9
Deep sea and Offshore/Pelagic Habitats

David Obura

Opposite page: Larval squid in the plankton of the WIO. © Cedric Guiguand/Emmanuel G. Reynaud.

INTRODUCTION

The deep sea habitats of the Western Indian Ocean (WIO) are very poorly known, particularly from the perspective of the governments in the region, which have limited capacity to engage in deep sea research or plan for exploitation of resources in this environment in the near future. Nevertheless, there are some emerging exceptions to this which will be presented in this chapter. In view of the paucity of general knowledge on deep sea habitats in the region, this introduction includes information on their basic structure, followed in later sections by a summary of their status, knowledge on their biodiversity, and pressures/trends in the future.

Plate tectonics

The WIO contains both active and fossil tectonic plate margins, some of the deepest fracture zones in the world, the most complex mid-ocean ridge configurations and some of the thickest sedimentary sequences in the world's ocean basins. The continental land mass of Africa, Madagascar, and the North Seychelles Bank are remnants of the supercontinent Gondwana, which dates from pre-Cambrian times over 650 million years ago (mya), and that started to break up 180 mya. Key events include:

- Formation of the Mozambique Channel, from about 180 -150 mya when Madagascar, Australia, India and Antarctica rifted from the African coast.
- Australia-Antarctica started to separate from Madagascar-India 120 mya.
- India split from Madagascar and moved northwards, leaving behind a fragment which is now the North Seychelles Bank 80 mya.

The WIO floor is composed of two major plates, the African and Indian plates; the Australian plate lies to the east, the Arabian plate to the north. The ocean floor is still tectonically active, with a spreading rift along the South West and Central Indian Ocean ridges, and northwards in the Carlsberg ridge that extends into the Red Sea. This continuous ridge system forms the approximate eastern boundary of the WIO and the African coastline defines the western boundary (ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b, Figure 9.1).

Hotspots and other geological features

Within its broader tectonic margins, the WIO contains a number of active hotspots, two of which are of global significance and scale. The Mascarene-Reunion hotspot became active at the Cretaceous-Tertiary (K-T) boundary about 67-64 mya, through a massive eruption of magma that formed the Deccan Traps in India (classified as a Large Igneous Province, or LIP). As the Indian plate moved northwards over the hotspot, a series of island chains were formed: Lakshadweep – Maldives (57-60 mya), the Chagos Archipelago (48 mya), Saya de Malha (45 mya), Nazareth and Cargados Carajos (34 mya), Mauritius (7-8 mya) and Reunion (0-2 mya). Only the youngest two, Mauritius and Reunion have volcanic features breaking the surface (the

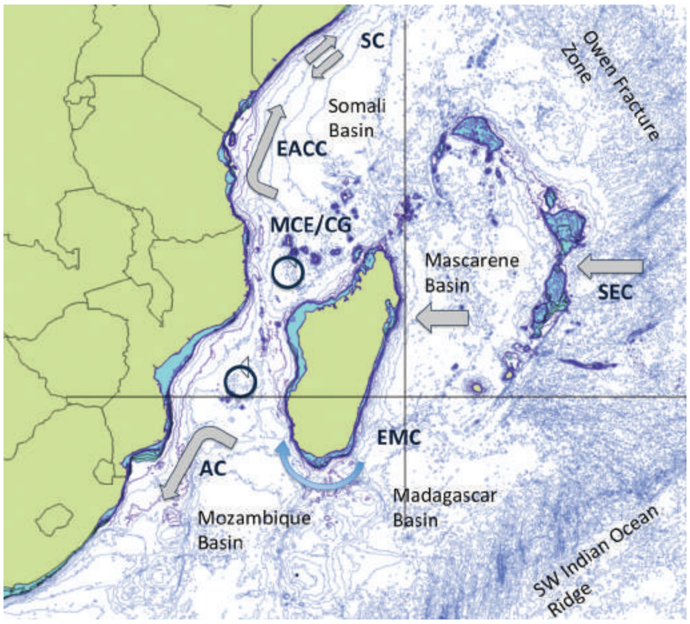


Figure 9.1. Deep sea features of the Western Indian Ocean, including principal basins and currents Bathymetry is shown at 100 m depth (light blue shading) then at 500 m and 500 m intervals thereafter. Abbreviations: AC Agulhas Current, EACC East Africa Coastal Current, EMC East Madagascar Current, MCE/CG Mozambique Channel Eddies/Comoros Gyre, SC Somali Current, SEC South Equatorial Current.

latter is still volcanically active today); all the others have sunken below the ocean surface and are capped by biogenic carbonate platforms and coral atolls or islands. The Central Indian Ocean ridge itself moved over the hotspot about 45 mya, separating the Chagos and Saya de Malha Banks. During the Cretaceous, the continental fragment of Madagascar lay over the Marion hotspot, creating a submarine Plateau which extends southwards some 1 300 km at depths of 1 000-2 000 m, rising above the deeper basins to the east and west up to 5 000 m deep.

Seamounts in the WIO are concentrated on the mid-ocean ridges, particularly the South West Indian Ridge, and scattered around the Mascarene Plateau. Approximately 700 seamounts have been identified in the WIO region from global studies of bathymetry ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b). Most seamounts in the WIO are outside national jurisdiction, with only those scattered around the Mascarene Plateau being within the EEZs of the regional countries. A complex geological history is suggested by the multiple islands and island groups within the Seychelles-Mascarene region (eg Aldabra group, Farquhar/Providence and the Amirantes). Other volcanic features include the island of Rodrigues and Soudan Bank, seamounts in the Seychelles that break the surface as coral reefs, the Comoros Archipelago, the Iles Eparses, and the Davies Ridge in the Mozambique Channel.

