Is there a Western Indian Ocean "coral triangle"?

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Abstract

The biogeography of shallow marine organisms in the western Indian Ocean (WIO) is poorly known, though there are indications of a peak of biodiversity (species and genus distributions) in the region at the northern end of the Mozambique Channel encompassed by northern Madagascar, northern Mozambique and southern Tanzania. This region is fed by the South Equatorial Current passing close to the northern tip of Madagascar, with some indications of the formation of a gyre around the Comoro Islands and the formation of large eddies that subsequently move southwards in the Mozambique Channel. The region also has the most intricate coastlines of the WIO. This study will investigate the oceanography of the region to determine if diversity-promoting processes are active, document levels of diversity as given by species distributions of reef building corals and reef fish, and estimate ecosystem resilience of coral reefs of the region. A historical biogeographic analysis will be done to determine how past tectonic events and sea level changes may have influenced extant biodiversity. Analyzed together, these data sets will shed light on whether this region does function as a high-diversity hotspot in the western Indian Ocean, analogous to the 'Coral Triangle' center of diversity for the Asia-Pacific region. The answers to this will have relevance to regional conservation planning as has been carried out in the East Africa and Western Indian Ocean marine ecoregions, and to long term vulnerability of the region and any peripheral regions dependent on it as a larval source, to climate change.

Goals and Objectives

The goal of this study is to establish whether there is basic evidence to support the existence of a WIO biodiversity core region to serve as a foundation for a) a large scale collaborative research programme investigating the physical and biological factors that relate to it and b) regional planning for resource management and conservation based on connectivity and spatial resilience concepts. This study examines a first subset of the key research hypotheses, and forms the initial phase of a larger scale research programme to extend over multiple grants and partners.

Specific objectives for this first project address the evolutionary hypotheses, processes and evidence for a biodiversity hotspot:

1. To determine the basic oceanography of the study region and in particular the presence and dynamics of a 'Comoros gyre';
2. To determine the biogeography of representative taxa in the region and in relation to peripheral regions;
3. To assess the resilience and current ecological state of coral reefs in the region;
4. To assess the possible influence of historical tectonic and sea level changes on the oceanography and evolutionary history behind current biogeographic patterns;
5. To assess current status and resilience of reefs in relation to oceanography, biogeography and human impacts to lay a platform for an integrated science and management agenda for the study region.

Relevance: If there is a core region of biodiversity and resilience in the WIO, then understanding its characteristics and relevance to peripheral areas will be one of the most important contributions to long-term conservation and sustainable management of shallow marine ecosystems throughout the WIO. This is critical for two main reasons: a) any dependence, through larval flows and connectivity of other regions on the core region will fundamentally affect long term sustainable use and management patterns, as well as species conservation strategies throughout the WIO; and b) with the large scale threat of climate change and the latitudinal gradients in stress and species migration that may result, it is critical to understand how climate change may affect the oceanography of the region (Lutjeharms et al. 2001) and to determine if the core region is more or less susceptible to climate change than peripheral regions (Maina et al. 2007, McClanahan et al. 2007).

These considerations are core to the ecoregion and seascape planning processes initiated in the region by WWF – the East African Marine Ecoregion (EAME) and the WIO Islands Marine Ecoregion (WIOMER) – and Conservation International (WIO Islands Seascape), and regional marine and coastal protection mandated by the Nairobi Convention. They are also central to objectives of the Agulhas and Somali Current Large Marine Ecosystem project (ASCLME) and regional fisheries issues (SWIOFP). Thus the findings of this project are directly relevant to the main conservation and marine management policies and aspirations of the WIO region, and will be linked directly with them during implementation.

