the density of lobsters is sufficient to support organized fisheries. In coral reef areas lobsters are widespread but nowhere sufficiently abundant to support an export industry.

The slipper lobsters (Scyllaridae), known locally as *cigale de mer*, are a common catch, especially *Scyllarides squamosus* (blunt locust lobster) around Nosy Be. Slipper lobsters are readily recognized by the flattened antennae which project forward from the head, looking like wide plates. Mud lobsters of the genus *Callichurus* are common on sandy bottoms south of Tanikely at Nosy Be, generally only detectable by the mounds of sand left above their burrows, as they search through the grains of sand for edible organic matter.

A NEW GIANT LOBSTER SPECIES FROM THE MADAGASCAR RIDGE

From the Walters Shoals, a submerged chain of underwater mountains stretching southwards from Madagascar, comes a new and unknown species of Giant Lobster. The new 18 kg rock lobster was recently caught by a deep-water fishing vessel. Named *Palinurus barbarae*, the lobster is half a metre long and could be up to 50 years old!

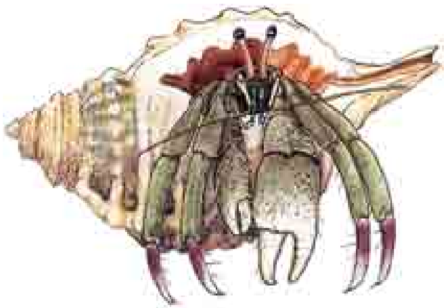
Hermit crabs

Hermit crabs are part of the order Anomura which also includes mole crabs, squat lobsters and porcelain crabs. Anomura are not closely related to true crabs but are allied to crawfish and slipper lobsters. Hermit crabs include some terrestrial species and a large number of marine species.

HERMIT CRAB DIVERSITY IN SOUTH WEST MADAGASCAR

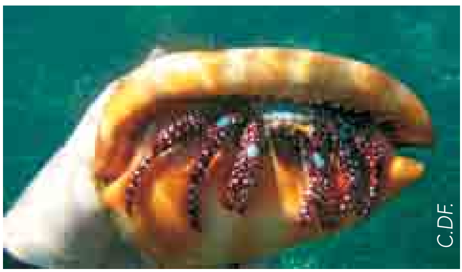
Over 20 species of hermit crabs have been reported from around Anakao, south west Madagascar. The most abundant species are *Calcinus latens* and *Clibanarius striolatus* which make up almost half of all inter-tidal hermit crabs. Some species are highly abundant in particular habitats (e.g., *Diogenes gardinieri* and *Clibanarius longitarsus* in sea grass beds), whilst others show similar abundance in most habitats (e.g. *Calcinus latens* and *Clibanarius striolatus*). Hermit crab biomass is highest on coral reefs, primarily because of the prevalence of members of the genus *Dardanus*, amongst which are some of the largest hermit crabs. After coral reefs, the highest hermit biomass is found in mangrove marshes. The more abundant species exhibit clustering behavior, apparently an adaptation to facilitate shell-exchange and to reduce desiccation. Hermits are among the few non-human species to have their own real-estate market!

Hermit crab



Calcinus latens

With the exception of the very large terrestrial coconut crab *Birgus latro*, all hermit crabs share the practice of using a gastropod shell for protection of their soft abdomen. As the hermit crab grows, it seeks a larger shell. The scarcity of vacant shells means that there is often stiff competition for shells. In most species the abdomen is coiled in the same direction (dextrally) as most gastropod shells and has specialized pads to hold it tightly in place and a set of muscles which enable the hermit crab to jerk quickly back into the safety of its shell if danger threatens. The right front claw is much larger than the one on the left, and is used as a door to its shell as well as a weapon and for shredding food.



Hermit crab in red helmet shell

True crabs (Brachyura)

About 350 species of true crabs have been described for Madagascar, the most for any western Indian Ocean country. True crabs have a flattened body, with the rest of the abdomen reduced and folded under the main shell. True crabs include small and inconspicuous crabs, such as the primitive sponge crabs (which have living sponges growing on their hairy backs), tiny pea crabs which live closely (commensally) with sea urchins, spider crabs (which have small triangular bodies and long slender legs), fiddler crabs and much larger species such as the widely eaten mangrove crab *Scylla serrata*.

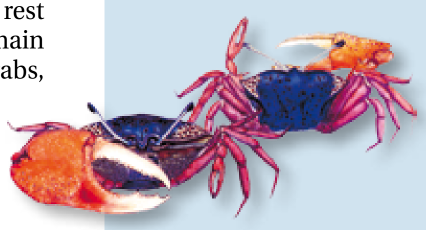
Mangrove crab

Madagascar's mangroves provide 3200 km^2 of suitable habitat for the edible mangrove crab *Scylla serrata*. In their most common form, the crab shell color varies from a deep, mottled green to very dark brown, and crabs may grow to have a shell width of 24 cm and a weight of 3.5 kg. Mangrove crabs are highly cannibalistic in nature and when another crab undergoes molting

Mangrove crab

those still with hard shells attack the molting crabs and devour them. The females can give birth to 1 million larvae, which are a major source of food for juvenile fish. Mangrove crabs play a vital ecological role in mangroves, by burying and consuming leaf litter and by helping to aerate the dark, oxygen starved soils of mangroves. Crab burrows may be up to 5 m deep. It has been found that removing mangrove crabs from an area negatively affects the growth of the mangrove trees.

FIDDLER CRABS AND SAND BALLS



Uca tetragonon

Fiddler crabs, so called because the males have one extremely large front claw resembling a violin, live in small burrows in the sand or mud, in the inter-tidal zone. During high tide, the entrances of the burrows are covered with sand; but the burrows contain a bubble of air which helps maintain a high oxygen concentration in the water of the burrow. When the tide ebbs, the fiddler crabs emerge and scurry about, collecting food in the drift lines left by the ebbing water. Both claws of the female and the smaller claw of the male are used to scoop up sand and pass the grains to the mouth. Specialized hairs on their legs are used to scrape organic matter from the sand grains. The sand grains are then rejected in the form of small sand balls.

Molluscs

The molluscs (from *mollis* (Lat) meaning 'soft') are a large and diverse phylum of animals including chitons, gastropods (abalone, limpets, snails, sea slugs, sea hares etc.), bivalves (clams, mussels, oysters etc.) and cephalopods (nautilus, squids, cuttlefish & octopus) and some more obscure deep sea groups. The cephalopods have highly developed vision and are some of the most intelligent invertebrate animals. The vast majority of molluscs live in marine environments. However, two groups, the bivalves and the gastropods, also contain freshwater species, and the gastropods have representatives that live on land and breathe air (snails and slugs).

Molluscs have a soft, unsegmented body with a blood-filled cavity and gut, a head (often with eyes & tentacles), a muscular foot and a body mass. The body mass is often surrounded by a thin, fleshy *mantle* which covers the gills and is responsible for secreting the external shell. Most molluscs have a specialised feeding structure

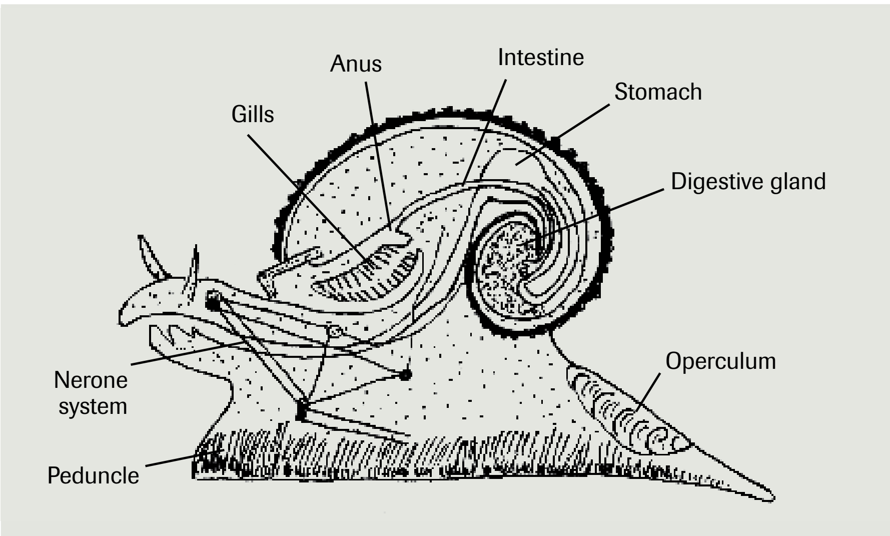
Giant clam *Tridacna maxima*

called the *radula* made of chitin which occurs in various forms. In gastropods the radula is used to scrape algae off rocks whereas in the cephalopods the radula has developed into tough beak. The radula is absent in the bivalves which are filter feeders.

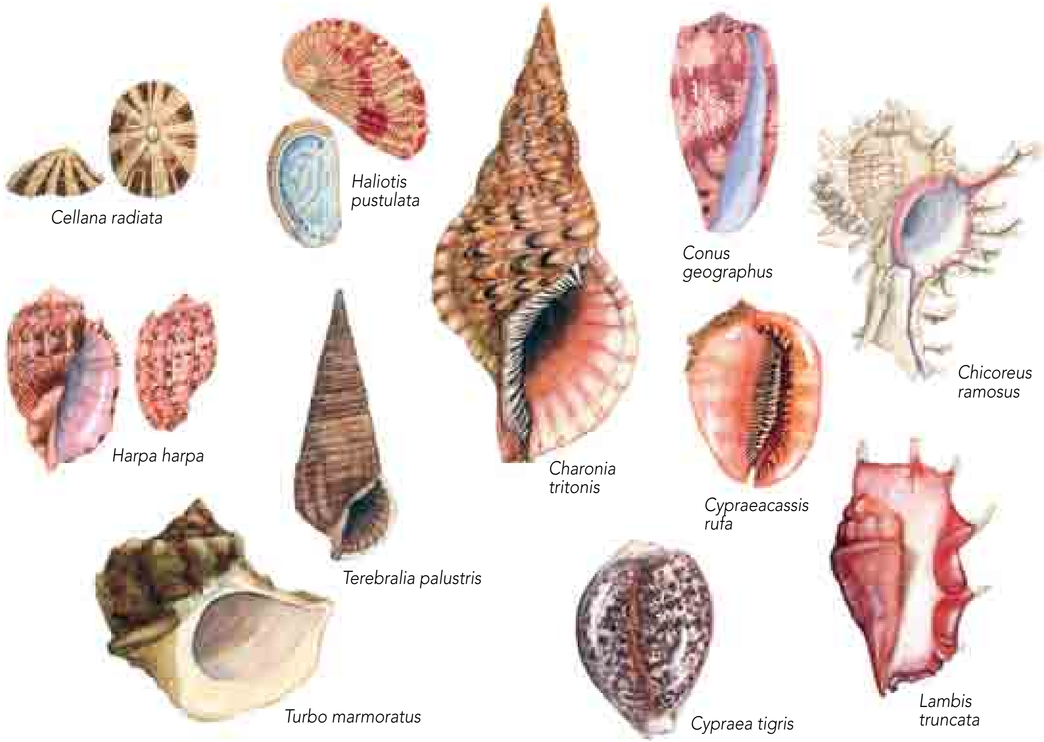
About 100,000 mollusc species are known worldwide. About 1500 species of mollusc have been described as occurring in Madagascar waters, which may be compared with a minimum of 3646 species for the western Indian Ocean as a whole. There has been relatively little research in the Indian Ocean or Madagascar and the number of species in the region is likely to be much higher than this.

Gastropods

The gastropods are a highly diverse group of molluscs with 60,000 - 75,000 known living species worldwide, including terrestrial and marine species. Gastropods include the snails and slugs on land and many of the most familiar marine species including abalone, limpets, whelks, conches, cowries, helmet shells, tritons and sea slugs. Most gastropods have hard external shells (these are grouped into the sub-class Prosobranchia indicating that their gills are covered). In some the shell is reduced or entirely absent (the Opisthobranchia or sea slugs whose gills are exposed). Gastropods may be herbivores (such as abalone), detritus feeders (the majority of species) or active carnivores (such as tritons) and they play an important regulatory role in marine ecosystems such as coral reefs, sea grass beds and mangroves.



Anatomy of gastropod prosobranch



Various gastropod shells (Source: Richmond 2002)

GASTROPOD SHELLS

The gastropod shell occurs in an astonishing variety of form and colour. In all gastropods the shell is secreted by the mantle. The shell is made of calcium carbonate and a protein matrix, giving it great strength. With the exception of the limpets, which have conical shells, gastropod shells are spirals. In most species the spiral is right-handed (dextral) while a small minority of species have left-handed (sinistral) shells. Most species have a closing device or *operculum* of chitin (which may be calcified in some species) that operates as a trapdoor to close the shell and protect the soft tissues of its occupant.

Most of the larger gastropods are edible and are collected for food. Large piles of empty shells, or *middens*, are a common site at fish landing sites and on islands used by fishers. Massive gastropod shells, such as the green turban *Turbo marmorata* are exploited for the manufacture of buttons and mother-of-pearl while others, such as cowries, helmet shells and cone shells, have a high value as ornamental curios. Close to population centres such as Toliara the large and ornamental gastropod species have become very rare.

ORNAMENTAL SHELLS

Madagascar's coral reefs have long been exploited for their ornamental shells. Today, with increasing tourism the demand for ornamental shells as curios has risen further. The most decorative shells come from the larger gastropods. These animals play an important role in the balance of life on the reef, as grazers on algae and as scavengers. Other gastropods are predators, feeding on invertebrates – often just the juveniles but the larger the gastropod the larger the prey. The large tritons with their beautiful shells are the only predator of the destructive, coral-eating, crown-of-thorns starfish *Acanthaster plancii*, limiting their aggressive destruction of the reefs. Helmet shells such as the horned helmet *Cassis cornuta* and the bull-mouth helmet *Cypraecassis rufa* feed on sea urchins, which graze on algae growing on soft corals. Empty gastropod shells provide homes for hermit crabs which are also grazers and scavengers. Collecting or buying shells therefore directly harms the coral reef ecosystem.

In 1993, 82 species of gastropods were reported to be traded in the Toliara ornamental shell markets. By 1997, the number of shell species had apparently risen to 138 species. Among the rarer and more valuable species traded are giant spider conch *(Lambis truncata)*, the Mauritius cowrie *(Cypraea mauritiana)*, helmet shells *(Cassis cornuta, Cypraecassis rufa)*, giant triton *(Charonia tritonis)*, tun shells *(Tonna canaliculata)*, and various cone shells (*Conus* spp.). The purchase of ornamental shells is strongly discouraged by conservation organisations and scientists.

COWRIES

Cowries are distinctive gastropods with glossy, attractively marked rounded or oval shells. In living animals, the shell is covered by two folds of a colourful, patterned, mantle. Cowries are highly prized as ornamental shells and the smaller cowries have traditionally been used as a form of money by coastal communities. The larger, ornamental, cowries, such as the tiger cowrie *Cypraea tigris*, graze on algae among rubble in shallow parts of the coral reef, making them especially vulnerable to collection. The blue Money cowrie *Cypraea moneta* lives in seagrass beds, where it feeds on algae attached to the leaf blades and may reach high densities (as many as 50 individuals per square metre or more).

Cowrie (Cypraeidea)

Phyllidia varicosa (Phyllidiidae)

Phidiana indica (Facelinidae)

SEA SLUGS (OPISTHOBRANCHIA)

Sea slugs are gastropods with reduced or absent shell and exposed dorsal gills, giving rise to their common name, 'nudibranchs' which means 'naked gills'. Gills are usually in the form of feathery plumes but are absent in a few species in which respiration may take place directly through the skin (such as in the common *Phyllidia varicosa*). Many species are flamboyantly coloured while others are camouflaged, matching the corals and seaweeds of their habitat. Primitive sea slugs are active predators but most species are herbivores. Many have distinct dietary preferences and regularly occur in association with certain species of algae or corals. Sea slugs lay fertilised eggs in ribbons on the reef, which may also be brightly coloured.

About 400 species of sea slugs are known from the Indian Ocean. A total of 175 species of nudibranch have been identified in recent years from Ile Ste Marie, Toliara, Tolagnaro and Nosy Be, resulting in a number of species new to science.

Bivalves

Bivalve molluscs have paired shells, dorsally hinged. The best known bivalves are the edible clams, oysters and mussels. Some bivalves attach themselves to surfaces such as rocks (by means of organic cement or chitinous fibres) while others bury themselves in sand or mud and typically have a strong digging foot. Some bivalves can swim by opening and closing their shells, notably the scallops, which also have well developed vision through thousands of photoreceptors along the mantle edge. Most bivalves feed by siphoning and filtering detritus and plankton from the water column and are an important component of the marine ecosystem.

Giant clam (Tridacna maxima)

SAROBOKA (FR. PALOURDE) *(Anadara antiquata)*

At low tide all around Madagascar on beaches and particularly on mud flats, people search for small, clam-like bivalves, known as *saroboka*, which are probably *Anadara antiquata*. These small bivalves have robust, white ribbed shells, and commonly burrow into muddy sand in the inter-tidal zone. *Anadara antiquata* is widespread throughout the Indo-Pacific region and has five other closely related species. All *Anadara* are important food resources to coastal people and are potential candidates for mariculture.