Ocean basins

As a result of these various geological features, the WIO is split into four deep basins: the Madagascar (5 500 m, south-east of Madagascar), Mascarene (4 900 m, west of the Mascarene Plateau), Mozambique (5 000 m, south of the Mozambique Channel) and Somali Basins (5 100 m, between Somalia and the Seychelles, Figure 9.1). Little work has been done on the abyssal plains and soft sediments of these basins, though drilling on and near the Mascarene Plateau shows thick accumulations of marine sediments, and terrestrial sediments in the Mozambique Channel, probably washed off the African and Madagascan landmasses by large rivers over >100 million years.

Oceanography

The oceanography of the Western Indian Ocean is determined by interactions between the geological features outlined above with the equatorial and western boundary currents of the ocean basin. The South Equatorial Current (SEC) enters the WIO as a broad slow surface current stretching from about 5-16°S, fed from the Indonesian Through-Flow with waters from the Pacific Ocean, and passing the Chagos Archipelago at its northern edge. At the Mascarene Plateau, the SEC is partially blocked, with 50 per cent of its flow forced through the narrow gap between the Saya de Malha and Nazareth Banks at about 12°S, the remainder flowing both north and south of these two banks.

Approaching Madagascar, the main flow of the current is at about 17°S. The banks and island systems lying in the pathway of the SEC function as stepping stones for species crossing the Indian Ocean, providing genetic connectivity. Interestingly, there is evidence pointing to west-east transport (Sheppard and others, 2012) as well as in the expected east-west direction.

The tip of Madagascar and the Comoros-Glorieuses chain interact with the flow of the SEC and open ocean features such as Rossby waves to generate unique and highly dynamic meso-scale eddies within the northern Mozambique Channel. The "Glorioso Front" probably marks the transition from the SEC to the waters of the channel, where a series of clockwise and anti-clockwise eddies and an intermittent gyre around the Comoros chain are induced (Ternon and others, 2014). Being driven by these features, water may flow in any direction, resulting in a highly mixed and dynamic water body in the northern part of the channel. As the channel narrows at about 17°S, the flow becomes more southward just offshore of the Mozambique coast. Complex forcing of biological parameters results from these dynamics, including up- and downwelling in the eddies and their interactions with the continental shelves and slopes below at least 1 000 m depth. As a result, the Mozambique Channel is one of the most energetic western boundary zones of all the world's oceans (Ternon and others, 2014).

The rapid flow of the East Madagascar Current interacts with the Madagascar Plateau, which extends southwards over 1 000 km at depths of 1 000 to 2 000 m, as it curls around the southern tip of Madagascar. This results in highly dynamic nearshore eddies and nearshore–offshore upwelling over 100s of square kilometres of sea, enriching highly productive food webs. This also results in unique communities and high levels of endemicity at the transition zone between the tropical and subtropical regions. These waters merge with waters from the Mozambique Channel and feed into the Agulhas Current, one of the fastest and narrowest coastal boundary currents in the world. Most of the Agulhas waters turn 180° (retroflect) and return to the southern part of the WIO at about 40°S.

In the north, the seasonally reversing Somali Current and seasonal northern Indian Ocean gyre are dominated by the influence of the Asian land mass and the monsoons, resulting in a highly dynamic system of currents and an intermittent North Equatorial Counter Current (NECC) that returns water from the East African coast towards the Seychelles, at about 0-2°S. The Asian landmass thus drives the seasonal monsoon system that dominates climate in the central and northern parts of the region. Seasonality in the NECC contributes to west-east connectivity that apparently passes through the Chagos/Maldives/Lakshadweep systems, returning genetic material to the Eastern Indian Ocean.

Productivity

Biological diversity patterns in the WIO are driven by the geological and oceanographic features described above. Interactions between water flow and shallow or deep bathymetric features can result in strong downstream dynamics as a result of eddies (mixing and turbulence) induced in the wake of the features, with raised productivity resulting from this and from the addition of nutrients and minerals to otherwise oligotrophic and mineral-poor oceanic waters. Closed circulation cells may also form around seamounts, inducing upwelling, trapping nutrients and enhancing primary productivity (Harris 2011, Keating and others, 1987).

The seasonal dynamics of the Somali Current strongly influence productivity in the northern part of the WIO (Schott and McCreary 2001), with strong upwelling in May to September along certain parts of the coast due to the northward-flowing East African Coastal Current. The seasonal upwelling shuts down during the northeast monsoon in December to April, but complex currents redistribute biological production from the upwelling events throughout the northern Indian Ocean.

Upwelling in the open ocean between 5-10°S in the Central and Western Indian Ocean is indicated by mesozooplankton and biochemistry (Murtugudde and others, 1999) but, although there is some evidence for topographically-induced upwelling on the lee side of the Mascarene Plateau, this is highly variable and has not been consistently or conclusively established (Gallienne and Smythe 2003). Preliminary results from an ASCLME cruise in 2008 revealed no indication of upwelling, nutrient enrichment or enhanced primary production along the leeward edge of the plateau (Stromme and others, 2008).

However, the influence of oceanographic variability and energetics on productivity in the Mozambique Channel is emerging (Ternon and others, 2014). Productivity is influenced by the direction of flow in the eddies. Clockwise (cyclonic) eddies cause upwelling in their centre of the eddy, thus raising the thermocline and nutricline closer to stronger sunlight near the surface, resulting in greater productivity in the core of the eddy. Conversely, counter-clockwise (anticyclonic) eddies depress the thermocline and nutricline, resulting in reduced productivity in the core. However, eddies frequently interact, particularly when a clockwise and anti-clockwise eddy are stably adjoined (called a dipole), raising productivity in the boundary between them. Finally, when eddies (singly or in a dipole) touch the continental slope - which may occur frequently as the eddies may extend over 2 000 m deep - they strip nutrients off the continental slope and make them available to pelagic ecosystems. As a result, the productivity of the Mozambique Channel is uniquely high.