Rationale: The biogeographic region spanning Indonesia, the Philippines, Papua New Guinea and the Solomon Islands, termed the Central Indo-Pacific (CI-P) is a core center of biodiversity and ecological function for marine and terrestrial environments in the Asia-Pacific (Stehli & Wells 1971, Bellwood & Hughes 2001). The subregion combines many features that contribute towards high diversity and resilience – thousands of islands with intricate channels and bays providing complex habitat, strong currents and connectivity with through-flow from the Pacific to the Indian Ocean, and an equatorial climate. The colloquial name for the region, the ‘Coral Triangle’, emphasizes the flagship and keystone role of corals and coral reefs as hotspots of biodiversity and foundation ecosystem for productivity and services (Roberts et al. 2002, Hoeksma 2007).

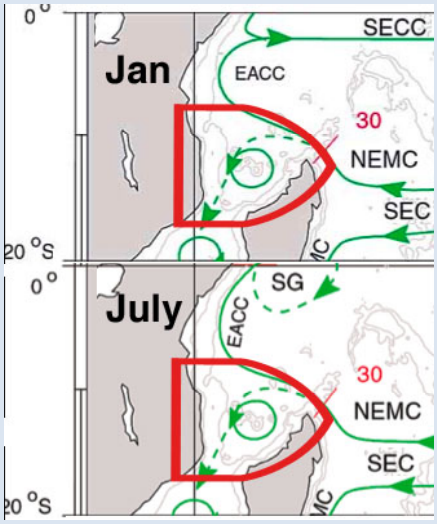

Fig. 1. The western Indian Ocean between 0 and 20°S. The red outlines the hypothesized core region.

The comparable part of the Indian Ocean, in the western equatorial/tropical zone has less intricately inter-twined marine and terrestrial habitats, smaller and more dispersed islands, and the barrier of the East African and Madagascan coasts. To date, no clear core region has been shown analogous to the Coral Triangle, and biodiversity and process studies in the Indian Ocean have been less comprehensive than in the Pacific and much less is known about the spatial distribution of species and oceanographic processes. Nevertheless, preliminary evidence does point towards a western Indian Ocean region of high diversity, delimited by northwest Madagascar, central Tanzania at Mafia Island and northern Mozambique from about Mozambique Island or Angoche northwards. Contained within this ‘triangle’ in the northern Mozambique Channel are the Comoros, Mayotte, Aldabra group of islands and some remote islands and banks (e.g. Juan de Nova). The region covers 7° of latitude (8-15°S) and 10° of longitude (40-50°E), an area of some 420,000 km^2.

The main current flow into the region occurs as an intensified South Equatorial Current (SEC) off the tip of Madagascar. There are few direct observations, but information from the best global circulation models suggests this flow passes predominantly to the north of the Comoro Islands, but can fluctuate to the south, and its magnitude is highly variable. On reaching the coast of the African continent this flow bifurcates in a northern branch, the East African Coastal Current (EACC) and a southern branch into the Mozambique Channel, but in unknown proportions. The flow into the Mozambique Channel follows the continental coast poleward, but breaks up into eddies either north of or at the narrowest part of the channel near 16°S (Lutjeharms, 2006). The result is a relatively closed circulation, the so-called Comores gyre, between the islands to the north and the channel narrows to the south. The existence of this gyre will have very important implications for larval dispersal within the region and to peripheral areas, as well as for physical factors such as water temperature that control the local climate experienced by reef and other marine organisms. The main objectives for the oceanography component of the project are to determine the inflow from the SEC and the outflows in the EACC and Mozambique Channel, b) the existence and strength of the Comores gyre and c) implications of these to marine climate, in particular sea surface temperature.

The biodiversity of the region is poorly described, as consistent sampling across it has been lacking. Several authors suggest biodiversity might be high; incomplete datasets on hard corals (Obura 2008) and reef fish (McKenna and Allen 2006) suggest species richness may be higher than other parts of the western Indian Ocean, and the literature contains references to a possible diversity peak in the western Indian Ocean (Sheppard 1987, Veron 2000). Diversity-generating properties of the marine habitats include the fact that the region includes the most complex coastlines in the WIO, creating areas with the greatest interaction between terrestrial and shallow marine ecosystems. High rainfall (in Madagascar) and large river systems (Tanzania/Mozambique) carry large amounts of freshwater and sediments to the sea adding further interactions between land and sea systems and increasing productivity. Recent genetic studies suggest that the phylogenetic distance between western Indian Ocean and Pacific populations and species is very high (e.g. prawns, You et al. in review; and corals Chuang 2007), and the WIO has a high number of monospecific coral genera, perhaps remnants of old taxa of Tethyan origin. The main objectives of the biogeography component of the project are to determine species diversity patterns within the core region and in relation to peripheral areas, and to relate these to historic and current oceanographic currents and macro-evolutionary processes (Rosen 1988).