Cephalopods

The cephalopods include the nautilus, squids and cuttlefish. They are the living relatives of the extinct ammonites which were abundant in the world's oceans in Jurassic and Cretaceous times and which are commonly found as fossils in western Madagascar. The name cephalopod means 'head-foot', and all the members have a large head with eight or more suckered tentacles. All species are exclusively marine. Cephalopods are the most advanced molluscs with well developed eyes, nervous system and a large brain. Cephalopods are active predators which catch prey with their tentacles and which have a strong, central mouth with a parrot-like beak adapted for biting. Cephalopods are able to move by expelling water through a modified foot-funnel and most also discharge ink when alarmed. The ink of cuttlefish (*Sepia* spp.) was particularly prized for dyeing purposes before synthetic

Octopus macropus (Octopodidae)

Cuttlefish *Sepia* sp.

equivalents became available. Cephalopod inks are still used in cuisine.

About 800 species of cephalopod are known worldwide, with just 20 so far reported in the western Indian Ocean. Malagasy cephalopods have not been systematically studied but are nevertheless very important in fisheries. Around Toliara, the common octopus species are *Octopus cyanea*, *O. aegina*, and, less common, *O. macropus*. Pelagic or open water squid (*Loligo* spp.) are also a very important food resource around Toliara, while at Nosy Be the big-fin reef squid (*Sepiatheulis lessoniana*) is the most important species. Cuttlefish (*Sepia* spp.) feature less in fisheries – *S. zanzibarica* is common on sandy bottoms around Nosy Be. According to the published literature nautilus (*Nautilus pompilius*) is distributed from the northeastern Indian Ocean to the central Pacific and is therefore probably absent from Malagasy waters. The Spirula or ram's horn shell *Spirula spirula*, superficially similar to nautilus, is a small deep water squid-like species with a buoyant, chambered, shell. Empty spirula shells are abundant on beaches north of Fort Dauphin.

Echinoderms

The echinoderms (from *echinos* (Gr) = spine and *dermos* (Gr) = skin) are an exclusively marine phylum of animals that first emerged in the early Cambrian and include the starfish, sea urchins, sea cucumbers, brittlestars and crinoids (sea lilies). Echinoderms are distributed throughout the world's oceans at all depths. The echinoderms share the common feature of having a bilaterally symmetrical larva but which develops into an adult with pentameral (five-sided) symmetry. Secondary bilateral symmetry may return in the adult form, such as in the sand dollars (flattened, mobile sea urchins). The bilateral symmetry of the larva is a clue to their common ancestry with chordates, including the vertebrates.

Echinoderms share the common features of an external skeleton of calcified plates or spines and a hydraulic vascular system with a network of canals linked to *tube feet*

Urchins, brittlestars and sea cucumbers

– small, fluid-filled projections which assist with locomotion. Echinoderms have a nerve net but no brain. Some echinoderms, such as the starfish, have remarkable powers of regeneration – a single limb will re-grow into a fully five-sided adult.

With an estimated 7000 echinoderm species worldwide, about 1300 species are known from near-shore and shallow waters of the Indo-Pacific. A recent review indicates 419 species for the western Indian Ocean, of which 373 are distributed in East Africa and Madagascar, with considerable regional endemism (81 species restricted to this zone). There is a strong global correlation between coastline length and number of species. Madagascar, with over 5000 km of variable of coastline, may therefore be expected to have a high diversity of echinoderms relative to other western Indian Ocean countries.

Certain echinoderms, notably the sea cucumbers and, to a lesser extent, the edible sea urchins, are of considerable economic value. Sea cucumbers are an important export product for Madagascar. One of the starfish, the crown-of-thorns *Acanthaster plancii*, is famously destructive of coral reefs and occurs in Madagascar. The majority of echinoderms are economically neutral but undoubtedly play important roles in the marine ecosystem as carnivores and detritus feeders.

Choriaster granulatus (Oreasteridae)

Starfish (Asteroidea)

Linckia **sp.** (Asteridae)

Starfish or seastars, which include the bulbous cushion stars, usually have five arms radiating from a central disc-like body. The mouth of the starfish is located on the underside of the disc-body and the anus on the upper side. They have an internal skeleton made up of a variety of connected plates which have spines and may be covered in thick skin. Tube feet, often with a sucker at the tip, are present in a furrow along the underside of the starfish arms. The tube feet are used to move the starfish along a surface, and the suckers to attach onto rocks or to catch prey. Starfish living on soft surfaces, such as sand, do not have suckers, and use their longer tube feet instead, to dig into the sand or other soft surface.

Most sea stars are carnivores and feed on gastropods, barnacles, sea anemones,

THE CROWN-OF-THORNS STARFISH *(Acanthaster plancii)*

The crown-of-thorns (COT) is a red-coloured starfish covered in sharp thorn-like venomous spines. Growing to a diameter of up to 40 cm and having 12 to 19 arms extending from the centre, the crown-of-thorns starfish is a voracious predator of living coral. The starfish climbs onto the coral, extrudes its stomach over the coral and releases enzymes to digest the coral tissues which are then absorbed before the stomach is retracted. Crown-of-thorn starfish feed alone at night, maintaining a constant distance between themselves and other crown-of-thorns starfish and are reported to be able to live on their own energy reserves for over six months during times of food shortage (e.g. during a coral bleaching event).

The crown-of-thorns is widespread but uncommon on Malagasy reefs. Outbreaks have been reported at Nosy Ve (Toliara) and Nosy Tanikely where local dive clubs and NGOs have organised removal campaigns by volunteers. The causes of such outbreaks are unknown, but are probably related to the effects of fishing and habitat degradation, including the reduced abundance of the crown-of-thorns only predator, the Giant triton *Charonia tritonis*.

sea snails, sea urchins, bivalves, crabs, dead fish and other sea stars. Instead of ingesting food through the mouth, starfish extrude their stomachs and digest their prey externally, drawing the stomach back into the body when digestion is complete.

Approximately 58 species of starfish are known from the western Indian Ocean, but the starfish fauna of Madagascar has been little studied and only 25 species have been reported so far.

Sea urchins (Echinoidea)

Sea urchins are spherical or round and flattened echinoderms with movable spines covering the body. They include the familiar sea urchins ('regular' urchins) and the sand dollars, shield urchins, sea-egg urchins and heart urchins ("irregular urchins") which are variously flattened and which depart from the fully circular shape of regular urchins. A notable feature of the regular urchins is the "Aristotle's lantern" or a box-like arrangement of calcareous plates inside the mouth which acts as a grinding mechanism to scrape and chew algae on which the urchins graze. The lantern is absent in most 'irregular' urchins.

In the regular urchins, the body wall is a calcareous shell with studs to which the movable spines are attached. The spines may be long and sharp as in the needle spine urchin *Diadema setosum* (one of the most common coral reef urchins in Madagascar) or massive, finger-like, coloured and patterned as in certain families. The spines are also used as levers, aiding in locomotion and may be used to dig burrows in hard rock.

Sea urchins feed on all kinds of plant and animal material; some eat sand or mud, digesting out organic material that is present. The mainly black needle urchins (*Diadema savignyi* and *Diadema setosum*) play an important role in the coral reef ecosystem by grazing algae. The noise of urchin grinding can be almost deafening when diving at dawn and dusk. Reef urchins are predated upon by triggerfish (Balistidae) and overfishing

Echinometra mathaei (Echinometridae) may be a factor in urchin population explosions, which may reduce parts of a reef to bare pavement without live coral.

Red urchin *Astropyga radiata*

Sixty-two echinoids are known for the western Indian Ocean, and about 30 species from Madagascar. 14 species have been reported from Toliara, and 14 for Nosy Be. Apart from the needle urchins, other urchin species commonly encountered in Madagascar include the red pencil urchin *Heterocentrotus mammilatus* which is common on tidally exposed reef flats and the edible urchin *Tripneustes gratilla* which dominates sea grass beds, typically festooned with sea grass leaves which serve as camouflage. The spectacular and venomous red urchin *Astropyga radiata* is common in shallow lagoons at Masoala and is likely to occur in other reefs areas. The edible urchin is exploited for its orange coloured roe which is sometimes served in restaurants and from which the vezo fishing people of the south west make a strong tasting cake.

Aggregation of ***Echinometra mathaei*** (Echinometridae)

Sea cucumbers (Holothuroidea)

Sea cucumbers (*dinga dingana* in Malagasy; *bêche de mer* in French) have an elongated body and leathery skin. Like all echinoderms, sea cucumbers have an endoskeleton of bony plates just below the skin. Sea cucumbers are generally scavengers, living on the sea floor feeding on decaying organic matter taken through the tentacles around the mouth. Some species position themselves in a current to catch food with their tentacles. Sea cucumbers "breathe" by drawing water through a pair of 'lungs' or respiratory 'trees' just inside their anus. Sea cucumbers play a major role in the marine ecosystem and are the most abundant macrofauna in the deep oceans.

Holothuria sp., *Bohadschia* sp. and *Stichopus* sp.

Sea cucumbers are collected from around the coast of Madagascar, dried and exported to the Far East where they are considered a delicacy. They are also highly valued for supposed medicinal properties. The flesh is cleaned in a process that takes several days, when it becomes known as *trépang* and is used in soups, stews and braised dishes due to its gelatinous texture.

About 1200 species of sea cucumbers are known worldwide. About 150 species have been reported from the Indian Ocean. 122 species have been described from Madagascar, including 47 new species described from specimens collected at Toliara, Nosy Be and various other sites. About

Thelenota ananas (Stichopodidae)

DEFENSIVE EVISCERATION

Sea cucumbers of the Aspidochirotid order, which include many of the most common coral reef species, have the peculiar adaptation of expelling sticky threads when disturbed. The threads may serve to entangle predators. The threads are part of the respiratory tree inside the animal. In extreme cases the sea cucumber will expel other internal organs.

40 are known from the waters around Nosy Be and at least 28 species of sea cucumber are known to occur in shallow water habitats of the Toliara region, of which 25 are harvested for commercial sale. Further north, off the Radama Islands, 19 species are exploited. So far, 11 species are known from Masoala and 11 species from Mananara. Most of the species harvested for commercial sale occur widely all along Madagascar's coast, but in the regions where the coastline is varied and offers different habitats, unique species occur which have limited distribution.

Featherstars (Crinoids)

Featherstars (also known as sea lilies) are surviving members of primitive echinoderms, the Crinoids, which were very abundant in the seas of the Palaeozoic (350 million years ago). The basic body plan includes a stem, the calyx (the body disk) and the arms. The living crinoids comprise the «foot crinoids» with five feet, always fixed by peduncle to a hard or movable substrate and the free-living comatules which live by attaching themselves temporarily to a substrate and opening their arms to filter food from the passing currents.

It has been reported that 24 species of featherstars are known from waters around Madagascar although since the published literature reports just 19 species for the western Indian Ocean as a whole this figure may be doubted. Nine species have been reported from Nosy Be and three species are known from near Toliara. Several species have been noted at Mananara although only one *(Antedon parviflora)* has been identified.


Free-living crinoid (comatule)

J.B.

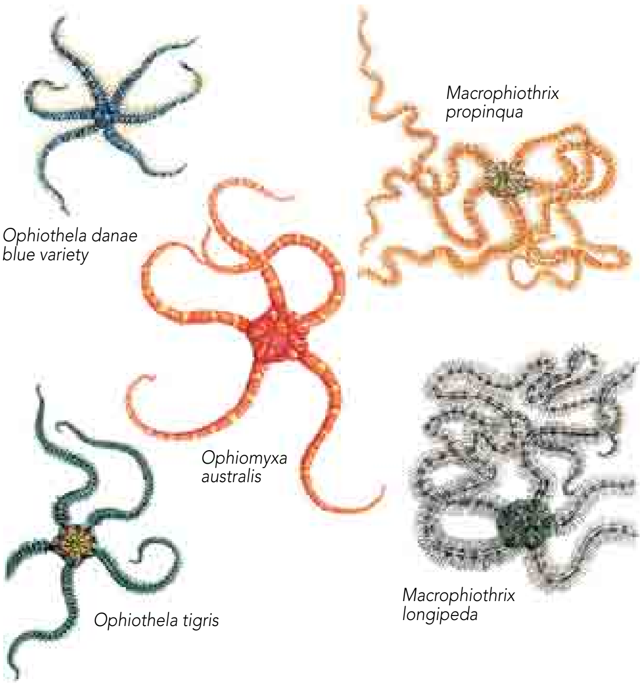
Brittlestars & Basketstars (Ophiuroidea)

Brittlestars and basketstars are delicately constructed echinoderms similar to seastars with a disk-like central body. Brittle stars have five slender arms while basket stars have numerous highly branched arms. Brittle stars are diverse and abundant at all depths whereas basket stars occur mostly at depth or are nocturnal and many fewer species are known. Brittlestars and basket stars are scavengers or detritus feeders.

Brittlestars are so called due to their habit of breaking off arms as a means of defence; new arms are easily regenerated. Brittlestars can be distinguished from starfish by their rounded central disk, sharply set off from the arms. They have tube feet common to all echinoderms but, unlike starfish, brittlestars lack open grooves on the lower surface of the arms and, also unlike starfish, brittlestars walk with their arms, only some species using the tube feet for locomotion. They are able to move quickly and in any direction.

Brittlestars are inconspicuous and often nocturnal, living under rocks, among seaweed, or buried in the sand. They may be easily found under stones in sandy tidal pools or in seagrass beds, where they may be present in very high densities.

At least 132 species of brittlestars are known for the western Indian Ocean. A recent literature review noted a total of 112 species of brittlestars reported from scattered locations in Madagascar, including one new genus (*Ophioneroides*) and 24 new species. This diversity compares well with the western Indian Ocean and merits further study. Most of the species described are known from several different locations along the Malagasy coast. Recent rapid field surveys reported 19 species for Toliara, five from Nosy Be and Masoala and four species for Mananara.

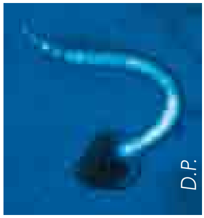


Examples of brittle star species of the western Indian Ocean
(Richmond, 2002)

CHORDATES

Colonial ascidians, invertebrate chordates

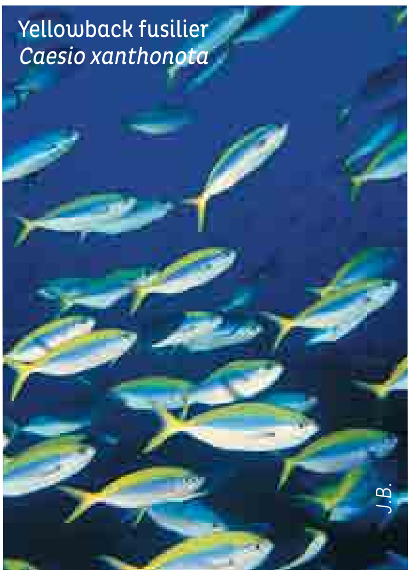
The phylum Chordata is a diverse group of animals which possess a notochord, a dorsal nerve chord, gill slits and a tail. The group includes the vertebrates (in which the notochord develops into a backbone) and about 3500 invertebrate species, which are all marine and include lancelets, salps and sea squirts (ascidians). While the lancelet resembles a tiny eyeless eel, the salps and sea squirts lose their elongated shape as adults and superficially resemble jellyfish or sponges. The clue to their relationship with the vertebrates lies with the larva, which resembles a tadpole.



Ascidian larva

VERTEBRATES

Fishes



Yellowback fusilier
Caesio xanthonota

The first vertebrates to appear in the early oceans were the marine fishes whose fossils date back to about 500 million years bp. These small jawless fishes, covered in a carapace of small bony plates, are placed in the super-class jawless fishes (Agnatha), class Ostracoderma. Fishes with jaws and paired fins (super-class Gnathostoma) first emerged in the Lower Silurian (440 million years bp).

The living fishes are vertebrate chordates which include two basic groups – the cartilaginous fishes or chondrichthyes (including the sharks, rays, skates and chimeras) and the bony fishes (Osteichthyes). The bony fish are divided into two main groups, the lobe-finned fishes or Sarcopterygii (which include the coelacanth) and the Actinopterygii or ray-finned fishes which include the vast majority of fish species (about 25,000 species worldwide).

Chondrichthyes (sharks, rays)

Chondrichthyes (often referred to simply as 'sharks & rays') are ancient cartilaginous fishes whose ancestors first appeared in the seas of the Carboniferous (350 million years ago); they include sharks, rays, sawfish, skates and chimaeras. Unlike modern bony fishes, sharks & rays lack a swim bladder for buoyancy control and may in some situations need to swim continuously to maintain a constant depth. This is partly compensated by a large oily liver in many species, which adds buoyancy. A few sharks need to keep swimming to maintain water flow over their gills, but most can breathe normally while stationary, including some of the open water species. Sharks and rays are long-lived and reproduce slowly, making them especially vulnerable to overfishing. Some species lay a small number of eggs while others keep the eggs inside their bodies and give birth to live young (pups).

All sharks & rays are carnivorous and include some of the ocean's most spectacular and dangerous predators such as the great white shark *Carcharodon carcharias*, bull shark *Carcharinus leucas*, tiger shark *Galeocerdo cuvier*, blue shark *Prionace glauca* and other 'requiem' sharks (so called because they bring death), and the world's largest fish, the docile plankton eating whale shark *Rhincodon typus*. The rays include plankton feeders such as the Manta ray *Manta birostris* and many bottom dwelling species that possess pavement-like dentition to crush molluscs and other invertebrate prey. Skates are similar to rays, while the sawfish have a unique 'saw' or rostrum used for locating and stunning prey. Finally, the chimaeras (*chimaera* means a monster resulting from the combination of the parts of different animals) are deep sea bottom dwelling fish with huge eyes and bizarre appearance. Possessing a rabbit-like snout, a rat-like tail and a shark-like body, they are alternatively known as 'rabbitfishes', 'ratfishes' or 'ghost sharks'.