SCALE OF BIOLOGICAL DIVERSITY (MAIN GRADIENTS OF DIVERSITY FOR SPECIES AND COMMUNITIES)

The open ocean and deep sea biota of the WIO are poorly known. Richmond (2001) compiled an inventory of species identified in the WIO from available records, totalling 10 627 species in the littoral and shallow subtidal zones. Griffiths (2005) updated this number to 11 257 through the Census of Marine Life, claiming this is probably half the actual number. Wafar and others (2011) also commented on the lack of biodiversity information for the region. Work in deeper habitats has resulted in the identification of new species (eg Randall and King 2009).

New surveys are revealing previously unknown hotspots of biological diversity for benthic invertebrates (Bouchet 2012), such as the subtropical-temperate southern coastline of Madagascar. It is likely that deeper regions, such as the Madagascar Plateau, will manifest even greater levels of endemism with previously undescribed diversity. Significant investment by the GEF in regional marine assessments over the last 5-10 years, particularly through the ASCLME and SWIOFP programmes, has yielded new data in a number of areas (ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b). The surveys run by SWIOFP and ASCLME covered a range of topics, including physicochemical conditions, plankton sampling, soft-bottom meiofauna, trawl samples, acoustic biomass estimates and megafauna observations; the sections below summarise information in the TDA.

Marine mammals

A variety of marine mammals frequent the open seas of the WIO, though little work has distinguished between those that are open oceanic or pelagic from those found in nearshore waters. Many of the large whales frequent both, though they probably spend the larger part of their time in open ocean waters. Beaked whales are more often restricted to open ocean and deep waters, but little is known of their ecology in the WIO. For example, there are a number of anecdotal records of sightings of colder water species in the WIO, including True's beaked whale (*Mesoplodon mirus*), Shepherd's beaked whale (*Tasmacetus shepherdi*), and the ginkgo-toothed beaked whale (*Mesoplodon ginkgodens*). Recent surveys of islands in the WIO have contributed significantly to distribution records of marine mammals in the WIO (REMMOA 2012)

Marine turtles

Marine turtles migrate thoughout the WIO, which hosts five species of sea turtle. They are well known from inshore waters due to their need to nest on beaches, resulting in their vulnerability to hunting and disturbance on populated shorelines. Recent tagging studies focused around the Mascarene Islands and Mozambique Channel have shown their extensive migrations in all directions (Bourjea 2007) across open ocean areas.

Seabirds

Eleven seabird families occur within the WIO as breeding species, and fall in three broad categories - Indo-Pacific or pan-tropical, highly migratory species from southern latitudes, and predominantly Atlantic species. Though levels of endemism are expectedly low, there are at least nine extant, breeding endemics of which five are listed as globally threatened, including two critically endangered species (BirdLife International 2012). Half of these are from Sub-Antarctic islands, two from Reunion Island and two from the Arabian seas. Some of the species found in the WIO are in globally important numbers: eg 25 per cent of the world's Sooty Terns *Sterna fuscata* are found on Juan de Nova island, Cosmoledo Atoll, Bird Island and Europa Island (Le Corre and Jaquemet 2005, ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b); >10 per cent of the world's Tropical Shearwaters (*Puffinus bailloni*) and Lesser Noddies (*Anous tenuirostris)* occur on Aride Island, Seychelles (Fishpool and Evans 2001); and Aldabra Atoll has the world's second-largest frigatebird colony and is the only oceanic breeding site for the Caspian Tern *Sterna caspia* (Fishpool and Evans 2001). All of these critical seabird nesting habitats are found in just three countries of the WIO - the French islands, Seychelles and South Africa (other subtropical or temperate species).

As with marine turtles, while seabirds nest on land and rocks within the coastal zone, their migratory routes and often their most important feeding grounds are in open ocean areas. Tropical seabirds associate very strongly with tuna and feed in association with them (Le Corre and others, 2012). Thus, their post-breeding dispersal is probably linked to broad-scale oceanic features (such as upwelling or mixing areas) to which fish are attracted. Recent tracking has identified five large-scale Important Bird Areas (IBAs) in the WIO, all in the open sea (Le Corre and others, 2012): 1) the Seychelles basin (east of the granitic Seychelles); 2) the pelagic waters encompassing the Aldabra Group northwards and west of the Seychelles Basin; 3) from Reunion southwards; 4) the area south of Madagascar and 5) the southern third of the Mozambique Channel and southwards to ~30°S (ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b).

Elasmobranchs

Less than 200 elasmobranch species have been recorded in the WIO and, except for South Africa, little effort has been made to assess the status of sharks and rays in the region. Some emblematic species have been the focus of attention, such as the whale shark (*Rhyncodon typus*), and there is now an increase in interest in open ocean sharks under the auspices of the Indian Ocean Tuna Commission (IOTC) and its Working Party on Ecosystems and Bycatch (WPEB). The most abundant pelagic shark families in the South West Indian Ocean (SWIO) are the Lamnidae, Carcharhinidae and Alopiidae ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b). Among the Lamnidae, great white sharks are mostly confined to southern Africa but occasionally make incursions into tropical waters and are caught occasionally off most countries.