As with other parts of the WIO, resource use imposes strong pressures on the shallow marine ecosystems of the study region. All countries in the region have active artisanal and small-scale commercial fisheries, and development pressures in the coastal zone are leading to increased land clearing and hardening of the coast, and increased pollution in inshore waters. Coral mortality following bleaching during the 1998 El Niño varied within the study region; 20-80% in the Quirimbass archipelago, Mozambique (Schleyer et al. 1999), 40-70% in Mafia island and Mnazi Bay, Tanzania (Muhando 1999, Mohammed et al. 2000), 55% in the Comores (Quod 1999), 30-60% in Mayotte (Quod and Bigot 2000), about 30-50% in NE Madagascar (McClanahan and Obura 1998), and negligible in NW Madagascar (Webster and McMahon 2002). Analysis of temperature and other physical climate variables suggest the region has a more stable temperature regime than areas farther north and south (Maina et al. 2007), and may explain why the NW Madagascar reefs did not bleach in 1998 (McClanahan et al. 2007). The objectives for the status component of the study are to assess the current health of study reefs using new resilience approaches (IUCN-CCCR) to assess their vulnerability to future climate change.

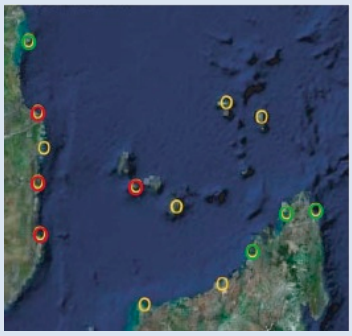

Fig. 2. Potential study sites in the core region. Red circles – supported by this budget; Green circles – other funds. Yellow – other sites, tentative listing.

5. Methodology

Study area: The region is operationally defined as that contained within the three points of a triangle at a) Cap d'Ambre, northern Madagascar; b) Mafia Island, Tanzania; and c) Mozambique Island, Mozambique. This serves as a working hypothesis, to be revised as an output of the study. Sample sites will be spread within the core region and at key peripheral sites. Site selection will focus on sites with complex habitats, availability of pre-existing research and monitoring and the presence of a framework for management responses based on findings. A shortlist of sites will be selected from the following:

Core region sites:	***Peripheral sites:***
○ Tanzania – Mnazi Bay; Mafia Island (WWF Tanzania, EAME and US) ○ Mozambique – southern Quirimbas; Mozambique Island/Angoche; Quirimbas, Vamizi Island (Zoological Society of London) ○ Madagascar – Nosy Hara/ Nosy Mitsio, NW Mozambique (WWF Madagascar), Sahamalaza (Wildlife Conservation Society), Diego/Ambohidavibe (Conservation International) ○ Comoros – Moheli/Grande Comore. ○ France – Mayotte, and potentially scattered islands in the Mozambique Channel.	○ Tanzania – Zanzibar-Dar es Salaam region ○ Mozambique – Primeiras-Segundas islands, Bazaruto archipelago (with WWF Mozambique). ○ Madagascar – southern Madagascar (Tulear – Ifaty – Andavadoaka) (with WWF Madagascar and IUCN-CCCR) ○ Seychelles – Aldabra group of islands, Farquhar atoll (Seychelles Island Foundation, Island Conservation Society, IUCN). ○ Kenya – Kiunga Marine Reserve (CORDIO, WWF, Kenya Wildlife Service) ○ Mauritius, Rodrigues – to be developed if feasible. ○ Reunion – to be developed if feasible.