Blacktail reefshark
Carcharhinus amblyrhyncos

Manta Ray *Manta birostris*

Zebra shark *Stegastoma fasciatum* (Stegastomatidae)

SHARKS AND RAYS OF MADAGASCAR (by Bernard Séret)

The chondrichthyan fauna (sharks, rays, skates and chimaeras) of Madagascar consists of 123 species recorded or likely to occur in Malagasy waters: 81 sharks, 40 rays and 2 chimaeras. This relatively low diversity is most probably due to the lack of knowledge, as few studies have been devoted to this fauna. In comparison, the chondrichthyan fauna in South African waters is more diverse with at least 171 species: 100 sharks, 64 rays (including 28 skates) and 7 chimaeras ; but this area has been long studied by well known sharks and rays experts.

Tawny nurse shark *Nebrius ferrugineus*

Most (58%) of these species are coastal or pelagic but the deep-water species are already well represented, and more species could be added with the development of deep-sea fisheries.

The rate of endemism is low, with only four confirmed endemic species so far known for Madagascar: the blue-spotted bamboo shark *Chiloscyllium caerulopunctatum*, broadhead catshark *Bythalaelurus clevai*, Madagascar skate *Dipturus crosnieri* and the Madagascar pygmy skate *Fenestraja maceachrani*. More endemic species are most probably still to be discovered, however the rate should remain relatively low because the Mozambique Channel is a biogeographic crossroads on the migration routes of marine fishes between the Indo-Pacific and the Atlantic.

According to the IUCN Red List, several shark species are threatened. The sawfishes (*Pristis* spp.) are Critically Endangered and are listed on Appendices I and II of the CITES convention. The whale shark *Rhincodon typus* has also been listed as vulnerable and is on Appendix II of CITES (as a result of a proposal by Madagascar). The deep-water skate *Rostroraja alba* is Endangered and 17 other species are Vulnerable.

Teleosts (ray-finned fishes)

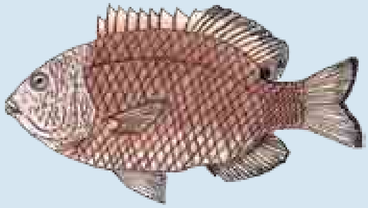
The ray-finned or teleost fishes make up the vast majority of all fishes and share the common features of fins with bony rays which provide manoeuvrability and propulsion. Ray-finned fishes include a vast range of species from the largest ocean going tunas and billfish (marlin, sailfish, swordfish) to the tiniest reef dwellers such as blennies and damselfish.

Ray-finned fishes have evolved and radiated to exploit a myriad of ecological niches and exhibit an astonishing variety of form, colour and ecology. While most species are carnivores and detritus feeders, many teleost fishes are herbivorous. Nowhere is a greater diversity of ray-finned fishes seen than on a coral reef where a single family may have dozens of species.

On Madagascar's coral reefs the most species-rich families are typically wrasses (Labridae), damselfish (Pomacentridae), butterflyfish (Chaetodontidae), surgeonfishes (Acanthuridae), parrotfish (Scaridae) and soldierfish (Holocentridae). Among other families, the planktonivorous fusliers (Caesionidae) are particularly well represented, as are the carnivorous groupers (Serranidae), emperors (Lethrinidae) and snappers (Lutjanidae), the detritivorous goatfish (Mullidae) and the omnivorous puffers (Tetradaontidae).

Mangrove red snapper *Lutjanus argentimaculatus*

ANGRY DAMSELS



Stegastes lividus
(Pomacentridae)

There is a great variety of herbivorous fish on coral reefs which all compete for the fast growing algae on which they mostly graze. Some species, such as the lined surgeon fish *Acanthurus lineatus*, or the dusky parrot fish *Scarus sordidus* rely on sheer volume of numbers to overwhelm the competition, moving in large shoals across the reef and displacing other grazers. Others, such as certain damselfish or gregories, actually take the time to farm their own algae by pecking back the corals, thus allowing the plants to grow unhindered on which they feed. These damsels will vigorously defend their "gardens" if threatened. This aggressive behaviour is well illustrated by the Bluntsount Gregory (aptly named *Stegastes lividus*) which will peck at a diver's mask making grunting noises in defence of its valuable crop. Various species, such as the smaller wrasses, respond to this by forming multi-species gangs which suddenly invade the garden simultaneously, making it impossible for the damsel to defend it.

CORAL REEF FISH AND SOUND

A healthy coral reef is full of different sounds, analogous to a rainforest. Coral reef fish have sensitive hearing and are able to discriminate between sounds in order to select preferred habitat. By recording healthy reef sounds and playing them back with underwater speakers, scientists have been able to attract reef fishes to colonize artificial reefs. Fish can also generate a range of different sounds with their swim bladder in order to communicate. One of the loudest fish to be found on the reef is the palette surgeonfish *Paracanthurus hepathus* - when found in aggregations the noise from this species can be impressive. Some damsel fish also emit loud grunts in defence of their territories.

Butterflyfish (Chaetodontidae)

MADAGASCAR'S CORAL REEF FISH DIVERSITY

The centre for coral reef fish diversity in the Indo-Pacific lies within the triangle described by Indonesia, Philippines and New Caledonia, with about 2,800 species. Species diversity declines with distance from this centre. Based on the observed diversity gradient, Madagascar is expected to harbour about 900 species. The published scientific literature confirms that Madagascar has at least 830 coral reef fish species. The national biodiversity data base REBIOMA, based on a combination of published and grey literature, lists 1133 coral reef fish species at the time of this publication. This species richness is a reflection of the large area and diversity of Madagascar's coral reefs.

Fish around coral head,
Radama Islands, NW Madagascar

Pelagic fishes

Pelagic fishes are fishes that swim and feed in surface waters, often in large shoals. Marine pelagic fishes occurring in Madagascar's waters include anchovies (Engraulids), sardines (Clupeids), trevallies (Carangids), mackerels & tunas (Scombrids), dorado or dolphinfish (Coryphaenids) and large billfish (Istiophorids) such as marlin, sailfish, swordfish and spearfish. Smaller pelagic fish, such as anchovies and sardines, feed off plankton while larger ones, such as tuna and billfish, feed mainly off other pelagic fishes. Pelagic fish are of considerable importance to small scale and industrial fisheries in Madagascar and throughout the Western Indian Ocean.

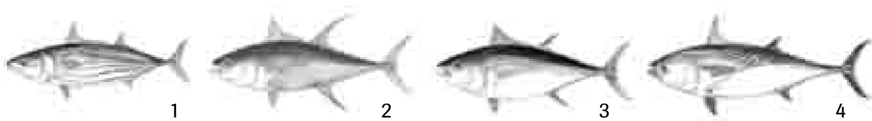
Shoal of small pelagic fish (Clupeids), off NW Madagascar

Tunas & mackerels (Scombrids)

Tuna are highly migratory carnivorous fish with behavioural and physiological adaptations enabling them to exploit widely scattered pockets of productivity in the open ocean. Tuna are highly versatile feeders, hunting not only on the surface for small pelagic fish and crustaceans, but also at greater depths (100 m or more), mainly for small fish and squid.

The principal species of tuna found offshore around Madagascar are skipjack *(Katsuwonus pelamis)*, yellowfin *(Thunnus albacares)*, big-eye *(T. obesus)* and albacore *(T. alalunga)*. Dogtooth tuna *(Gymnosarda unicolor)* and the smaller kawakawa or mackerel-tunny *(Euthynnus affinis)* are inshore species. Southern bluefin tuna *(Thunnus maccoyii)*, now a critically endangered species, occurs off southern Madagascar (see Chapter 3).

The mackerels are generally coastal, pelagic fishes, including kingfish *(Scomberomorus commerson)* and wahoo *(Acanthocybium solandri)*, known locally as lamatra or angoho or thon blanc, and Indian mackerel *(Rastrelliger kanagurta)*. Mackerels are important in small scale fisheries.

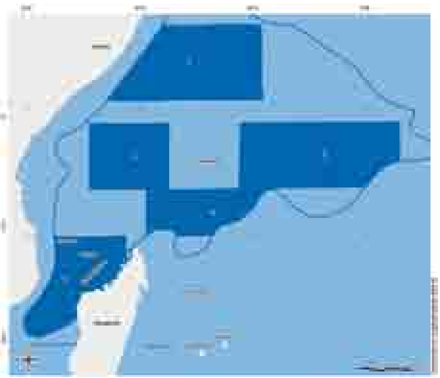


Oceanic tunas – 1. Skipjack *(Katsuwonus pelamis)*; 2. Yellowfin *(Thunnus albacares)*; 3. Big-eye *(Thunnus obesus)*; 4. Albacore *(Thunnus alalunga)*. Source: FAO

Feeding oceanic tuna in the Western Indian Ocean migrate between seasonal areas of high primary productivity in areas of upwelling across the Seychelles

Dogtooth tuna *(Gymnosarda unicolor)*, Nosy Be, NW Madagascar

ridge and opposite the Somali coast, and nutrient rich areas in the Mozambique Channel. Skipjack and yellowfin tuna migrate southwards into Madagascar's waters during the warm season (October to April). Tunas tend to aggregate above bottom features, such as seamounts, reefs, banks or shipwrecks, or around floating objects (a tendency exploited by industrial fisheries). Skipjack and yellowfin spawn primarily in waters of the Seychelles and off North West Madagascar.

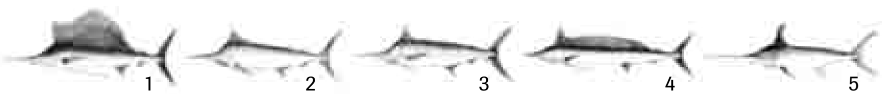


Principal tuna fishing grounds around northern Madagascar
(Source: Le Blanc 1996, adapted by SOGREAH)

Spawning grounds of yellowfin and skipjack tuna close to Madagascar
(Source: Marsac & Stéquert 1986, adapted by SOGREAH)

Billfish

Associated with the tuna are several large species of billfishes feeding off the tuna including sailfish *(Istiophorus platypterus)*, black marlin *(Makaria indica)*, blue marlin *(Makaria mazara)*, short-billed spearfish *(Tetrapturus angustirostris)* and swordfish *(Xiphias gladius)*. Swordfish are abundant off the east, south, and southwest coasts of Madagascar. Sailfish are seasonally abundant around Nosy Be, where they are observed in large shoals around offshore banks in August-October.



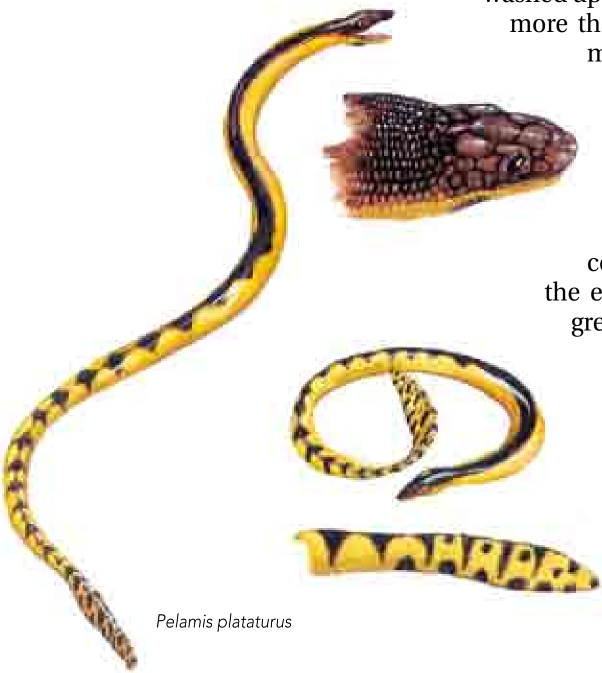
Billfishes of Madagascar – 1. Sailfish *(Istiophorus platypterus)*; 2. Black marlin *(Makaria indica)*; 3. Blue marlin *(Makaria mazara)*; 4. Spearfish *(Tetrapturus angustirostris)*; 5. Swordfish *(Xiphias gladius)*. Source : FAO

Marine reptiles

Reptiles are an ancient group of animals that dominated land and sea during the Cretaceous period (135-70 million years ago). They share the characteristics of being cold blooded, egg laying and air breathing. Today the only marine reptiles remaining are the sea turtles (Chelonidae), crocodiles and sea snakes (Hyrdrophiidae). Sea turtles and Nile crocodiles *(Crocodylus niloticus)* are described in Chapter 3 (marine species of conservation concern).

Hawksbill turtle *Eretmochelys imbricata*

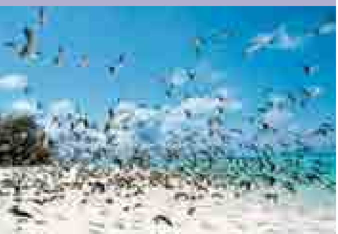
Sea snakes (Hydrophiidae) are open sea species not commonly encountered in coastal waters, but specimens are occasionally washed up after storms. While there are more than 50 species in 14 genera, most of these occur in the Australasian region. Two species have been reported from Madagascar's coastal waters - yellow-bellied sea snake *Pelamis platurus* (the most commonly encountered in the east African region) and the grey-backed and white-bellied *Enhydrina schistosa.* A black and red banded sea snake missing part of its tail was found washed up on a beach south of Antalaha in 1999 indicating a possible third species. Sea snakes are highly venomous and should be avoided.



Sea snakes

SEABIRDS ON THE ISLANDS OF THE MOZAMBIQUE CHANNEL (by Mathieu Le Corre)

Approximately 3 million seabirds nest on the islands of the Mozambique Channel, of which over 99% are sooty terns *Onychoprion fuscata*, which breed mostly on three remote



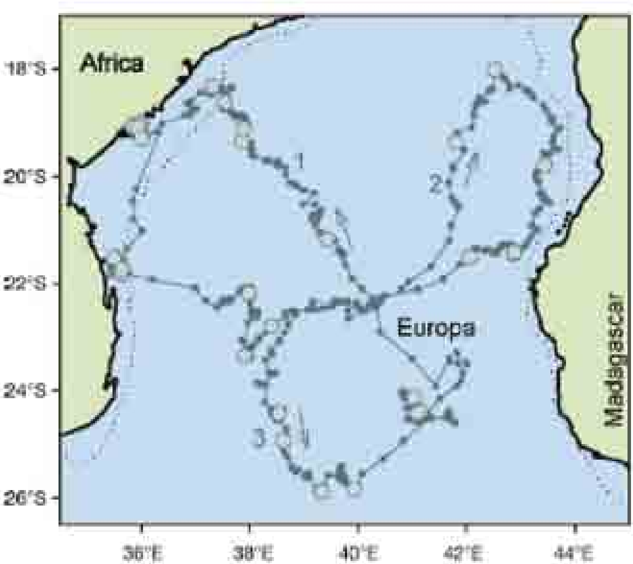
Sooty terns
Onychoprion fuscata,
Ile Juan da Nova
(Photo: M Le Corre)

locations – Europa 25%, Juan de Nova 66% and Iles Glorieuses 19%.

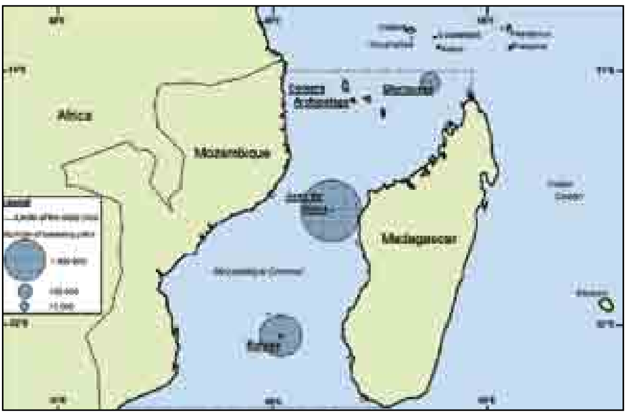
Remaining species in the Mozambique Channel are red tailed tropic birds, great frigate birds *Fregata minor* and red-footed boobies *Sula sula*. Continental islands such as the Barren Islands in the west and Nosy Manitse in the south west supported abundant seabirds in the past, but persistent human disturbance forced seabirds to retreat to the most inaccessible oceanic islands.

Sea birds

Seabirds are birds exclusively adapted to the marine environment but do not constitute a taxonomic group, even if they share common adaptations. About 40 species of seabirds occur around the coasts of Madagascar including albatrosses, petrels, tropicbirds, boobies,



Foraging migrations of Great Frigate Bird *Fregata minor*
(Source: Wiemerskirch et al 2004)



Mozambique Channel showing the different nesting sites of bird colonies (Source : Le Corre & Jaquemet 2005)

Sooty tern *Onychoprion fuscata* in flight (Nosy Ve, South West Madagascar)

frigatebirds, skuas, gulls and terns. Terns are the best represented group with 17 species including sooty tern *Onychoprion fuscata*, lesser crested tern, *Sterna bengalensis*, roseate tern *Sterna dougallii*, common tern *Sterna hirundo* and smaller numbers of greater crested tern *Sterna bergii* and blacknaped tern *Sterna sumatrana*. By far the most abundant species is the sooty tern *Onychoprion fuscata*, with about 3 million pairs in the Mozambique Channel. Apart from

FORAGING MIGRATIONS OF GREAT FRIGATE BIRDS (*Fregata minor*)

Frigate birds migrate extensively, tracking the zones of high productivity which occur around eddies in the Mozambique Channel, sometimes approaching western Madagascar, where eddies often develop. Feeding frigatebirds are generally observed in multispecific flocks (with terns and boobies), associated with subsurface predators that drive their prey to the surface, such as tuna and dolphins. Their prey is mainly small pelagic fish and squid.