Bony fish

While fish are among the best known of marine taxa, and some 2 200 species are reported from the WIO (Smith and Heemstra 1986, Nelson 2006), a tally of those present in the open ocean or deep sea has not been made and there would probably be significant gaps. Notably, the coelacanth *Latimeria chalumnae* was first found live in the WIO (Box 9.1) and, though originally thought to be restricted to a few sites in South Africa and the Comoros, it is now known to be widespread on continental rises throughout the Mozambique Channel and up the East African coast to Kenya. It may be no coincidence that the age and stability of this continental margin, going back 180 million years, and the deeply cut canyons that are the coelacanth's home, have probably been stable throughout this time, even with sea level fluctuations. This might be the reason for persistence of this 'living fossil' here, as it has gone locally extinct from continental slope habitats elsewhere.

PROPORTION OF MAJOR GROUPS OF SPECIES THAT ARE ASSESSED ON A SYSTEMATIC BASIS FOR STATUS

There is insufficient information for oceanic and deep sea habitats to estimate the proportion of groups that have been assessed systematically. The International Indian Ocean Expedition (IIOE) of 1959–1965 collected information on a broad range of subjects, including taxonomy, but the coverage of the WIO was patchy. Information on the megafauna named above is reasonably complete due to global interest in the species, and many are wide-ranging. However, limited sampling of invertebrate and even fish species with a view to their biodiversity assessment at all depths in the water column and on the deep sea floor renders systematic estimates impossible.

Recent surveys by the MESOBIO and ASCLME programmes have nevertheless resulted in significant additions to our knowledge. ASCLME cruises covered parts of the Mozambique Channel and Seychelles Basin, and west of the Mascarene Plateau (see reports at www.asclme.org), while the MESOBIO programme focused on the Mozambique Channel (Ternon and others, 2014). However, in both cases, the bulk of work was on oceanographic and ecosystem processes, not diversity and taxonomy. Nevertheless, Huggett (2014) quantified the abundance of zooplankton species in the Mozambique Channel from four cruises undertaken in 2007-2010, but did not attempt to estimate the proportion of biodiversity identified or assessed. ASCLME cruises collected voucher specimens of fish, zooplankton and jellyfish, as well as tissue specimens for later DNA analysis.

TRENDS AND THREATS

Future trends and threats to the deep sea and pelagic environments were most recently and comprehensively covered in the ASCLME/SWIOFP TDA (2012) and are discussed below within the DPSIR framework.

Drivers

The TDA identified ten root causes (or drivers) of change, all of them applicable to threats to deep sea and offshore areas: inappropriate governance, economic drivers, inadequate financial resources, inadequate knowledge and awareness, cultural traditions, population pressure and demographics, poverty and inequality, climate change and natural processes, and personal attitudes

Of particular importance for the open ocean, which remains the last frontier for intensive human activity, are the following consequences of growing human populations and the attendant increase in pressures.

• Globalization of markets and trade, with the open ocean providing the main transport and shipping channels. For example, 30 per cent of global tanker traffic passes through the Mozambique Channel, transporting oil from the Middle East to Atlantic markets, the tankers being too large to pass through the Suez Canal.

• Climate change and ocean acidification impacts on marine environments are becoming increasingly well known, these being driven by rising concentrations of greenhouse gases in the atmosphere. Carbon dioxide has the greatest impact on ocean chemistry as it affects the buffering system in seawater, resulting in acidification and changes to the biochemistry of marine life.

Pressures, state and impacts

Four 'main areas of concern' are summarised here, combining information on pressures, state and impacts through causal chain analysis, providing guidance on needs at the both national and transboundary level.

• Water quality: a) alteration of natural river flow and changes in freshwater input and sediment load, b) degradation of ground and surface water quality, c) microbiological contamination from land-based and marine sources, d) solid wastes and marine debris from shipping and land-based sources and e) oil spills from drilling, exploitation, transport, processing, storage and shipping.

• Habitat and community modification: a) a broad range of habitat disturbances in watershed and nearshore areas, which may have cascading effects in offshore and deep waters; b) the introduction of invasive alien species. The emerging threat of deep sea mining was not included in the assessment (eg minerals on the seabed), neither were other extractive industries (eg for oil and gas), which can have severe impacts on surrounding habitats through physical alteration and/or pollution.

Declines in living marine resources, including sharks and rays, pelagic and bottom fish, and excessive bycatch and discards as a result of fisheries expansion in artisanal, national and trans-national operations. Of twelve fish listed as threatened (ASCLME/SWIOFP 2012a, ASCLME/SWIOFP 2012b) three are deep sea or open ocean species - the coelacanth (Critically Endangered), southern bluefin tuna (*Thunnus maccoyii*, Critically Endangered) and the big eye tuna (*Thunnus obesus*, Vulnerable). At present, marine mammal mortality through fisheries interactions in the SWIO, while not exhaustively studied, are generally low and certainly lower than in many other regions of the world. Expansion in mariculture and associated consequences in terms of biosecurity, the introduction of diseases to wild stocks, invasive species, habitat implications, and water quality were noted. While mariculture occurs mainly in shallow waters, impacts to connected deeper waters and to the seabed are possible.

• Unpredictable environmental variability and extreme events, including climate hazards and extreme weather events: a) ocean acidification, b) changes in seawater temperatures, c) changes to hydrodynamics and ocean circulation, d) changes in productivity (shifts in primary and secondary production) and e) geo-hazards, which in the deep sea may include volcanic eruptions and earthquakes.

The TDA finally identified a number of emerging issues that may intensify and become significant threats in the future, including noise pollution, radioactive contamination and bio-prospecting. Prospecting for hydrocarbons and minerals, particularly for the former in the Mozambique Channel in the immediate future, and further afield in future decades, will become major pressures on these presently unexploited resources.