Fregata minor

Red-tailed tropic bird *Phaethon rubricauda* nesting on Nosy Ve

the terns, there are the highly migratory frigatebirds (Great Frigatebird *Fregata minor* and Lesser Frigatebird *F. aeriel*), the non-migratory boobies (red-footed booby *Sula sula*, brown booby *Sula leucogaster*, masked booby *Sula dactylatra*) and the tropicbirds (white tailed tropicbird *Phaeton lepturus*, redbilled tropicbird *P. aethereus* and red tailed tropicbird *P. rubricauda*).

About 13 species of sea birds are known to breed off the coast of Madagascar, but population sizes are mostly low and many are threatened by poaching, particularly from egg collection. Breeding sea birds in Madagascar are mainly limited to steep sea stacks or offshore islands protected by strong winds in the breeding season (July-August). The greatest number of suitable sites for sea birds occurs between Nosy Mitsio and Cap d'Ambre, where there are globally important populations

CONSERVATION SUCCESSES OF SEABIRDS IN MADAGASCAR (by Mathieu Le Corre)

Conservation or regulation can have a significant positive impact on breeding sea birds. Nosy Manampaho, on the east coast of Northern Madagascar, a partially regulated site, supports a colony of over 20,000 pairs of sooty tern *Onychoprion fuscata*. At Nosy Foty in the Nosy Hara archipelago, on the west coast of Northern Madagascar, the colony of Crested terns *Thalasseus bergii* increased from 1000 pairs in 1997 to 10,000 pairs in 2008 (Nosy Hara became a marine national park in 2001). Another example is the small colony (250 pairs) of red tailed tropicbirds Phaeton rubricauda on Nosy Ve islet, opposite the village of Anakao, SW Madagascar, whose survival depends on to a local taboo that protects the birds, reinforced by a traditional local agreement or *dina*.

Colony of Sooty Terns *Onychoprion fuscata* at Nosy Manampaho, east coast of Northern Madagascar

Colony of Crested terns *Thalasseus bergii* at Nosy Foty, west coast of Northern Madagascar of Crested tern *Thalasseus bergii* and Roseate Tern *Sterna dougallii* on offshore islets, as well as smaller populations of brown booby *Sula leucogaster*, white tailed tropic bird and frigate birds (*Fregata minor* and *F. aeriel*).

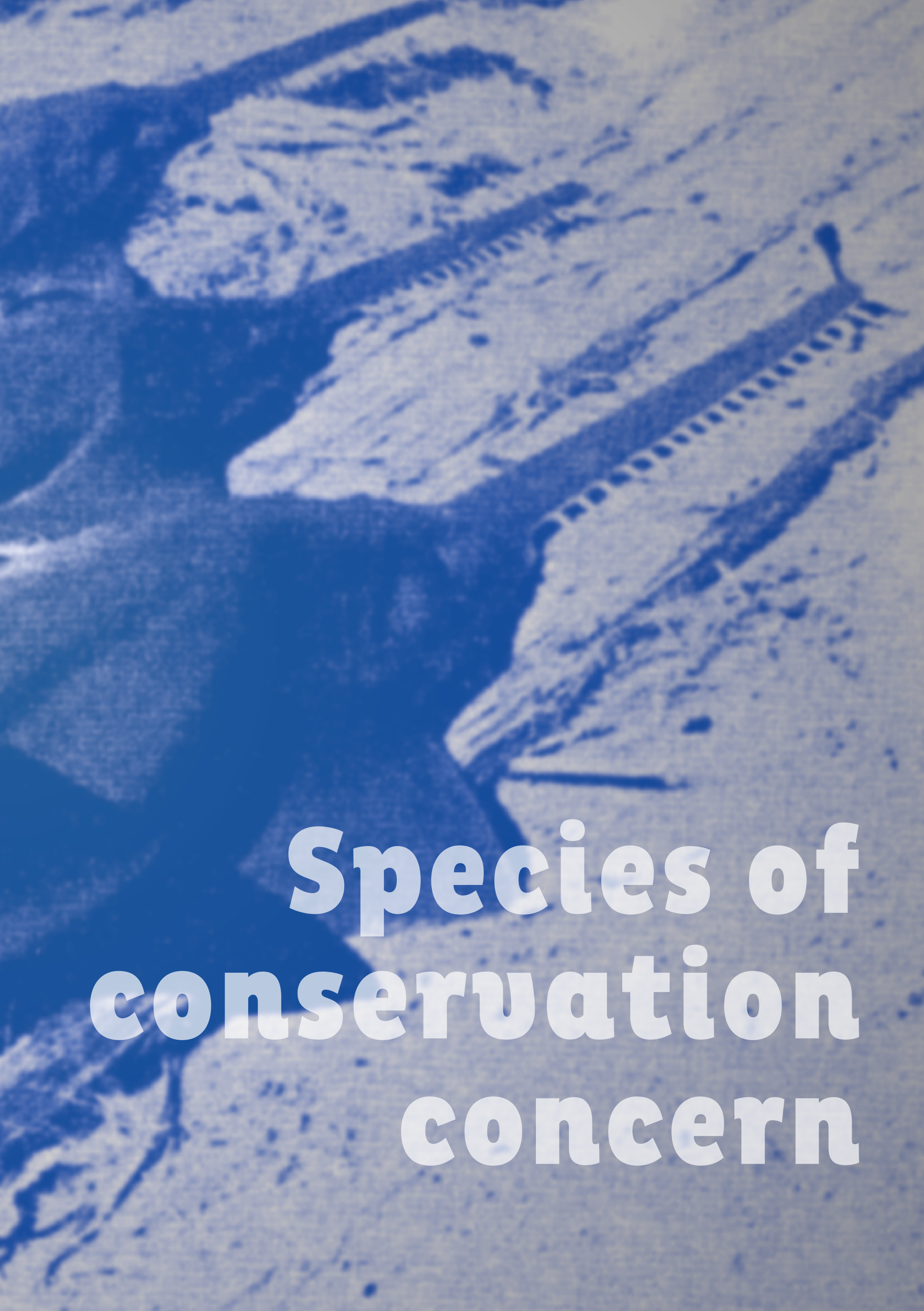
Marine mammals

Marine mammals include the cetaceans (whales & dolphins), dugong or seacow *Dugong dugon* and seals and sea lions (Pinnipeds). Cetaceans and dugong are of global conservation concern and are strictly protected under Malagasy law, and are therefore addressed in Chapter 3. Seals and sea lions occur only rarely as stray migrants to Madagascar and are not covered in this guide.

Bottlenose dolphins *Tursiops truncata*

Dugong *(Dugong dugon)*
(Source: WWF – Jürgen Freund)

Humpback whale *Megaptera novaeangliae*



Species of conservation concern

What is a 'species of concern'?

The purpose of this chapter is to introduce the reader to marine species occurring in Madagascar's waters which are important for conservation. The identification of a species as being of conservation concern has a considerable influence on the focus of conservation and resource management efforts and may even affect decisions on major investments, such as the choice of location for a port, new beach hotel or protected area. How do we determine which species are of conservation concern and which are not? Is it because of the important role they play in the ecosystem? Is it because of their 'charismatic' nature? Is it because they are endemic? Or is it because of some other value?


Dugong *(Dugong dugon)* (Source: WWF – Jürgen Freund)

It is a fact that most marine species considered important for conservation are also charismatic – they tend to be large, fearsome or colourful species which serve as 'flagships' of the ecosystems they inhabit – the whales, the sea turtles, the great white shark, reef corals and so on. Such species attract human attention and we notice when they go into decline. Their importance as a necessary component of a healthy ecosystem is often less clear, inspiring scientific research to determine their role (as in the case of sharks which have been found to contribute to marine ecosystem stability). Most marine species are widely distributed, with relatively few being endemic to any particular country (only 10-20 endemic marine animal species are known so far from Madagascar, in stark contrast to the mainly endemic terrestrial fauna). Many marine species of conservation concern are of economic importance because they are hunted for food or because their products are valuable for trade, such as turtle shell, sharkfin or ornamental corals and shells. Sometimes they are of particular scientific importance, such as the coelacanth, or of local cultural significance, such as the red-tailed tropicbird.

While the perceived values of species may be diverse and sometimes subjective, the objective basis used by conservation professionals to determine whether they merit protection is whether they are *threatened with extinction*. In order to help prioritise between species, conservationists assess the *relative risk* of extinction. Several internationally recognised systems exist for the listing of species of conservation concern, the most established of which is the IUCN 'Red List' of Threatened Species. These systems exhibit a trend of convergence towards a single, global, list with a single set of criteria but remain distinct for the time being. For marine species, in particular, there is not always agreement between systems and it is therefore necessary to consider them all in order to identify all marine species occurring in Madagascar which have some form of conservation status. For the purpose of this guide we have considered marine species which are:

1. listed in the international 'Red List' of Threatened Species issued by the IUCN (International Union for the Conservation of Nature);
2. listed in Appendices 1, 2 or 3 of CITES (Convention on International Trade in Endangered Species of 1973, also known as the 'Washington Convention');
3. listed in Appendices 1 or 2 of the Convention on the Conservation of Migratory Species of Wild Animals (the 'Bonn Convention' or 'CMS');
4. listed in regional conventions to which Madagascar is a party (Nairobi & Algiers conventions);
5. listed as protected species under Malagasy law (Annex to Decree 2006-400 of 13 June 2006 or other national laws and regulations).

The international, regional and national lists are subject to revision as new data become available. In the case of the IUCN Red List revision is likely for species which are members of any group of global concern, such as cetaceans, sharks & rays, large ray-finned fishes threatened by fishing or corals. Proposals for CITES listing are made when international trade threatens to have a significant impact on wild populations. A relevant example is the whale shark which relatively recently became a target species for the shark fin trade and which in 2004 was listed in Appendix 2 of CITES following a proposal from Madagascar. Regional conventions to which Madagascar is a party (Algiers, Nairobi) are also supposed to undertake reviews but have not done so to date. Madagascar's national wildlife protection text, originally promulgated in 1961 (Decree 61-126), was updated in 1988 (Decree 88-243) and again in 2006 (Decree 400-2006). As this chapter will show, a further update is needed to address marine species. Finally, recognised scientists may express concern about the populations in Madagascar of marine species not yet included in any recognised list (such as the manta ray).

Volunteers monitoring sea turtle nests in SW Madagascar (Source: Blue Ventures Conservation)

Marine species in IUCN Red List

The IUCN Red List of Threatened Species was conceived in 1963 as an international mechanism for highlighting species threatened with extinction and to promote their conservation. Originally, the list was limited to threatened species, with the result that valuable information on species assessed but found not threatened was not retained in the system. Since 2003, however, the approach has been to assess systematically all species within entire taxonomic groups and to include new categories of:

- "least concern" (for those assessed and found currently not to be at risk of extinction),
- "not evaluated" (for those not yet assessed),
- "data deficient" (for those for which data were insufficient for reliable assessment).

Systematic assessments have been completed to date for amphibians, birds (including seabirds), mammals (including marine mammals), freshwater crabs, warm-water reef building corals (an important marine invertebrate group) and certain plants (conifers and cycads). Systematic assessments have also been undertaken for certain groups of marine species including sharks and rays (chondrichthyans), groupers (Serranidae) and seahorses (Sygnathidae). However, systematic assessments have still not yet been made for ray-finned fishes as a whole or for marine invertebrates other than warm-water corals.

The IUCN Red List categories are based on rigorous assessment of population decline, restricted geographic range, population size and extinction risk. Identifying a species as threatened has no legal effect but has a direct influence on other conventions (such as CITES) and on national wildlife legislation.

IUCN Category	Meaning
Extinct	Totally extinct
Extinct in the wild	Extinct in the wild but surviving in captivity
Critically endangered (CR)	Extremely high risk of extinction in the wild
Endangered (EN)	Very high risk of extinction in the wild
Vulnerable (VU)	High risk of extinction in the wild
Near-threatened (NT)	Close to qualifying for a threatened category in the near future
Least concern (LC)	Does not qualify for threatened category
Data deficient (DD)	Inadequate information to make an assessment
Not evaluated (NE)	Has not yet been evaluated against the criteria

Napoleon wrasse *Cheilinus undulatus* (EN)

Common seahorse *Hippocampus kuda* (VU)

The assessment of marine species has developed only recently with the revelation that marine species too can be threatened with extinction, for example by overfishing or habitat loss. Assessments to date have been focused mainly on larger, charismatic, species such as marine mammals, sea turtles, sharks & rays and some of the larger species of fishes, such as tunas, cod, groupers and large coral reef fish or species strongly affected by trade, such as seahorses and Napoleon wrasse. Most listed marine species are still classed as “data deficient” (DD) or “not evaluated” (NE), reflecting the challenges of evaluating the status of marine species.

The IUCN Red List should not be considered as a substitute for regional or national conservation priority setting. For example, the global status of the dugong *Dugong dugon* is ‘Vulnerable’, whereas in the Western Indian Ocean region and in Madagascar its situation could be considered critical, meriting top conservation priority. On the other hand, species considered endangered (EN) globally such as the Napoleon wrasse *Cheilinus undulatus* are still relatively common in the Western Indian Ocean and Madagascar and may thus merit less priority than, for example, the dugong.

Marine species listed in the Appendices of the CITES convention

The Washington Convention on Trade in Endangered Species of 1973 (ratified by Madagascar in 1975) commits member states to regulate trans-frontier trade in endangered species listed under the convention. CITES was first conceived in 1963 and shares a common origin with the IUCN Red List of Threatened Species. Appendix I lists the species threatened with extinction and CITES generally prohibits commercial international trade in these species. Appendix II lists the species that are not necessarily now threatened with extinction but which may become so, unless trade is closely controlled. Appendix III includes species listed at the request of any country which already regulates trade in the species and which requires the cooperation of other countries to help control illegal trade. Madagascar’s implementing legislation is Law 75-014 and subsequent decrees (77-246 and 83-108) which implement CITES Annexes I, II & III.

Marine species of conservation concern in Madagascar listed under the CITES convention include several cetaceans, the dugong, some seabirds, sea turtles, Nile crocodile, certain fishes, the coelacanth, many sharks (including the great white shark *Carcharodon carcharias*, whale shark *Rhincodon typus*) and rays, including the sawfish *Pristis* spp. and various invertebrates, notably corals (stony corals, black corals, blue corals and fire corals).

Madagascar has not included all CITES-listed Malagasy species in its own implementing legislation. Decree 77-276 lists in Appendix I dugong, cetaceans and sea turtles, while placing the coelacanth (which is unprotected under domestic law) in Appendix II (it has subsequently been placed in Appendix I). For example, blue corals, black corals, stony corals, fire corals, giant conch and giant clams (all Appendix II species) are absent from Malagasy implementing texts.

Marine species listed in the Convention on Migratory Species (CMS)

The Convention on the Conservation of Migratory Species of Wild Animals of 1979 (also known as CMS or the Bonn Convention) aims to conserve migratory terrestrial, marine and aerial species throughout their range. Appendix I to the CMS lists migratory species threatened with extinction. Member countries should strictly protect Appendix I species, as well as take measures to conserve or restore their habitat, mitigate obstacles to migration and control other threats. Appendix II lists migratory species that need or would benefit from international cooperation. For these species, range states (i.e. countries in which the species occur) are encouraged to conclude regional or global cooperation agreements. Species listed in Appendix I are often also listed in Appendix II.

Madagascar ratified the CMS with effect from 1st January 2007. Under CMS, Madagascar has ratified the agreement on the conservation of migratory African-Eurasian Waterbirds (AEWA) and has signed MoUs for the regional conservation of marine turtles, dugongs and birds of prey. As a result of ratifying the convention, Madagascar is obliged to strictly protect all marine species listed in Appendix I to CMS, including several whales, sea turtles and the great white shark. Madagascar is encouraged to enter into regional cooperation agreements for Appendix II species, including various whales and dolphins, the dugong, several species of seabirds, sea turtles, the whale shark and the great white shark.

Marine species listed in the Nairobi convention (1985)

The Nairobi Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region was signed in 1985 and came into force in 1996. Madagascar ratified the convention on 26 June 1990. The convention obliges the parties to prevent pollution and ensure sound environmental management of natural resources in the marine and coastal environment falling under jurisdiction of the member states. Member states have negotiated supplementary agreements under the convention including an action plan/convention on 'protection, management and development of the marine & coastal environment' and protocols on protected areas and wild fauna & flora and combating marine pollution in cases of emergency.

The Protocol Concerning Protected Areas and Wild Fauna and Flora in the Eastern African Region obliges countries to protect fragile ecosystems and rare, depleted or threatened species of fauna & flora. Annex II to the protocol lists animal species that the countries should strictly protect and includes the dugong, humpback whale, blue whale, olive ridley turtle, loggerhead turtle, leatherback turtle, several molluscs (see below), the coconut crab, black coral and whip corals. Annex III lists 'harvestable' species requiring protection, and includes spiny lobsters, green turtles and hawksbill turtles. Annex IV lists protected migratory species and includes the dugong, humpback whale, blue whale and all five marine turtles occurring in the region.

Marine species listed under the Algiers Convention (1968)

By Law 70-004, Madagascar ratified the African Convention on the Conservation of Nature and Natural Resources (Algiers, 1968), which lists dugongs and sea turtles among other protected species. However, Madagascar has never passed specific implementing legislation (although it has followed the convention in creating protected areas). An updated and revised version of the Algiers convention prepared under the aegis of the African Union was agreed on 13th February 2004 but has not yet been ratified by Madagascar. On 1 March 2010 the convention was extensively amended. In the meantime, the old version (and annexed list of protected species) remains in force.

Marine species protected under national legislation

The national legislation for the protection of marine species derives from the following principal texts:

- Ordinance 60-126 which provides the basis for wildlife protection legislation;
- Decree 2006-400 under 60-126 (replacing Decree 88-243 and repealing Decree 61-196) revising and updating the list of totally protected species and adding certain marine species (sea turtles, crocodiles and sea birds);
- Ordinance 93-022, the fisheries law, which totally protects marine mammals.

Green turtles awaiting sale, Tsongoritelo, SW Madagascar

Decree 2006-400 repealed decree 61-096 under Ordinance 60-126 which provided for the protection of certain marine fauna including whales and dugong. While whales and dugong are not included in Decree 2006-400, they are fully protected under the fisheries law (93-022).

In addition, there are numerous older regulations, mainly passed under the fisheries decree of 5 June 1922 or the Code Maritime of 1966, regulating the exploitation of whales, dugongs, turtles, lobsters, pearl oysters, ornamental shells, shells for button making, sponges, edible oysters, sea cucumbers and algae. For example, two colonial orders of 1923 established a series of island turtle reserves, banned the capture of nesting female turtles and limited capture to turtles measuring more than 50 cm across the plastron.

THREATENED MARINE SPECIES IN MADAGASCAR – STATUS UNDER IUCN RED LIST, INTERNATIONAL CONVENTIONS & NATIONAL LEGISLATION

Type of animal	Common name	Malagasy name	Scientific name	IUCN Red List	International conventions				National legislation & regulations		
					CITES	CMS	Nairobi	Algiers	CITES regula-tions	Wildlife legislation	Other legislation
Cetaceans (whales & dolphins)	Various	Various	Various	Various	Ann I	Ann I & II	Annex II (2 species)	-	Regulated	Unprotected (after repeal of Decree 61-096)	Protected under fisheries law 93-022
Sirenians (sea cows)	Dugong	Lambohara	*Dugong dugon*	VU	Ann I	Ann II	Annexes II & IV	Class A	Regulated		
Seabirds	Various	Various	*Various*	-	-	Ann II	-	-	-	Protected (15 species)	-
Chelonians (sea turtles)	Leatherback turtle	Fano valozoro	*Dermochelys coriacea*	CR	Ann I	Ann I & II	Annex II	Class A	Regulated	Protected (under decree 2006-400)	Orders of 23.05.1923 24.10.1923 (partial protection & turtle reserves)
	Hawksbill turtle)	Fanohara	*Eretmochelys imbricate*	CR			Annex III				
	Loggerhead turtle	Fano apombo	*Caretta caretta*	EN			Annex II				
	Green turtle	Fano zaty	*Chelonia mydas*	EN			Annex III				
	Olive ridley	Fano tsakoy	*Lepidochelys olivacea*	EN			Annex II				
Crocodile	Nile crocodile	Voay, Mamba	Crocodylus niloticus	LC	App 2	-	-	-	-	Regulated	-

Type of animal	Common name	Malagasy name	Scientific name	IUCN Red List	International conventions				National legislation & regulations		
					CITES	CMS	Nairobi	Algiers	CITES regula-tions	Wildlife legislation	Other legislation
Pisces (fishes)	Coelacanth	Fiandolo	*Latimeria chalumnae*	CR	Ann I	-	-	-	Regulated	Unprotected	See main text
Chondrich-thyes (sharks & rays)	Largetooth sawfish	Vava	*Pristis microdon*	CR	Ann II*	-	-	-	Unregulated	Unprotected	-
	Smalltooth sawfish	Vava	*Pristis pectinata*	CR	Ann I	-	-	-	Unregulated	Unprotected	-
	Green sawfish	Vava	*Pristis zijsron*	CR	Ann I	-	-	-	Unregulated	Unprotected	-
	Rays, skates	Makobo, fay	-	Various	-	-	-	-	-	Unprotected	-
	Whale shark	-	*Rhincodon typus*	VU	Ann II	Ann II	-	-	Unregulated	Unprotected	-
	Great white shark	Akio	*Carcharodon carcharias*	VU	Ann II	Ann I & II	-	-	Unregulated	Unprotected	-
	Other Sharks	Akio	-	Various	-		-	-	-	Unprotected	-
Ray-finned fishes	Various	Various	Various	Various	-		-	-	Unregulated	Unprotected	-
Invertebrates	Various	Various	Various	Various	Ann II	App 1	Annex II	-	Unregulated	Unprotected	See main text

* Exclusively for trade to aquaria for conservation purposes.

Humpback whale *Megaptera novaeangliae* (LC)

Cetaceans (whales, dolphins and porpoises)

Cetaceans are marine mammals derived from an ancient stock of water dwelling carnivorous mammals that also gave rise to the modern hippopotamus. Fully marine cetaceans first appeared in the world's oceans about 40 million years ago. All cetaceans are active carnivores. Like all mammals, they breath air, are warm blooded and suckle their young.

Modern cetaceans comprise two main groups:

1. the **baleen whales (Mysticetes)** possessing plates of baleen, a keratinous material with a hair-like fringe derived from ridges in the roof of the mouth, which are used to filter plankton and small fishes from the water. Baleen whales also possess twin blowholes or 'respiratory events'.
2. the **toothed whales (Odontocetes)** which are active hunters and include the familiar killer whale and dolphins. They have teeth and a single respiratory event. They are also active predators. Many of the toothed whales use echolocation for sensing prey and the surrounding environment.

BALEEN AND TOOTHED WHALES KNOWN FROM MADAGASCAR AND INTERNATIONAL STATUS (IUCN RED LIST, CMS & NAIROBI CONVENTION)

Cetaceans	Common name	Scientific name	IUCN	CMS	Nairobi
Baleen whales (Mysticetes)	Southern Right whale	*Eubalaena australis*	LC	Ann I	-
	Pygmy right whale	*Caperea marginata*	DD	-	-
	Minke whale	*Balenoptera acutorostrata*	LC	-	-
	Bride's whale	*Balenoptera edeni*	DD	-	-
	Humpback whale	*Megaptera novaeangliae*	LC	Ann I	Annex II
	Fin whale	*Balaenoptera physalus*	EN	Ann I & II	-
	Sei whale	*Balaenoptera borealis*	EN	Ann I & II	-
	Blue whale	*Balaenoptera musculus*	EN	Ann I	Annex II
	Pygmy blue whale	*Balaenoptera musculus*	EN	Ann I	-
Toothed whales (Odontocetes)	Sperm whale	*Physeter macrocephalus*	VU	Ann I & II	-
	Pygmy sperm whale	*Kogia breviceps*	DD	-	-
	Dwarf sperm whale	*Kogia simus*	DD	-	-
	Cuvier's beaked whale	*Ziphius cavirostris*	LC	-	-
	Blainville's beaked whale	*Mesoplodon densirostris*	DD	-	-
	True's beaked whale	*Mesoplodon mirus*	DD	-	-
	Hector's beaked whale	*Mesoplodon hectori*	DD	-	-
	Bottlenose dolphin	*Tursiops truncate*	DD	-	-
	Long-beaked Common dolphin	*Delphinus capensis*	DD	-	-
	Risso's dolphin	*Grampus griseus*	DD	-	-
	Short-finned Pilot whale	*Globicephala macrorhynchus*	DD	-	-
	Long-finned pilot whale	*G. melas*	DD	-	-
	Melon-headed whale	*Peponocephala electra*	LC	-	-
	Indo-Pacific humpback dolphin	*Souza chinensis*	NT	Ann II	-
	Spinner dolphin	*Stenella longirostris*	DD	-	-
	Pan-tropical Spotted dolphin	*S. attenuata*	LC	-	-
	Striped dolphin	*Stenella coeruleoalba*	LC	-	-
	Killer whale	*Orcinus orca*	DD	Ann II	-
	False killer whale	*Pseudorca crassidens*	DD	-	-
	Fraser's dolphin	*Lagenodolphis hosei*	DD		
		Tursiops aduncus	DD		

Baleen whales tend to be larger than toothed whales and include the world's largest animal, the blue whale *Balaeonoptera musculus*. The largest of the toothed whales is the sperm whale *Physeter macrocephalus*, a deep sea predator that feeds on giant squid. Both of these giants occur in Madagascar's waters.

Tail of humpback whale *Megaptera novaeangliae*

There are about 80 described species of cetaceans world-wide. All cetacean species are listed in the IUCN Red List and in Appendix I of CITES. About 30 species are known to occur in coastal and pelagic waters around Madagascar, including nine baleen whales and 21 toothed whales and dolphins. Of the 30 species of cetaceans found in Malagasy waters, six are considered vulnerable, threatened or endangered by IUCN, seven are reported as 'Least Concern' (including the humpback whale) while the remaining 17, mostly small, toothed whales and dolphins, are 'data deficient'. Several species are also listed under the CMS and two species (humpback and blue whales) are listed in Annex II of the Nairobi Convention. All are strictly protected under Malagasy fisheries law (Ordinance 93-022) without distinction.

The principal threat to cetaceans in the waters around Madagascar is industrial-scale fishing which reduces abundance of prey (such as tuna) and leads to occasional harmful interactions. In the case of tuna fishing, small whales or dolphins are sometimes caught in fishing gear. In a more severe form of interaction, killer whales have been known to attack the nets of deep sea trawlers as their nets are brought to the surface. Anecdotal reports exist of dead whales with bullet wounds washed up on the coast of southern Madagascar. Small, coastal species, particularly dolphins, are threatened in some areas by illegal traditional hunting, particularly in the North West and South West of Madagascar. A growing threat to all cetaceans around Madagascar is marine noise from shipping and seismic or sonar surveys undertaken by the offshore petroleum industry which compromise the ability of cetaceans to communicate with one another, cause disorientation (sometimes leading to strandings) or even cause physical ear damage where the sound source is close to the affected animals. The impacts of noise are likely to be of secondary importance compared with fishing and measures do exist to mitigate the impacts, such as designating narrow shipping corridors and sensitive management of seismic campaigns.

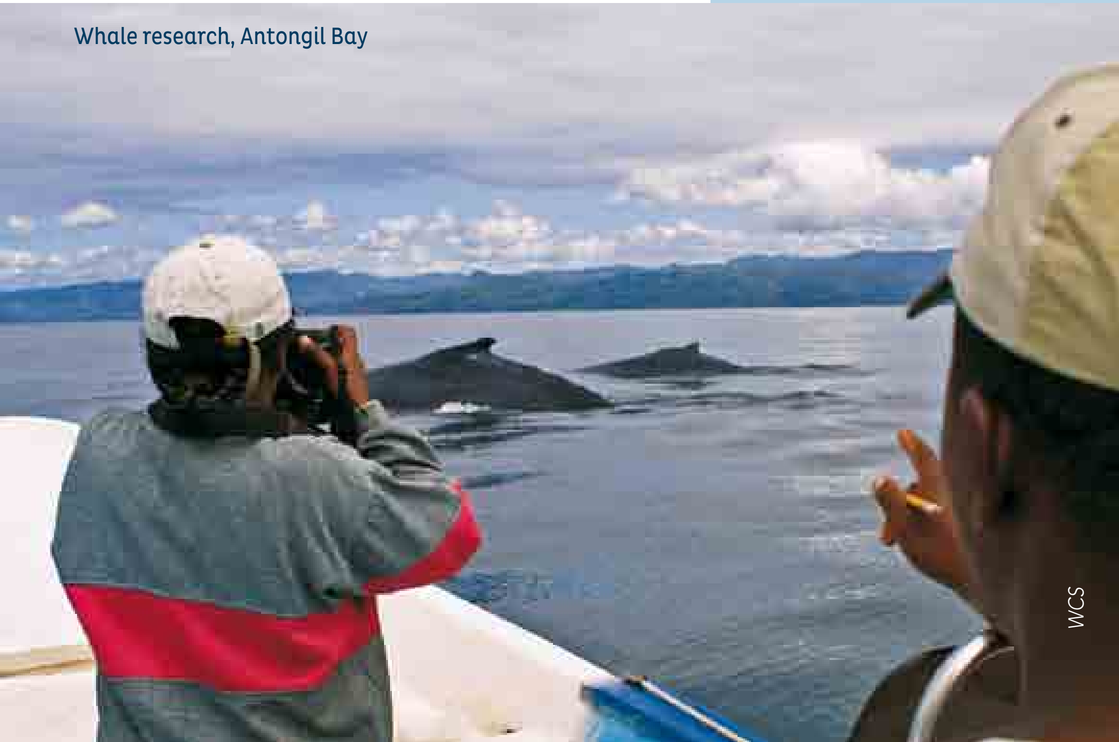
Humpback whale (LC)

Without doubt the flagship marine species of Madagascar is the humpback whale. Madagascar provides breeding and calving grounds for well over 2000 whales at several locations, including the Bay of Antongil and Ile Ste Marie. The humpback is an important national emblem of marine conservation and a major marine tourism attraction.

Humpbacks are baleen whales related to the blue whale and the fin whale (rorqual whales). In common with other rorquals, humpbacks possess throat grooves enabling them to expand their mouth volume. Humpbacks are among the largest of the baleen whales, growing up to 15 m in length and weighing up to 36 tonnes. Females give birth to a single calf every other year and seek coastal sheltered areas to give birth before mating with a male.

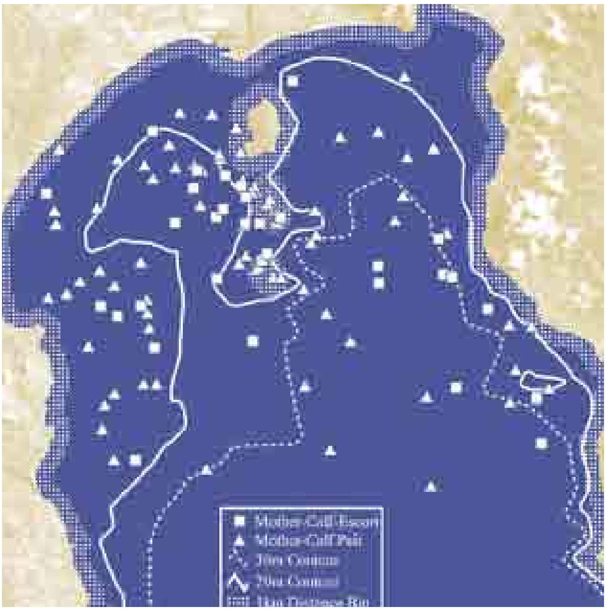
FEEDING AND FASTING

While in the Antarctic, humpbacks are voracious feeders, preying on small fish and krill. Humpbacks use a technique known as "bubble netting" in which the whales work in groups or alone, circling below a fish shoal while blowing bubbles, concentrating the fish into a narrow column before one or several whales rise towards the surface openmouthed to swallow the fish shoal. During the feeding season mature whales may increase their body mass by as much as 40%. In contrast, while on migration in the warm tropical waters of Madagascar, humpbacks generally do not feed at all but rely upon fat reserves built up during the Antarctic summer.


Whale research, Antongil Bay

WCS

Humpback migration routes
(Peter Farrell, MacroEnvironmental)



Humpbacks in Antongil Bay (WCS)

Humpback whales in the Indian Ocean were once the target of intensive industrial whaling which ended in about 1955 when stocks fell below economic levels for the hunting methods of the day. Since that time, humpback whales have steadily recovered. Until recently listed as 'vulnerable', humpback whales were reclassified in August 2008 as "least concern" (LC). They can therefore be considered a conservation success story in global terms.

Every year from May to December, humpback whales migrate from their Antarctic feeding grounds to the coastal waters of Madagascar (both east and west) to reproduce. Three migration routes have been identified in the Mozambique Channel (east African, central, western Madagascar) and an important route along eastern Madagascar, running upstream against the East Madagascar Current (EMC) up to Ile Ste Marie and the Bay of Antongil. Whales begin to arrive off southern Madagascar in May and the last whales leave Cap Ste Marie in December.

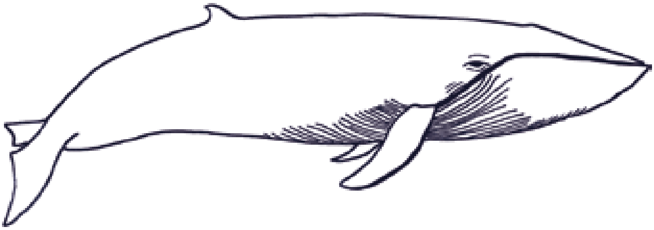
Migrating herds comprise mature males and mature females (which may or may not be pregnant), moving in groups of up to a dozen animals. Males tend to arrive first, congregating in the calving grounds to await the females. Upon arrival, the pregnant females find an area of calm water of suitable depth (10-30 m) to give birth to their calves. The birth of the calf may be assisted by another female. During this time the males indulge in courtship behaviour, including singing and breaching. Males compete to mate and several males may escort a female for several days before one male is selected. At these times, whales may be oblivious to events around them, such as the presence of small boats, and this can lead to collisions. Male songs are complex and evolve from year to year. The structure of the songs varies between different populations of whales, enabling scientists to determine their origin.