Responses

Countries of the WIO are hampered from action in the open ocean and deep sea by a lack of resources to manage remote expanses of sea beyond their immediate coastlines. Nevertheless, almost the entire region recognized as the

WIO is within the Exclusive Economic Zones of its member states, more so with the extension granted to Mauritius and Seychelles for the inclusion of the Saya de Malha Bank in their continental shelf claims. Apart from South Africa, France, Mauritius and the Seychelles, other countries of the region have few resources to actively manage the waters under their jurisdiction.

Beyond territorial waters, responses by states of the WIO to threats in the deep sea are dealt with under the aegis of regional agencies mandated with resource extraction and management (eg the Regional Fishery Management Organizations, or RFMOs), the regional marine environmental protection convention arising from the UNEP Regional Seas process (Nairobi Convention), or more bilateral actions (eg the seabed extension jointly sought by Mauritius and Seychelles). Other avenues to reduce threats in the open sea such as the risk of pollution and oils spills, include the 'Marine Highway Project' (GEF-WIOMHD 2012).

The generation and provision of information on deep sea and offshore ecosystems is increasing, building on the recent round of regional projects such as the ASCLME and SWIOFP. These and other projects have compiled existing knowledge and conducted fresh research that is being disseminated through online portals and information resources, such as the Africa Marine Atlas (www.africanmarineatlas.org) supported by UNESCO and the Nairobi Convention Clearing House Mechanism, supported by UNEP/Nairobi Convention Secretariat (2009). Linking these portals with global resources, such as the Ocean Biogeographic Information System (OBIS) is underway, and will do much to fill the information gaps noted here. New regional programmes, such as the SAPPHIRE and SWIOFish programmes that will succeed those aforementioned, will include major components on biodiversity data and information systems in support of this process.

In terms of on-the-ground interventions, there are several global conventions that include mechanisms to protect marine waters, summarised below. A process to clearly identify Ecological and Biologically Significant Areas (EBSAs) has been underway under the umbrella of the Convention on Biological Diversity (CBD). As in other processes, marine ecosystems, and particularly the open oceans and deep seas – termed Areas Beyond National Jurisdiction (ABNJ) or the High Seas – have been among the last to be considered. Since 2007, a process has been convened to rectify this, assisted by the Global Oceans Biodiversity Initiative (GOBI). Scientific and technical experts have met to provide scientific and technical guidance on the use and further development of biogeographic classification systems, and to identify sites which meet the criteria, including deep sea and open ocean sites (Table 1). This was accomplished in a workshop that focused on the Indian Ocean in July 2012 and its findings were accepted by the 12th Conference of Parties of the CBD in Pyeongchang, South Korea, in October 2014, laying a framework for marine spatial planning by states in the region.

Table 9.1. Ecologically and Biologically Significant Areas (EBSAs) described in the open ocean and deep seas of the Western Indian Ocean. Source CBD (2012).

1	Agulhas Bank Nursery Area
2	Agulhas slope and seamounts
3	Offshore of Port Elizabeth
4	Protea Banks and sardine route
5	Natal Bight
7	Delagoa shelf edge, canyons and slope
9	Morrumbene to Zavora bay (Southern Mozambique)
19	Mozambique Channel
22	Walters Shoal
23	Coral Seamount and fracture zone feature
24	Northern Mozambique Channel
26	Prince Edward Islands , Del Cano Rise and Crozet Islands
27	Southern Madagascar (Part of Mozambique Channel)
28	Tromelin Island
29	Mahe, Alphonse and Amirantes Plateau
30	Atlantis Seamount
32	Saya de Malha Bank
Areas mentioned, but not assessed due to lack of information:	
1	Coco de Mer (north Seychelles)
2	North Seychelles Oceanic Basin
4	Saint Brandon*
6	Dragon Vent Field, SW Indian Ridge

The UN Food and Agricultural Organization (FAO) has noted the importance of identifying Vulnerable Marine Ecosystems (VMEs) to promote the sustainability of fisheries worldwide (FAO 2009). The agency established standards and prepared International Guidelines for VMEs and, in July 2012, held a workshop in Mauritius to introduce the concept of VMEs to WIO countries (FAO 2013). VME standards have been formulated at the global level for both national waters and areas beyond national jurisdiction (ABNJs), as well as for deep sea areas vulnerable to

BOX 9.1. COELACANTHS IN THE WIO by Matt Richmond and David Obura

A coelacanth and technical diver in the iSimangaliso Wetland Park, South Africa. © L. Ballesta.