Within the waters of Madagascar humpback whales appear to be free of major threats. There are, however, concerns that marine noise from shipping or seismic surveys could have detrimental effects on their breeding success. Another possible concern is the impact of poorly regulated whale watching. Ongoing research and monitoring, in cooperation with the industries concerned, can be very helpful in elucidating these issues.

Breaching male humpback whale, Antongil Bay

C.W.

Blue whale (EN)



The blue whale *Balaenoptera musculus* measures up to 33 m in length and weighs up to 180 tonnes. It is the largest of the whales and may be the largest animal to have existed. Blue whales are rorquals (family Balaenopteridae) which include the humpback, fin, Bryde's, sei and minke whales. Genetic studies have indicated that blue whales are closely related to the humpback whale. The blue whale is also known to hybridise with the fin whale and produce fertile offspring, indicating a relatively close genetic relationship.

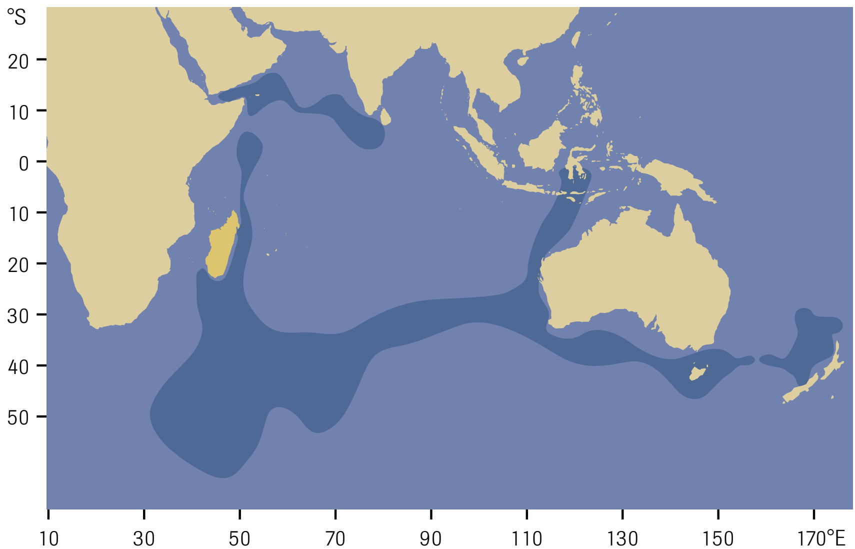
In the Indian Ocean the blue whale comes in two forms, the pygmy blue whale *B. m. brevicauda* with a tadpole-shaped body, and the Antarctic blue whale *B. musculus* with a torpedo-shaped body, and which migrates to the Antarctic in summer. The pygmy blue is about 60% of the size of the Antarctic blue whale. The genetic relationship between the two forms is to date unclear, as is the relationship between pygmy blue whales in the Indian Ocean and local populations of non-Antarctic blue whales in other parts of the world. The blue whales occurring on the Madagascar


NOAA


NOAA

Plateau in the austral summer are pygmy blue whales, and it is suspected that they may winter in waters of the Seychelles. It is possible that some Antarctic blue whales may migrate into or through Madagascan waters in spring and autumn.

Blue whales were hunted mercilessly between 1870 and 1966, during which global populations were reduced to less than 1% of their former levels. Since hunting was banned in 1966 there have been signs of a slow recovery and blue whales are currently classed as Endangered by IUCN. In 2002 their global population was estimated at 5,000 to 12,000 animals (compared with an estimated pre-whaling population of at least 350,000). Blue whales in the Indian Ocean were less severely affected than the Atlantic and southern ocean populations. The waters of the Madagascar ridge support one of the world's largest concentrations of pygmy blue whales. A survey in 1996 estimated a population of 424 pygmy blues south of Madagascar and about 1500 for the south West Indian Ocean as a whole.



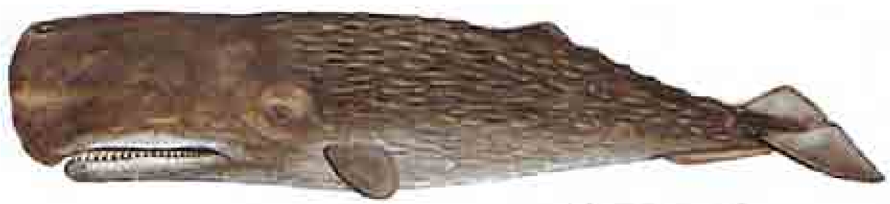
Distribution of blue whales in the Indian Ocean based mainly on Soviet whaling data (Source: Best et al 2003)

Blue whales feed mainly on krill (euphasiid crustaceans) but take fish and squid as an incidental part of their catch. Their feeding season is limited to as little as three months during the Antarctic summer when they may consume as much as four tons of krill every 24 hours, diving to about 100 m to feed on the krill concentrations during the day and feeding on the surface at night. During the southern autumn and winter the whales migrate northwards to warmer breeding grounds. Little is known about breeding behaviour or the location of breeding grounds. Females give birth to one calf every two or three years.

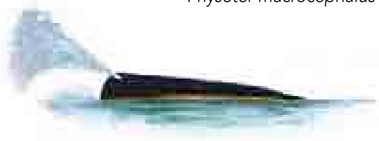
To conclude, Madagascar is a country of importance for the blue whale, particularly the pygmy blue. This importance will increase if Madagascar's request to extend the southern part of its EEZ from the current 200 miles to 350 miles along the Madagascar ridge is successful. Improved management and surveillance of fisheries in this important part of the southern Indian Ocean should provide opportunities for monitoring the populations of endangered blue whales.

Sperm whale (VU)

The sperm whale *Physeter macrocephalus* is the largest of the toothed whales (Odontocetes). Adult males measure up to 20 m and weigh up to 35 tons. Females are markedly smaller (12 m, 20 tons). The sperm whale is closely related to the much smaller pygmy *Kogia breviceps* and dwarf *Kogia simus* sperm whales. The name 'sperm' whale derives from the semen-like spermaceti which fills the animal's head.



Physeter macrocephalus



Sperm whales are globally distributed and occur in all the oceans, usually along submarine trenches at the edge of the continental shelf. During the 18th, 19th and 20th centuries sperm whales were hunted for their valuable oil, bone, ambergris and other products. Since the moratorium on commercial whaling in 1971, the sperm whale has been recovering

AMBERGRIS (GREY AMBER)

Ambergris is a secretion of the intestine of sperm whales, possibly serving to protect the whale from internal laceration by the sharp beaks of the giant squid upon which it feeds. After ejection from the mouth, the ambergris floats on the surface of the sea and is gradually transformed by weathering over months or years into a hard, grey, substance resembling amber that has a subtle, earthy, odour and is traditionally used in cosmetics. Madagascar is known as a source of ambergris and has been an exporting country.

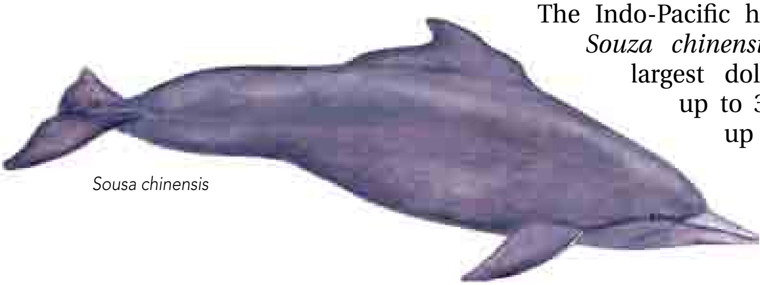
Ambregris in laboratory
(Photos: courtesy of Olivier Behra)

in most parts of its range, and is now estimated to number about 2 million animals worldwide. However, its status according to IUCN remains 'Vulnerable' given the relatively small size of individual populations.

Sperm whales feed on fish, octopus and oceanic squid, occasionally descending to depths of 1000 metres or more to feed on giant squid which inhabit the deep ocean 'scattering layer' (see Ch. 1). Sperm whales possess a range of physiological adaptations enabling them to survive the extreme pressures encountered during deep dives, including modified blood pigment (haemoglobin), collapsible rib cage and reinforced arteries. The whale is also able to alter the density of the spermaceti in the head, enabling it to dive and rise to the surface with comparative ease.

Sperm whales have a unique social structure, in which groups of females and juveniles form schools while the males usually travel in bachelor groups with a dominant large male or 'harem master'. Sperm whales feeding in colder seas migrate to warmer waters to breed while populations feeding in warmer seas will breed in the same area as they feed. Madagascar is known as a feeding, mating and calving area and it is likely that whales are resident year round. Females give birth to one calf every 2 or 3 years. During survey flights in 2010, some sperm whales were observed off Masoala, north of Sainte Marie (North East) and off Toliara (South West), Maintirano (West) and Nosy Be (North West). A dead sperm whale was also detected at Morombe.

Humpback dolphin (NT)



Sousa chinensis

The Indo-Pacific humpback dolphin *Souza chinensis* is one of the largest dolphins, measuring up to 3 m and weighing up to 280 kg. It is formally considered to be a single highly variable species existing in two distinct forms – the lighter-coloured *'chinensis'* form, occurring in South East Asia and Australia and the darker *'plumbea'* form occurring in the western Indian Ocean including Madagascar. Recent genetic evidence indicates that the Australian *'chinensis'* is genetically distinct while the Atlantic, Indian Ocean and South East Asian forms may constitute a group of several related species.

Whatever the precise genetic relationship between the different forms of humpback dolphin, all of them are gregarious inshore dolphins occurring near reefs, mangroves and estuaries, making them highly vulnerable to hunting, incidental capture in fishing nets, habitat loss and pollution. Estimates suggest that humpback dolphins have declined by as much as 30% across much of their range. Populations of the 'plumbea' form are small (500 or less) and fragmented and their total population throughout the Indian Ocean is probably less than 10,000. Overall, the species has been categorised by IUCN as 'Near Threatened' but this is an average rating and is likely to be revised as new information becomes available.

Humpback dolphin pair showing the distinctive dorsal fin

M.M.

In Madagascar, humpback dolphins have been recorded around Nosy Be, Mahajanga and Toliara, with no reports so far from the east coast. The species is territorial, with one group generally occupying a stretch of coast. For example, five groups, totalling 65 animals, have been reported for the Anakao area, south of Toliara, with groups ranging in size from five to 25 animals. In the same area, humpback dolphins have been found in mixed schools with other species (bottlenose and spinner dolphins). Humpback dolphins are actively hunted by traditional fishers around Mahajanga and Toliara and sometimes get entangled in shark nets. Humpback dolphins are generally considered to be the most threatened cetacean in Madagascar. Further surveys are required to determine their status and design appropriate conservation measures.

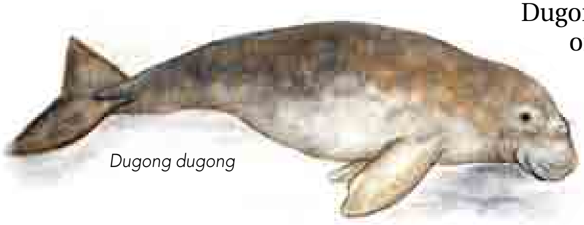
Other whales & dolphins

Other threatened whales and dolphins occurring in Madagascar are the fin whale (EN) and sei whale (EN). The fin whale is primarily a sub-tropical or temperate species rare in tropical waters, but is known to occur off southern Madagascar. Originally classed as 'vulnerable', it was reassessed as 'endangered' in 1996 and remains in this high risk category. The sei whale, while primarily a sub-polar species, is known to migrate to tropical wintering grounds and to occur around southern Madagascar. As large baleen whales that were once intensively hunted, their status is similar to that of the blue whales, although not as severe. While the majority of the remaining species are listed as 'data deficient' (15 species), six species (in addition to the humpback whale) have been assessed as 'least concern', namely the southern right whale, minke whale, cuvier's beaked whale, melon-headed whale, spotted dolphin and striped dolphin.

Fin whale *Balaeonoptera physalus* (EN)

Sei whale *Balaenoptera borealis* (EN)

Dugong (VU)

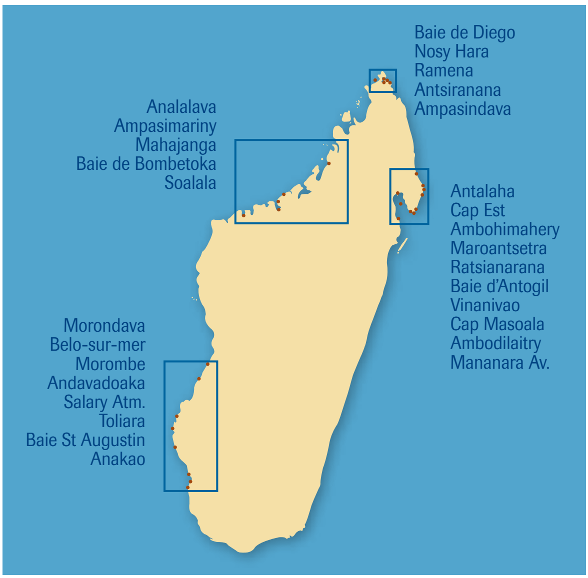

Dugong dugong

Dugong is one of three representatives of the Sirenia order of mammals, also including the African and Caribbean manatee and the extinct Steller's sea cow of the North Atlantic. Recent molecular genetic studies have shown that Sirenians share a common ancestry with a group or 'clade' of African mammals possessing mobile snouts which include the elephants, hyraxes, aardvarks, elephant shrews, golden moles and even the tenrecs of Madagascar!

In contrast to the manatees, which are confined mainly to rivers and estuaries, the dugong is exclusively marine, and occurs throughout the Indian Ocean. The dugong is rare throughout its range except in Western Australia, where it is effectively protected. Dugongs have been legally protected in Madagascar since 1961 and are listed on Appendix I of CITES, but this has not prevented continued hunting which became rampant during the 1980s. Classed as Vulnerable by IUCN at the global level, the dugong is without doubt the most endangered marine mammal in Madagascar, and has virtually disappeared from many parts of its former range.

Dugongs are large herbivorous animals that feed on seagrass. Dugongs once occurred around much of the Madagascar coastline but are now reduced to a few remnant populations in the West and North East of the island. While hunting has been the major cause of their decline, the degradation of seagrass beds by sedimentation and industrial shrimp trawling and the increase in background marine noise are likely to have been contributing factors.

The zone between Cap St. André and Nosy Be appears to be one of the most important areas for dugong in Madagascar. A national



Location of dugong observations in Madagascar 1990-2010 (WCS GIS Unit)

Dugong (Source: WWF)

Pair of dugong in Mayotte as seen from a boat (Source: Kiszka et al 2003)

survey in 2004 reported persisting populations of dugong associated with Bombetoka & Sokoany bays and around Katsepy and Antrema, near Mahajanga (part of the Mahavavy-Kinkony coastal wetlands complex). Anecdotal reports also exist for continuing presence of dugong around the Baie de Baly area. The far North (around Antsiranana) also appears to be a stronghold, with recent reports from Ampasindava, Diego bay, Ramena and Nosy Hara. The South West (Morombe area) and North East (Bay of Antongil) have also produced some reports in recent years.

Little is known about the migration or seasonal behaviours of dugong in Madagascar. Dugongs generally remain in their coastal home range but are also known to undertake long sea journeys. Fishers frequently report that dugong tend to stay a little offshore (outside the reef barrier when there is one) during the day and come into shallower water to feed on seagrass beds at night. Most encounters with dugong are in the summer months (October to March) suggesting they are more active during this period.

Dugong caught by fishermen at Nosy Hara in August 2003 (Source: WWF 2004 / Photo by Lyn Robinson)

Dugong butchered at Ramena, Northern Madagascar in 2003
(Source: WWF 2004)

Seabirds

Sooty tern *Onychoprion fuscata* (LC)
(Birds of Madagascar, 1998)

The seabird fauna of Madagascar has been described in Chapter 2. Most seabird species are migratory, and several species have nesting sites on the Madagascar coast or offshore islands, making them vulnerable to human disturbance and predation (particularly nest raiding). Just one seabird species occurring in Madagascar (Southern Giant Petrel) is listed by IUCN as Near Threatened (NT), while the remaining species are listed as Least Concern (LC) or are unlisted. Several species are listed in Appendix 2 of the Convention on Migratory Species (CMS). No seabirds are listed under CITES, or the Nairobi or Algiers conventions. A total of 15 species are protected under national legislation, 14 of which are listed by IUCN and five of which are also listed in Appendix 2 of the CMS.

STATUS OF THREATENED SEABIRD SPECIES

Name	Scientific name	IUCN	CMS	National
Black-browed albatross	*Diomedea melanophris*	-	Ann II	-
Shy albatross	*Diomedea cauta*	-	Ann II	-
Yellow-nosed albatross	*Diomedea chlororhyncos*	-	Ann II	Protected
Southern giant petrel	*Macronectes giganteus*	NT	Ann II	Protected
Crab plover	*Dromas ardeola*	LC	Ann II	-
Gull billed tern	*Sterna nilotica*	LC	-	Protected
Caspian tern	*Sterna caspia*	LC	-	Protected
Little tern	*Sterna albifrons*	LC	Ann II	-
Greater crested tern	*Sterna bergii*	LC	Ann II	Protected
Lesser-crested tern	*Sterna bengalensis*	LC	Ann II	Protected
Black-naped tern	*Sterna sumatrana*	LC	-	Protected
Roseate tern	*Sterna dougalii*	LC	-	Protected
Common tern	*Sterna hirundo*	LC	-	Protected
Bridled tern	*Sterna anaethetus*	LC	-	Protected
Sooty tern	*Onychoprion fuscata*	LC	-	Protected
Sandwich tern	*Sterna sandvicensis*	LC	Ann II	-
Saunders' tern	*Sterna saundersi*	LC	Ann II	Protected
Black tern	*Chlidonias niger*	LC	Ann II	-
White-winged tern	*Chlidonias leucopterus*	LC	Ann II	-
Red-billed tropic bird	*Phaethon aethereus*	LC	-	Protected
Red-tailed tropic bird	*Phaethon rubricauda*	LC	-	Protected
While-tailed tropic bird	*Phaethon lepturus*	LC	-	Protected

Marine turtles

Sea turtles are members of the reptile superfamily of Cheloniidea, with seven species worldwide. Six of the seven species are hard-shelled and placed in the family Cheloniidae, while the leatherback turtle *Dermochelys coriacea* has a ridged leathery shell and is placed on its own in the family Dermochelidae. Sea turtles are primitive anapsid reptiles (lacking openings in their skulls for muscle attachment) which have been present in the world's oceans for over 50 million

Hawksbill turtle
Eretmochelys imbricata (CR)

J.B.

TURTLE TUMOUR DISEASE
(fibropapillomonas)

The Maintirano region turtle conservation project coordinated by the Geneva Museum of Natural History and supported by WWF reported a high incidence of the disease fibropapillomonas in sea turtles captured for research around the island of Maroantaly, one of the Barren Islands. The disease causes tumours on the soft parts of the turtle. As the tumours grow they restrict movement of the neck and limbs, eventually causing death through asphyxiation or immobility. The disease was found to be affecting about 25% of animals captured and is therefore likely to be a significant cause of mortality in sea turtles.

Source: Bulletin de la tortue marine (WWF 2007)

SEA TURTLE NAVIGATION AND MIGRATION

Marine turtles make long journeys between feeding grounds and rookeries and show remarkable fidelity to their home base. While their migratory routes are determined primarily by ocean surface currents (they are slow swimmers), there is evidence that turtles are able to sense the direction of the earth's magnetic field and to use this to recognise local magnetic topography. Researchers working on Europa island in the Mozambique channel have found that when strong magnets are fitted to turtles' heads, their navigation is not as good. However, some turtles still manage to return home and it is therefore likely that they use other cues such as smell. Among the longest turtle migrations recorded are by loggerheads, which have been known to travel between Western Australia and the Natal coast of South Africa. In Madagascar, loggerhead turtles tagged in Durban have been recaptured along the Toliara coast.

IMPORTANCE OF ISLANDS FOR TURTLE NESTING

Turtle nesting on the Madagascar mainland has declined due to systematic egg collection and the taking of females. Significant nesting now only occurs on oceanic and continental islands. The major nesting sites are on oceanic islands belonging to France (Europa, Bassas de India, Ile Juan da Nova, Iles Glorieuses, Ile de Tromelin) and on Aldabra atoll (Seychelles). These nesting sites probably supply most of the turtles around Madagascar, particularly of green turtles. A few continental islands within Madagascar's territorial waters may still be important. A colonial order of 1923 declared five small islands along the west coast (Nosy Ve, Nosy Trozona, Nosy Chesterfield, Nosy Iranja and Nosy Anambo) as nesting reserves for green and hawksbill turtles. The last reported nest on Nosy Ve was in 1986, whereas nesting still continues on Nosy Iranja, with over 100 nests annually. The status of nesting on the other three islands is unknown. Other known nesting sites include Nosy Sakatia (Nosy Be) with about 15 nests annually, the Radama Islands and the Barren Islands, opposite Maintirano, where 10 nests (all green turtle) were reported in 2007.

Tim Healy of Aquaterre recording green turtle nesting for BBC radio's *World on the Move Series*, Sakatia Island, Nosy Be, NW Madagascar

Green turtle *Chelonia mydas* (EN) (Photo: Jérôme Bourjea, IFREMER)

years and show few signs of change since that time. Like most reptiles, they breathe air and lay eggs on land, necessitating annual migration to breeding and nesting sites (called rookeries).

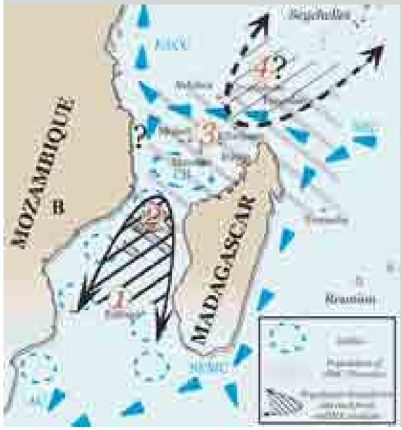
Five species of sea turtles occur in Madagascar waters – green turtle (*Chelonia mydas)*, hawksbill (*Eretmochelys imbricata*), loggerhead (*Caretta caretta*), olive ridley (*Lepidochelys olivacea*) and leatherback (*Dermochelys coriacea*). All, with the exception of the leatherback, are known to nest in Madagascar. The most common and widespread species is the green turtle which accounts for over 90% of captures in most areas. Next is the hawksbill which accounts for about 3-4% of captures and is also widespread. Hawksbills are often seen on protected coral reefs such as at Nosy Tanikely. Olive ridely turtles are distributed in the west, where they may locally account for 5% of captures. Olive ridley turtles form breeding aggregations (*arribada*) before mass nesting making them especially vulnerable. Nesting has ceased at the only known site at Betania, near Morondava. The loggerhead turtle is widespread but uncommon. In the 1970s loggerheads still nested in significant numbers in the south east of Madagascar north of Tolagnaro, but researchers reported just 23 nests in the 2001-2002 nesting season, about 10 of which were raided and the nesting females killed. Leatherback is encountered only offshore in deep water and has never been known to nest in Madagascar. It is very occasionally caught by fishers.

Turtles are subject to numerous threats, including longline fishing, industrial trawling, artisanal hunting, nest raiding, loss of habitat and disease. Of the five species occurring in Madagascar, two (leatherback and hawksbill) are classed as critically endangered (CR) while green, loggerhead and olive ridley are classed as endangered (EN). All species are listed in Appendix 1 of CITES and Appendix 1 of CMS. Three out of five species (leatherback, olive ridley, loggerhead) are listed in Annex II to the Nairobi Convention and two in Annex III (green, hawksbill). All marine turtles are listed as Class A species in the Algiers Convention. Since 2006, all five species of sea turtles occurring in Madagascar are fully protected under Decree 2006-400 of

GREEN TURTLE RACES IN THE MOZAMBIQUE CHANNEL

Green turtle *Chelonia mydas* is the dominant species in the Mozambique channel. Recent genetic studies of the green turtle identify four separate nesting populations in the Mozambique Channel, with one centred on the Comoros and North West Madagascar. Sea turtles in the northern part of the Mozambique channel tend to nest during austral winter, whereas those in the southern half nest during austral summer. The population on Ile Juan de Nova, a little south of Cap St. André and roughly mid-channel, nests all year round, suggesting that the nesting season is determined at least in part by water temperature.

(Source: Bourjea et al., 2007)



13 June 2006. Turtles have also benefited from partial legal protection under two colonial orders of 1923 which declared nesting reserves on five small islands and banned capture of nesting females and undersized animals. The orders have not been enforced with the possible exception of the reserve of Nosy Iranja which is privately owned and which supports Madagascar's largest nesting population of green turtles.

Nile crocodile (LC)

Crocodiles are members of the reptile order Crocodylia which includes the alligators, caimans, gavials and crocodiles. The Crocodylia are descendants of the crocodile-like Eusuchians which first appeared in the Paleocene about 100 million years ago. They are diapsid reptiles (having two skull openings on each side) and are members of the archosaurs, the group that gave rise to dinosaurs and birds. Despite their archaic appearance, crocodiles possess several advanced features such as a 4-chambered heart and a cerebral cortex.

Nile crocodile *Crocodylus niloticus* (Ankarafantsika, North West Madagascar)

T.S.

MADAGASCAR'S CROCODILES CAN BE CONSIDERED A MARINE SPECIES (Olivier Behra)

Recent genetic studies confirm the classification of crocodylia into two main assemblages – the Indo-Pacific assemblage (including the crocodiles and gavials) and a New World assemblage (alligators and caimans), with a common ancestor which existed about 70 million years ago.

The Indo-Pacific assemblage includes the crocodiles which possess a gland on their tongue for secreting salt, which is absent in the alligators. This suggests an adaptation to brackish or marine environments. The Indo-Pacific salt water crocodile *Crocodylus porosus* can survive permanently in the sea and can reach 7 metres in length, making it the largest living reptile.

The Nile Crocodile *Crocodylus niloticus* is the principal crocodile species in Africa and Madagascar. Recent genetic studies confirm that *C.niloticus* comprises two distinct lineages, west and east, with a common ancestor dating back about 8 million years. The distribution of crocodiles around Africa indicates that they have made frequent marine migrations. Madagascar crocodiles are within the eastern lineage and are closely related to crocodiles of Tanzania and Zimbabwe. The populations in Madagascar have mixed genetic origins, suggesting that east African crocodiles have crossed the Mozambique Channel to Madagascar on multiple occasions.

In Madagascar, Nile crocodiles are regularly encountered in mangroves, confirming their capacity to survive in salt water. While confirmed reports are lacking, it is likely that Nile crocodiles occur regularly in the seas around Madagascar, especially along the west coast where there are many large estuaries.

Sharks and rays

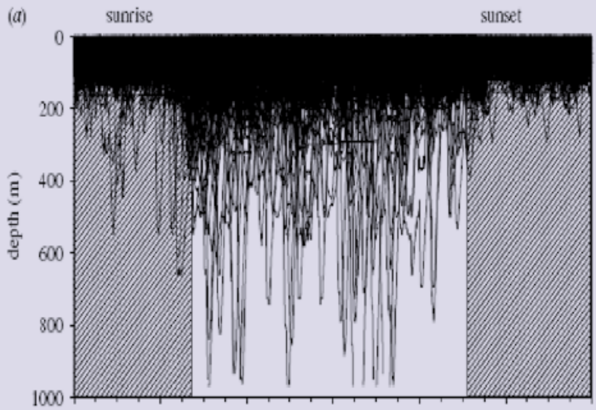
The sharks and rays (which include the sawfish and chimaeras) share the common characteristics of slow growth rate, low fecundity and large size, making them potentially vulnerable to extinction from fishing or other threats. Sharks and rays are thus of conservation concern as a group of species. Out of the estimated 123 shark and ray species occurring in Madagascar, 31 species are classed as threatened including three 'Critically Endangered' (all three of the sawfish species which may occur), one 'Endangered' (the bottlenosed skate *Rostroraja alba*), 17 'Vulnerable' (including the whale shark and the endemic Madagascar skate) and 10 'Near Threatened'. Only six species are listed as 'Least Concern' while the remainder are 'Data Deficient' (21) or 'Not Evaluated' (48).

Here we describe a selection of the better known vulnerable species which occur in Madagascar (whale shark, Madagascar skate, manta ray) and the critically endangered sawfish.

Blacktail reef shark *Carcharhinus amblyrhyncos*
South Pass, Ranobe Lagoon, Ifaty

WHALE SHARK (VU) by Rachel Graham, WCS

Whale sharks *(Rhincodon typus)* reach a confirmed length of 12.75 m but are purported to reach 20m and weigh up to 34 tons, making whale shark the world's largest fish. Like baleen whales, the whale shark is a filter feeder, using modified gill rakers rather than baleen plates to filter zooplankton, small fish and jellyfish from the water. Slow moving and docile, they are generally harmless to humans. Whale sharks are highly migratory and capable of transoceanic movements when targeting predictable seasonal pulses including fish spawning events. The migratory routes and site fidelity of whale sharks



Diurnal diving behaviour in whale shark
(from Graham et al 2006)

Whale shark *Rhincodon typus (VU)*

WCS/Rachel Graham

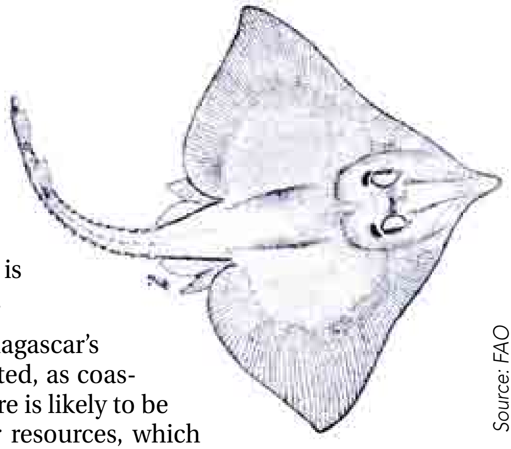
in the Western Indian Ocean are becoming increasingly known through the use of satellite and acoustic tagging techniques. Whale sharks tagged and photo-identified in Nosy Be were found to travel towards the Comoros Islands, to the east coast of Madagascar and to Seychelles and the Maldives respectively and a whale shark tagged in Mozambique travelled to southern Madagascar suggesting connectivity with East Africa. Results also suggest that although whale sharks do not reside permanently in Nosy Be, they may return seasonally to the area to feed on blooms of copepods and pelagic clupeids. The highly migratory nature of whale sharks makes it difficult to assess population size, which remains unresolved both globally and in the Western Indian Ocean.

Whale sharks migrate vertically, following the daytime vertical migration of zooplankton which descend to deeper water during the middle of the day. Whale sharks also undertake deep dives to as much as 1000 m to feed on the deep scattering layer, a thin band of deep water organisms which inhabit the ocean depths by day and then migrate close to the surface at night to feed.

Whale sharks occur along all the coasts of Madagascar but are most predictable in North West Madagascar. Whale sharks have been reported from the Mahajanga area and from several locations to the north (Sahamalaza, Iranja, Nosy Be). In Nosy Be, whale sharks are present all year round, although most predictably encountered during the rainy season (November-December) when zooplankton levels are highest. Around Juan de Nova they have been observed in December. Whale shark has also been reported from the Toamasina area. Further south whale sharks are observed seasonally around Toliara in March-May and around Tolagnaro in April.

Whale sharks are considered *fady* or taboo in NW Madagascar and are not targeted by coastal fishers. Incidental captures occasionally occur through entanglement with nets in nearshore and offshore tuna fisheries. The growing international trade in whale shark fins and captures for aquaria remains a significant potential threat, and while whale sharks are listed on Appendix II of CITES (in response to a submission from Madagascar) and Appendix 2 of CMS, they are not listed under regional conventions or protected under domestic legislation.

Madagascar skate (VU)


Source: FAO

The Madagascar skate *Dipturus crosnieri* is one of few marine fish species endemic to Madagascar. It is a relatively small and rare deepwater skate with a limited distribution on the continental slope off the west coast of Madagascar (known from Nosy Be and Toliara at depths of 300 to 850 m). Virtually nothing is known of the biology of the species.

While fishing pressure on Madagascar's continental slope is currently limited, as coastal resources become depleted there is likely to be increased pressure on deep water resources, which may threaten the Madagascar skate. The Madagascar skate may already be affected by deep water shrimp fishing off north west Madagascar. More information is required to determine distribution, population size and life history, as well as careful monitoring of fishing activities in Madagascar which could affect the species.

MANTA RAYS *Manta birostris* & *Manta alfredi* (VU) by Rachel Graham (WCS)


Manta ray *Manta* sp.
J.B.

The manta rays (the largest members of the family Mobulidae) inhabit temperate, tropical, and subtropical waters worldwide, between 35°N and 35°S latitudes. Recently manta rays were found to comprise two species with different morphological and genetic features: the larger *Manta birostris*, an oceanic and migratory species that occasionally frequents coastal areas and *M. alfredi*, a smaller, mainly coastal species. Both species propel themselves through the water using broad muscular triangular pectoral fins and occasionally jumping clear of the water, possibly to dislodge parasites upon reentry. Adults are easily recognized by their projecting cephalic fins - extensions of the pectoral fins, which are furled like spirals when swimming and extended to guide prey into their large terminal mouths when feeding near the surface or midwater. All mobulids are primarily filter feeders which occasionally consume small fish. In areas where zooplankton is plentiful, mantas have been observed in large aggregations of 50 individuals or more, often swimming in slow vertical loops, concentrating their prey while feeding. Manta rays have the largest brain to body ratio of any elasmobranch and may have a rete, or countercurrent blood exchange

Round ribbontail ray *Taeniura meyeni* (VU)

system that keeps the brain and eyes warm, suggesting a highly evolved species. The species are ovoviviparous, giving birth to one or occasionally two pups after a gestation of a year. Manta rays are increasingly targeted in the Indo-Pacific for their meat, skin (which has abrasive properties) and gill rakers, a component of Chinese medicine. In Madagascar, mantas and mobulas have been occasionally captured in the area of Nosy Be, most often due to entanglement in shark nets. Fishers and dive guides have noted a dramatic decline in captures and sightings over the last five years, which suggests that mantas in that area have been extirpated. The IUCN lists *Manta birostris* and *Manta alfredi* as "Vulnerable".