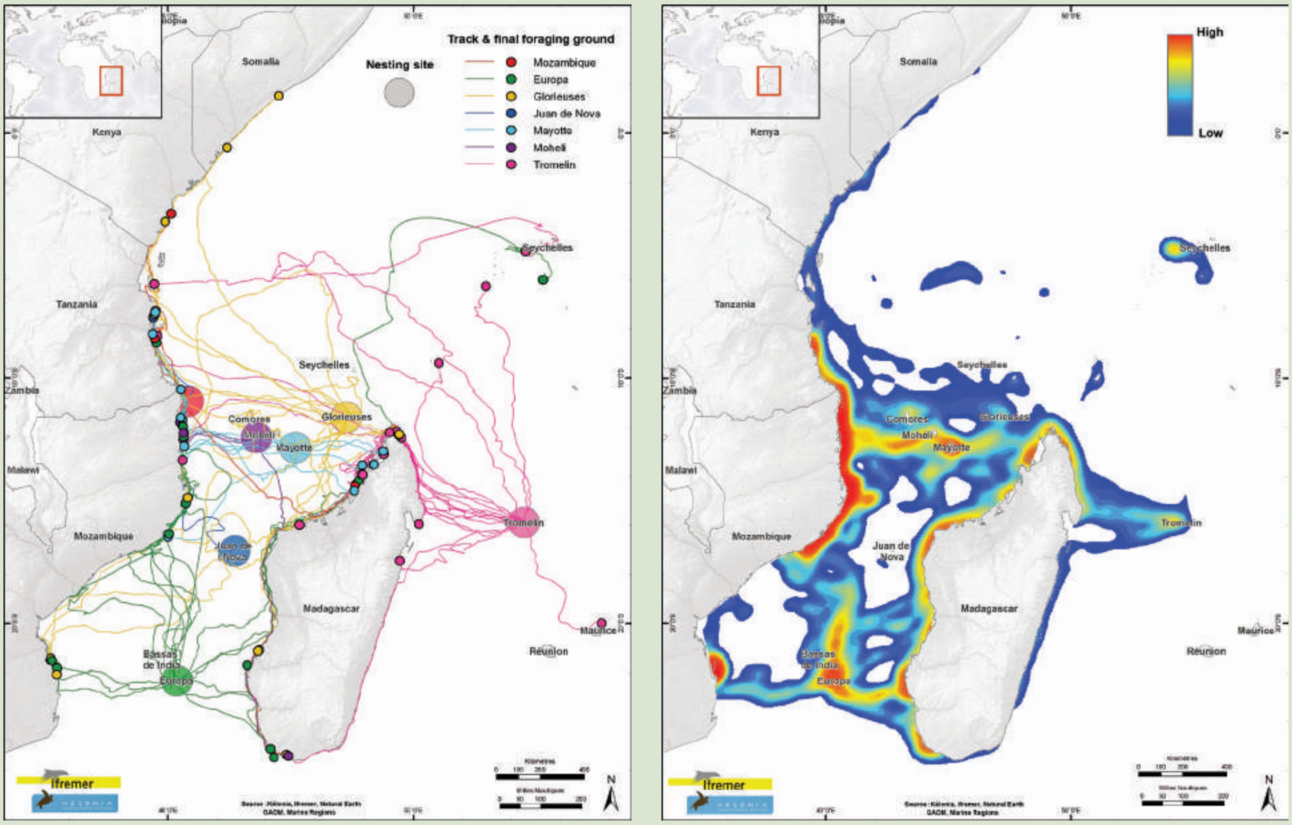
Coelacanths (*Latimeria chalumnae*) are unique fish that surprised the world when discovered alive in 1938 after they were thought to have become extinct along with the dinosaurs. Coelacanths belong to a special division of bony fish (Subclass Sarcopterygii), characterised by their unique lobed fins that are considered to be the origins of fleshy limbs in vertebrates. They have a hollow fluid-filled notochord rather than the hard spine of other fish or the cartilaginous backbone of sharks. They also have a distinct tail with a small epicaudal fin at its tip. Coelacanths live for up to 60 years, give birth to as many as 26 live young, and can attain 2 m in length (or 70 kg) with females growing larger than males. Apart from the WIO species, *Latimeria chalumnae*, a more restricted species is found in Indonesia, *L. menadoensis*.

In the WIO, coelacanths live in deep tropical and subtropical waters in South Africa, Tanzania, Madagascar and Comoros, with single catch records in Mozambique and Kenya. They occur at depths between 40 m and 400 m. Their persistence in the Mozambique Channel may be related to the age and stability of the coastline, going back over 100 my. Coelacanths have been studied using mixed gas diving, by submersible and by Remotely Operated Vehicle (ROV). They are considered rare fish and are globally IUCN Red-listed as critically endangered. Each individual has a unique white spot pattern that allows for recognition and monitoring.

Coelacanths are believed to be slow-growing and very vulnerable to overfishing. With increasing numbers of fishers, and greater use of shark and deep gill nets, larger numbers of coelacanth are being caught. For example, 37 specimens had been landed up to October 2010 in Tanga, Tanzania, alone, leading to the formation of the Tanga Coelacanth Marine Protected Area.

deep fishing technologies. The most vulnerable ecosystems are those that are both easily disturbed and very slow to recover, or may never recover. The aim of identifying VMEs is to facilitate the adoption and implementation of conservation and management measures by Regional Fishery Management Organizations (RFMOs) and flag states of

BOX 9.2. OCEANIC CONNECTIVITY BY GREEN TURTLES IN THE WIO by Jérôme Bourjea and Mayeul Dalleau



Tracks of green turtles from nesting to foraging grounds (left) and space utilization density during migration (right). Extracted from Bourjea and others (2013) and Dalleau (2013).

Sea turtles have migrated for millions of years between nesting sites and feeding grounds, sometimes swimming thousands of kilometers, passing through several countries and ecosystems, and interacting with human activities along the way—sometimes to their advantage but sometimes resulting in a premature end of their lives' journeys. So it is in the Southwest Indian Ocean (SWIO). This region hosts some of the most important green turtle (*Chelonia mydas*) nesting sites in the world, most of which are isolated on remote islands (for example, at Europa [Îles Eparses, France], Aldabra and Cosmoledo [Seychelles], and Moheli [Union of the Comoros]). Nesting also occurs in significant numbers along the coasts of East Africa and Madagascar, which are better known for their vast seagrass pastures where green turtles graze. Mayotte (France), Grande Comoros, and Mauritius also have noteworthy foraging areas adjacent to their shores. However, very little is known about the migratory pathways that sea turtles ply between their nesting and feeding grounds—and even less is known about how they spend their time among the various countries in the SWIO.