Their conservation status in Madagascar is unknown and further research is required into species distributions, relative abundance and fisheries.

Manta ray *Manta* sp.

Sawfish (Pristidae) (CR)

Sawfish are cartilaginous fishes of the family Pristidae found in tropical coastal seas and estuaries. Superficially shark-like, they are really a kind of ray with spiracles (water intakes) and gill slits on the underside of their head. Sawfish possess a remarkable toothed saw or rostrum which they use for stunning fish or sweeping invertebrates out of the sand and mud.

Sawfish were once widely distributed in the northern Indian Ocean, around South and South-East Asia and around northern Australia, but during the 20th century they became rare or virtually extinct throughout their respective ranges. The decline in the numbers of sawfish is often ascribed to their vulnerability to entanglement in nets and their very low breeding rates, something they have in common with other cartilaginous fishes. Sawfish are classified as Critically Endangered in the IUCN Red List and as Appendix I species under CITES. However, they are not listed under the Nairobi or Algiers conventions and are unprotected under national wildlife legislation.

Captured sawfish *(Pristis microdon)*
from Kiener (1963)

Five to seven species are recognized worldwide of which up to three may occur in Madagascar - the large tooth sawfish *Pristis microdon*, the green sawfish *P. zijsron* and the knifetooth sawfish *Anoxypristis cuspidata*. Based on the rostra seen as ornaments in beach hotels and on old literature, the large tooth sawfish is (or has been) the main species in Madagascar.

In the 1960s, sawfish were still relatively common in Madagascar, for which there were fisheries in west coast estuaries and coastal wetlands. They were even observed to travel as far as 200 km up major rivers. Today, sawfish are very rare, probably due to a combination of shrimp trawling, the use of gill nets across rivers and the setting of estuarine fish fences *(valakira)*. Sawfish may also have been

Largetooth sawfish *Pristis microdon* (CR)

adversely affected by sedimentation of their habitat due to inland deforestation.

Recent field surveys and anecdotal reports suggest that sawfish still exist in reduced numbers, particularly in the west and northwest around Nosy Be and the Mahavavy, Tsiribihina and Mangoky river deltas. Madagascar (and particularly west Madagascar) may therefore constitute a last stronghold in the Western Indian Ocean for sawfish. Surveys are urgently needed to determine their status, prove the need for legal protection and design a conservation action plan.

Ray-finned fishes

There is increasing recognition that ray-finned or 'teleost' fishes may be vulnerable to extinction from fishing and habitat loss. Particularly at risk are the very large, reef dependent species (e.g. giant grouper *Epinephelus lanceolatus* and the bumphead parrotfish *Bolbometopon muricatum*) or those which are affected by international trade, such as the Napoleon wrasse *Cheilinus undulatus* (whose fleshy lips are highly prized in Asian countries) and the sea horses (Syngnathidae) which are used in Chinese traditional medicine. Species subject to industrial fishing are also of increasing concern, such as tuna (southern bluefin and big-eye tunas).

Napoleon wrasse *Cheilinus undulatus* (EN)

A total of 14 marine teleost fish species known from Madagascar are included

Southern bluefin tuna *Thunnus maccoyii* (CR)

in the IUCN Red List. This number is likely to increase as new fish species are added to the Red List and as knowledge of Madagascar's marine fish fauna improves.

The IUCN notes only one critically endangered (CR) species for Madagascar, *Thunnus maccoyii* or Southern Bluefin tuna. Southern bluefin tuna occurs in the most southern part of Madagascar's 200 mile EEZ where it is targeted by mainly Asian longline tuna vessels.

Brown marbled grouper *Epinepheleus fuscoguttatus* (NT)

MARINE RAY-FINNED FISH OCCURRING IN MADAGASCAR AND INCLUDED IN THE IUCN RED LIST OF THREATENED SPECIES

Species	English Name	Occurrence in Madagascar	Habitat	UICN	CITES
Epinephelus lanceolatus	Giant grouper	Rare, occurs in all reef regions of Madagascar	Reefs, to 100 m	VU	-
Epinephelus marginatus	Dusky grouper	Uncertain (IUCN); occurs according to FishBase; not reported in local research	Reefs, to 300 m	EN	-
Epinephelus fuscoguttatus	Brown marbled grouper	Occurs in reefs of NW and SW Madagascar	Reefs, to 60 m	NT	-
Cephalopholis boenak	Bluelined coral cod	Occurs in all coral reef regions of Madagascar	Reefs, to 50 m	LC	-
Dermatolepis striolata	Smooth grouper	Uncertain occurrence according to IUCN but reported locally in NW and SW	Reefs, to 15 m	DD	-
Cheilinus undulatus	Napoleon wrasse	Widespread on coral reefs of Madagascar but uncommon	Reefs, to 60 m	EN	App II
Bolbometopon muricatum	Bumphead parrotfish	Rare, reported from coral reefs in NNE, NW and SW reef regions	Reefs, to 50 m	VU	-
Argyrosomus hololepidotus	Madagascar meagre	Endemic to SE Madagascar (estuaries & marine), not on coral reefs	Shallow marine	EN	-
Thunnus maccoyii	Southern Bluefin tuna	All around Madagascar, particularly in the southern part of EEZ	Pelagic, to 50 m	CR	-
Thunnus obesus	Big-eye tuna	Widespread, but occurs mainly in waters to the south and east of Madagascar	Pelagic, to 250 m	VU	-
Eurypegasus draconis	Short dragonfish	IUCN indicates all coasts, although not reported in local research	Reefs, to 90 m	DD	App II
Hippocampus borboniensis	Reunion seahorse	Not reported in Madagascar, but may occur due to proximity to Reunion	Demersal, to 60 m	DD	App II
Hippocampus fuscus	Sea pony	Not reported in Madagascar, but presence likely due to large range	Demersal, to 10 m	DD	App II
Hippocampus kuda	Common seahorse	Reported by local research to occur in NW and SW	Reefs, shallow	VU	App II
Syngnathoides biaculeatus	Alligator pipefish	Reported by local research to occur in SW	Reefs, shallow	DD	App II

Bumphead parrotfish *Bolbometopon muricatum* (VU)

Three ray-finned species are listed as Endangered (EN) (Dusky Grouper *Epinephelus marginatus* (EN), Napoleon wrasse *Cheilinus undulatus* and the Madagascar meagre *Argyrosomus hololepidotus*). The dusky grouper has not been reported to occur in Madagascar by local ichthyologists but is present according to FishBase. While globally threatened by the fish trade (and listed in Appendix II of CITES), the Napoleon wrasse is still common in Madagascar where it is relatively less threatened.

Four species are listed as vulnerable (VU). The giant grouper *Epinephelus lanceolatus* has been reported from all coral reef areas in Madagascar but is rarely seen by divers or reported caught in fisheries and is presumed to be in decline. The bumphead parrotfish *Bolbometopon muricatum* has been reported on a few occasions from reefs in the north west, south west and north east but appears to be rare. Big-eye tuna *Thunnus obesus* (VU) is still relatively common in Madagascar, particularly in the south. The common seahorse *Hippocampus kuda* has been reported from reefs in the NW and SW but its relative abundance is unknown.

Of the data deficient (DD) species, *Eurypegasus draconis*, *Hippocampus borboinensis* and *H. fuscus* have not been reported to occur in Madagascar. The remaining assessed species all occur in Madagascar but their status is unknown.

Coelacanth *Latimeria chalumnae* (CR)

The coelacanths are primitive lobe-finned fishes (Sarcopterygians) which first appeared about 400 million years ago and were believed to have been extinct for over 50 million years until the surprise first capture of a coelacanth in deep water off East London, South Africa, in 1938 The 'fossil' fish was subsequently named *Latimeria chalumnae* after its discoverer, Marjorie Courtenay-Latimer and the Chalumna river near which it was caught. The coelacanths (from the Greek *koilos* (hollow) and *akantha* (spine) possess limb-like fins and are considered to be close to the ancestral stock which gave rise to four-footed land animals (tetrapods). Like many of the sharks, coelacanths give birth to live young (usually a litter of 5 to 10 pups).

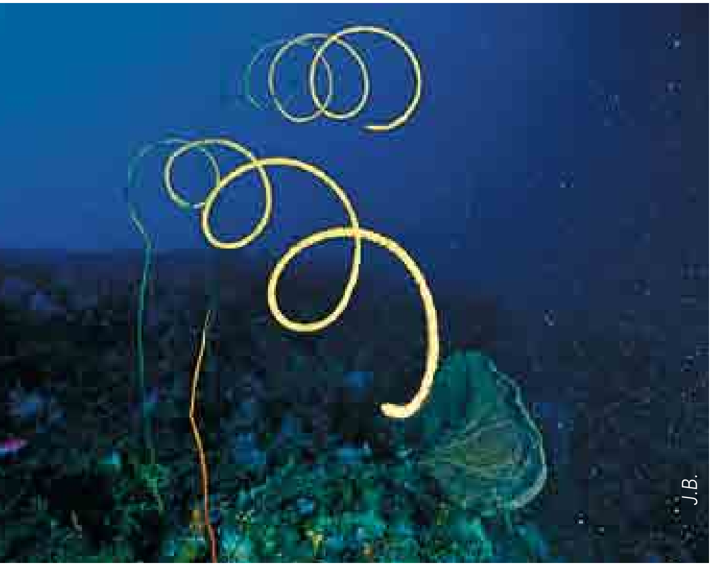
Coelacanth *Latimeria chalumnae* (CR)

For many years after its first capture, the coelacanth was unknown except from regular captures in the Comoros islands. In the 1990s, the advent of deep water shark fishing to supply the shark fin trade led to an explosion of capture records in the Western Indian Ocean, with five captures in Madagascar, several in Mozambique, more than 30 in Tanzania and several in South Africa. These new records have much improved understanding of coelacanth biology and habitat preference, which is for caves and hollows at depths of 200-300 m. Based on their small population sizes, slow reproduction and vulnerability to fishing and specimen collecting, coelacanths are classed as Critically Endangered by IUCN and listed in Appendix 1 of CITES. In Madagascar there is no domestic legal protection but the export of specimens is controlled under national regulations from the colonial period.

In Madagascar coelacanths are mainly known from sites in the southwest, near Toliara (Soalara, Anakao, Tsiandamba, Fiherenamasay) where several have been caught since 1995 and where the fish is known as *fiandolo* or 'ghostfish'. In 2006, a further coelacanth was caught off the Barren Islands offshore from Maintirano, west Madagascar, substantially extending its known range in Madagascar.

Coelacanth on Barren islands, 2006

Invertebrates



Whip corals, Nosy Hara, Northern Madagascar

Invertebrates have received less species-based conservation attention than vertebrates. Rarely monitored and often difficult to identify, quantitative assessment of the impact of human exploitation on invertebrates is rarely possible. Thus, no marine invertebrate is yet listed in the IUCN Red List. Certain invertebrates affected by international trade, including large molluscs, hard corals and black corals have been listed in Appendix II of CITES and several large molluscs and the coconut crab are listed under the Nairobi convention. National protection of invertebrates is limited to regulations on the harvesting of commercially fished species such as shrimps, sea cucumbers, pearl oysters, edible oysters and sponges.

Large molluscs

Large molluscs are extensively exploited for food and as ornaments and widely traded internationally. Species particularly affected include the giant clams, conches, tritons, trochus shells and pearl oysters. All giant clams and the queen

Giant clam *Tridacna maxima*

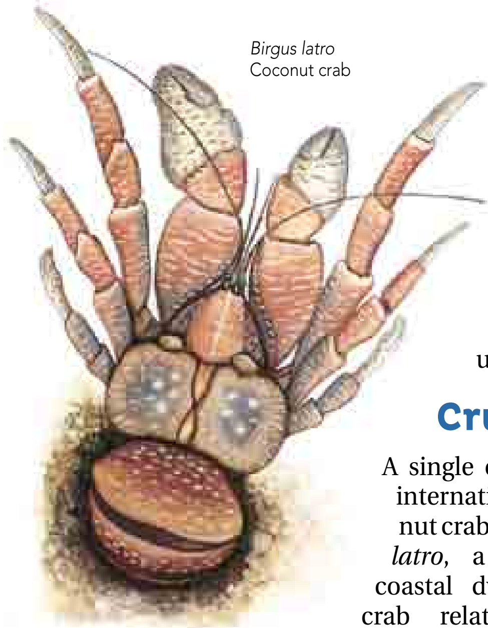
Giant clam *Tridacna maxima*

conch are listed in Appendix II of CITES, and tritons, trochus, three giant clams and pearl oysters are listed in Annex 2 of the Nairobi convention. Other ornamental species, such as cowries, helmet shells and cone shells, are widely impacted by collection but have not yet been the subject of international protection. Madagascar harbours all of the mollusc species listed in CITES and the Nairobi convention, but has to date not passed any domestic legislation to protect large molluscs, apart from some old regulations on the harvesting of pearl oysters.

Corals

Various types of coral are affected by international trade. Among the reef building corals, the readily harvested branching corals and table corals are the most affected by the ornamental trade. A relatively small volume of living corals is harvested for the live aquarium trade. More massive corals are used locally in construction, for septic tanks and for firing to make lime. Other 'hard' corals affected by trade include blue corals, fire corals and the red organ pipe coral (which is in fact a relative of the soft corals). As a precautionary measure, all hard corals are listed under Appendix II of CITES, regulating international trade in these species. Hard corals are not, however, listed in the Nairobi convention

Rose coral *Montipora tuberculosum*, Andavadoaka, SW Madagascar and none is protected under domestic regulations. Among the soft corals, the black corals and sea whips (also known as antipatharians) are traded for making jewellery. All black corals are listed in Appendix II of CITES and one species of black coral and all whip corals are listed in Annex 2 of the Nairobi convention, but none is protected under domestic legislation.



Birgus latro
Coconut crab

Crustaceans

A single crustacean species is the subject of international protection – the massive coconut crab *Birgus latro*, a giant coastal dwelling crab related to the hermit crabs, but which does not carry any shell. Rare but widely distributed throughout the Indian Ocean, coconut crabs almost certainly occur in remote coastal areas and on some of Madagascar's 250 small islands where they may be threatened by occasional hunting for food or loss of habitat. While not listed in the appendices of CITES, the coconut crab is listed in Annex 2 of the Nairobi convention and is listed in the IUCN Red List as "data deficient" but remains unprotected under domestic legislation.

Other invertebrates

Certain other invertebrates are commercially harvested in Madagascar and have been the subject of fisheries regulations – notably lobsters, shrimps, sea cucumbers and sponges. However, none of these species is protected internationally or nationally.

Panulirus homarus

INVERTEBRATE SPECIES OF CONSERVATION CONCERN OCCURRING IN MADAGASCAR

Name	Scientific name	CITES	Nairobi	National
CORALS				
Hard corals (all species)	*Scleractinia*	App II	-	-
Blue corals (all species)	*Helioporidae*	App II	-	-
Fire corals (all species)	*Milliporina / Milliporidae*	App II	-	-
Lace corals (all species)	*Stylasterina / Stylasteridae*	App II	-	-
Organ pipe corals (all species)	*Stolonifera / Tubiporida*	App II	-	-
Black corals (all species)	*Antipatharia*	App II	-	-
Black coral (one species)	*Antipathes dichotoma*	App II	Annex 2	-
Whip corals	*Cirripathes* spp.	-	Annex 2	-
MOLLUSCS				
Giant clams (all species)	*Tridacnidae*	App II	-	-
Queen conch (Megagastropoda)	*Strombus gigas*	App II	-	-
Fluted giant clam	*Tridacna squamosa*	App II	Annex 2	-
Small giant clam	*Tridacna maxima*	App II	Annex 2	-
Horse's hoof clam	*Hippopus hippopus*	App II	Annex 2	-
Triton's trumpet shell	*Charonia tritonia*	-	Annex 2	-
Commercial trochus	*Trochus niloticus*	-	Annex 2	-
Pearl oysters	*Pinctada* spp.	-	Annex 2	Regulated
CRUSTACEANS				
Coconut crab	*Birgus latro*	-	Annex 2	-

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Madagascar is world-renowned for its unique terrestrial biodiversity, which has been the inspiration of naturalists for centuries and remains so for conservationists today. Madagascar's marine biodiversity has received markedly less scientific attention. Although levels of endemism are low in marine environments, Madagascar's size and tropical location in the Western Indian Ocean make it an important regional centre for marine biodiversity.

Building upon a foundation of ecological and oceanographic knowledge laid by French scientists working in Madagascar in the 1960s and 70s, the author and contributors have drawn from an extensive array of published and unpublished sources, including the latest research in marine ecology, oceanography and climate change, to provide a comprehensive and informative introduction to the marine biodiversity of Madagascar, with historical depth yet a modern, ecosystem-based, perspective.

The guide is richly illustrated by the underwater photographs of Jürg Brand, whose images capture the full range of Madagascar's marine biodiversity, from the grand oceanic seascapes of the offshore reefs and marine megafauna to the minutest, colourful details of the marine invertebrates. Some high quality images from other photographers fill the few remaining gaps.

In the last 10 years, interest in marine conservation has risen exponentially in Madagascar. Almost a dozen new marine protected areas have been designated since 2000 and all the major international NGOs now have substantial marine conservation programs. Fisheries management authorities and private operators are also playing an important part. This book should be welcomed by marine conservation professionals, fisheries managers, scientists, students, divers and anyone with an interest in Madagascar's marine environment.

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