To shed light on regional migratory issues related to interaction with human activities, Ifremer and Kélonia, both based in Reunion, finished in 2013 an ambitious satellite tagging project that started in 2009 to better understand the spatial dynamics and connectivity of SWIO marine turtle populations. The project deployed 105 satellite tags on nesting green turtles at Europa, Juan de Nova, Mayotte, Glorieuses, Moheli, and Tromelin (left map) and cooperated with Mozambique to gather tracks from Vamizi Island. Results showed that tracked turtles did their migration in 21,4 ± 16,2 days and travelled an average of 1359 ± 832 km from nesting site to their foraging ground, crossing from 2 to 7 different EEZ. This dataset also allowed identifying 5 key foraging hotspots in the SWIO, 2 in Mozambique (Bazaruto and Quirimbas archipelagos), 2 in Madagascar (northwest and south) and one in Tanzania (Mafia area). Thirty-five per cent of the final foraging grounds of tracked turtles were in Marine Protected Areas.

To better estimate migratory corridors, a Movement-based Kernel Density Estimation (MKDE) was used to characterize the space utilization density during the migration (right map). Results allowed highlighting hotspots of migration at the oceanic and coastal scales. Oceanic corridors are diffused all along the Mozambique Channel and migrating individuals most probably faced few threats from open sea fisheries, composed on purse-seiners and longliners that do not interact with adult green turtle. Coastal corridors are more interesting as they are very dense from the north of Mozambique to south Tanzania, in Bazaruto and all along the west Malagasy coast. Knowing that interaction between East African and Malagasy artisanal fisheries and adults green turtles are very important in all the SWIO, and that coastal development due to the discovery of Gas fields in the Mozambique Channel (ie in the Quirimbas area, Mozambique) is increasing, such results are of great importance for management issues, allowing to identify areas of priority for the conservation of this endangered species.

fishing vessels.

Furthermore, the designation of Particularly Sensitive Sea Area (PSSA) under the International Maritime Organization (IMO) may be of assistance, particularly in limiting impacts from maritime operations. However, this designation has not yet been applied in the WIO, though its value has been recognized (Guerreiro and others, 2011). The provisions of the United Nations Convention on the Law of the Sea (UNCLOS) are also relevant, as they identify 'Special Areas' relative to their vulnerability to maritime pollution under MARPOL, and an ongoing process under UNCLOS to establish mechanisms for governance of Areas Under National Jurisdiction will make this increasingly relevant.

CONCLUSION

Until recently, countries of the WIO have taken few steps to fully use, or manage, open sea areas under their jurisdiction. However, with growing evidence of the limits to terrestrial resources, the oceans are being seen as a final frontier to support economic development. Use of these areas without their adequate protection and knowledge of the associated consequences could result in severe degradation of the open ocean resources. As countries begin to embrace a 'Blue Economy' for wealth creation, ensuring the sustainability and protection of deep sea assets that may support such growth will be essential.

References

ASCLME/SWIOFP (2012a). Transboundary Diagnostic Analysis for the western Indian Ocean. vol.1: Baseline. South Africa

ASCLME/SWIOFP (2012b). Transboundary Diagnostic Analysis for the western Indian Ocean. vol.2: Diagnostic Analysis. South Africa

ASCLME *ASCLME Cruise Results*. http://www.asclme.org/data-and-information/asclme-cruise-results.html

African Coastal & Marine Atlas. http://www.africanmarineatlas.org

BirdLife International (2012). *Marine Protected Areas and Regional Synthesis Report on Birds as Indicators of Ecosystem Health*. The Seventh Conference of the Parties to the Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Western Indian Ocean (Nairobi Convention). UNEP-DEPI-EAF-CP.7.12

Bouchet, P. (2012). The "Atimo Vatae" Expedition. Museum of National History of Paris. http://www.laplaneterevisitee.org/fr/87/accueil

Bourjea, J., Ciccione, S. and Dalleau, M. (2013). Dynamique migratoire des tortues marines nidifiant dans les îles françaises de l'océan Indien. Rapport Scientifique et Technique Ifremer, RST-DOI/2013-02, 55 pp

Bourjea, J., LapèGue, S., Gagnevin, L., Broderick, D., Mortimer, J.A., Ciccione, S., Roos D., Taquet, C. and Grizel, H. (2007). Phylogeography of the green turtle, Chelonia mydas, in the Southwest Indian Ocean. *Molecular Ecology* 16, 175–186

CBD (2012). Southern Indian Ocean Regional Workshop To Facilitate The Description Of Ecologically Or Biologically Significant Marine Areas. Flic en Flac, Mauritius. 31 July - 3 August

Dalleau, M. (2013). Ecologie spatiale des tortues marines dans le Sud-ouest de l'océan Indien. Apport de la géomatique et de la modélisation pour la conservation. PhD thesis, University of La Réunion, 330 pp

FAO (2009). International Guidelines for the Management of Deep-Sea Fisheries in the High Seas. FAO, Rome

FAO (2013). Report of the Regional Workshop On Vulnerable Marine Ecosystems (VMEs) in the Indian Ocean. Flic en Flac, Mauritius, 25–27 July 2012. FAO Fisheries and Aquaculture Report No. 1030

Fishpool, L.D.C. and Evans, M.I. (eds.). (2001). *Important Bird Areas in Africa and Associated Islands: Priority Sites for Conservation*. Newbury and Cambridge, UK: Pisces Publications and BirdLife International

Gallienne, C.P. and Smythe-Wright, D. (2005). Epipelagic mesozooplankton dynamics around the Mascarene Plateau and Basin, Southwestern Indian Ocean. *Phil. Trans. R. Soc. A*. 363, 191–202

GEF-WIOMHD (2012). GEF-Western Indian Ocean marine highway development and coastal and marine contamination prevention project, GEF-WIOMHD. Environmental Components B & C. Post completion Report

Griffiths, C. (2005). Coral marine biodiversity in East Africa. *Indian J Mar Sci,* 34, 35–41

Guerreiro, J., Chircop, A., Dzidzornu, D., Grilo, C., Ribeiro, R., van der Elst, R. and Viras, A. (2011). The role of international environmental instruments in enhancing transboundary marine protected areas: An approach in East Africa. *Marine Policy*, 35, 95–104

Harris, P.T. (2011). Seafloor Geomorphology–Coast, Shelf, and Abyss. In *Seafloor Geomorphology as Benthic Habitat: GeoHAB Atlas of Seafloor Geomorphic Features and Benthic Habitats* (eds. Harris P.T. and Baker E.K) pp. 125–127. Elsevier.

Huggett J.A. (2014) Mesoscale distribution and community composition of zooplankton in the Mozambique Channel. *Deep Sea Research Part II: Topical Studies in Oceanography*, 100, 119–135

Keating, B.H., Fryer, P., Batiza, R. and Boehlert, G.W. (eds.) (1987). *Seamounts, Islands and Atolls*. Geophysical Monograph 43. American Geophysical Union

Le Corre, M., Jaeger, A., Pinet, P., Kappes, M.A., Weimerskirch, H., Catry, T., Ramos, J.A., Russell, J.C., Shah, N. and Jaquemet, S. (2012). Tracking seabirds to identify potential Marine Protected Areas in the tropical western Indian Ocean. *Biol. Conserv.* 156, 83–93

Le Corre, M. and Jaquemet, S. (2005). Assessment of the seabird community of the Mozambique Channel and its potential use as an indicator of tuna abundance. *Estuar. Coast. Shelf. S*. 63, 421–428

Murtugudde, R.G., Signorini, S. R., Christian, J.R., Busalacchi, A.J., McClain, C.R. and Picaut, J. (1999). Ocean color variability of the tropical Indo-Pacific basin observed by SeaWiFS during 1997–1998. *Journal of Geophysical Research: Oceans* 104(C8), 18351-18366

Nelson, J.S. (2006). *Fishes of the world, 4th edition*. John Wiley & Sons, Inc. New Jersey

Randall, J.E. and King, D.R. (2009). *Parupeneus fraserorum*, a new species of goatfish (Perciformes: Mullidae) from South Africa and Madagascar. *Smithiana Bulletin* 10, 31-35

REMMOA (2012). Campagnes REMMOA: *Recensement des Mammifères marins et autre Mégafaune pélagique par Observation Aérienne*. Agence des aires marines protégées. France

Richmond, M.D. (2001) The marine biodiversity of the western Indian Ocean and its biogeography: How much do we know? In *Marine science development in Tanzania and eastern Africa. Proceedings of the 20th Anniversary Conference on Advances in Marine Science in Tanzania (IMS/WIOMSA)* (eds. Richmond, M.D. and Francis, J.) pp. 241–261. Dar es Salaam, Tanzania

Schott, F.A. and McCreary, J.P. (2001). The monsoon circulation of the Indian Ocean. *Prog Oceanogr.* 51(1), 1-123

Sheppard, C.R.C., Ateweberhan, M., Bowen, B.W., Carr, P., Chen, C.A., Clubbe, C., Craig, M.T., Ebinghaus, R., Eble, J., Fitzsimmons, N., Gaither, M. R., Gan, C-H., Gollock, M., Guzman, N., Graham, N.A.J., Harris, A., Jones, R., Keshavmurthy, S., Koldewey, H., Lundin, C.G., Mortimer, J.A., Obura, D., Pfeiffer, M., Price, A.R.G., Purkis, S., Raines, P., Readman, J.W., Riegl, B., Roger, A., Schleyer, M., Seaward, M.R.D, Sheppard, A.L.S., Tamelander, J., Turner, J.R., Visram, S., Vogler, C., Vogt, S., Wolschke, H., Yang, J.M-C., Yang, S-Y. and Yesson, C. (2012). Reefs and islands of the Chagos Archipelago, Indian Ocean: why it is the world's largest no-take marine protected area. *Aquatic Conservation: Marine and Freshwater Ecosystems*. 22, 232-261

Smith, M.M. and Heemstra, P.C.H. (1986). *Smiths' Sea Fishes*. McMillan, Johannesburg

Stromme, T., Ansorge, I., Bornman, T., Kaehler, S., Ostrowski, M., Tweddle, D. and Alvheim, O. (2008). *Survey of the Mascarene Plateau*. ASCLME Survey number 3. ASCLME FAO Preliminary report

Ternon, J.F., Bach, P., Barlow, R., Huggett, J., Jaquemet, S., Marsac, F., Ménard, F., Penven, P., Potier, M. and Roberts, M.J. (2014). The Mozambique Channel: From physics to upper trophic levels. *Deep Sea Research Part*

II: Topical Studies in Oceanography 100, 1–9

UNEP/Nairobi Convention Secretariat. (2009). Strategic Action Programme for the Protection of the Coastal and Marine Environment of the Western Indian Ocean from Land-based Sources and Activities, Nairobi, Kenya

Wafar, M., Venkataraman, K., Ingole, B., Khan, S.A. and LokaBharathi, P. (2011). State of knowledge of coastal and marine biodiversity of Indian Ocean countries. *PLoS ONE* 6, e14613