All of these sites have multiple-use management frameworks in place under local or national institutions, and most of them have additional support from NGOs and research bodies. Funding within this MASMA proposal cannot support fieldwork at all the sites, so as much as possible, co-funding from partners at each site will be sought, with a goal of funding primary fieldwork at 6 sites within the core region and 2 control sites just outside.

Module 1 – oceanography

The primary objective of the oceanography module is to establish the oceanographic processes that underlie biodiversity relationships in the core region and with peripheral areas of the WIO. This will comprise:

- a desktop review including large scale modes of climate variability such as ENSO and the Subtropical and Tropical Indian Ocean Dipole Modes, and satellite observation data for validating modeling results
- a collaborative research cruise with the ASCLME programme on the research vessel *Dr Fritjof Nansen* in the Comoros basin, to determine the existence of the Comoros gyre and its effects on currents in the core region (late 2009). Data to be measured will include temperature, salinity, oxygen, phosphate, nitrate, silicate, phytoplankton, zooplankton, fish and acoustic surveys for fish, and will provide benchmark information for the region for many years to come.
- modeling of the region, using large-scale models such as NEMO, now used as a consensus model by the DRAKKAR modeling community in Europe, and finer scale modeling using the ROMS model (Regional Ocean Model System), which has been successfully applied in the Agulhas Current system (Penven *et al.* 2006), Southwest Tropical Indian Ocean (Hermes and Reason, submitted, 2008) and Zanzibar Channel (Mayorga-Adame, 2007). This work will be conducted by selected students who will be invited to a ROMS workshop, with follow up meetings to ensure the correct implementation of the model.

Module 2 – biogeography of key taxa

Biodiversity field surveys at the six core sites (those supported by this grant) will focus on scleractinian corals and reef fishes, both of which have an extensive literature and identification resources. Time-based field surveys for presence/absence of species will be conducted, allowing generation of species accumulation curves to generate predictions for a total species count standardized against effort (Obura 2008, McKenna and Allen 2006).

Module 3 Coral reef status

Field surveys at the six core sites will be conducted using the Resilience Assessment protocol developed by the IUCN-Climate Change Coral Reef working group (Obura 2005, Obura & Grimsditch 2009). Data to be collected will include: a) benthic cover using photo-quadrats, b) coral recruitment and size class structure, c) coral bleaching and disease prevalence, d) fish abundance and size classes in key functional groups (herbivores, corallivores, piscivores, planktivores), and e) resilience indicators (reef site factors such as shading, cooling etc). Field and analysis manuals and training programmes are available from the CCCR for local and national team members. Background information on anthropogenic factors (population, fishing, pollution, etc) at the sample sites will also be compiled, from existing data sets (e.g. catch per unit effort (CPUE) fishery survey data) to build a comprehensive picture of the factors affecting the sites' health and status. Field information on oceanographic parameters such as temperature, light, bathymetry, will also be collected for further input to module 1.

Module 4 – evolutionary hypotheses for the IO center of diversity.

Biogeographic patterns are influenced by past connectivity and transport in ocean currents and by their effect on evolutionary pressures for speciation, extinction, and dispersal. Multiple evolutionary hypotheses may act in synergy or contrary to one another particularly over geological time frames involving changes in regional climate (e.g. Potts 1985, Rosen 1988), requiring consideration of all plausible hypotheses against current biogeographic patterns and historical influences. The following historical changes will be researched and built into circulation models in ROMS adapted from work in module 1:

a. tectonic events affecting major ocean currents in the Indian Ocean, i.e. the migration of the Indian sub-continent, the migration of Madagascar, formation of the Mascarene plateau and closure of the Tethys Sea.
b. sea-level changes, focusing on the influence of the Mascarene plateau on the South Equatorial Current during glacial cycles during the Pleistocene using high-resolution bathymetric models of the central/western Indian Ocean relevant and the influence of the Seychelles/Mascarene Plateau (Kowalik et al. 2006).

With the above information, alternative evolutionary hypotheses on the formation and maintenance of biodiversity hotspots will be considered, assessing them against findings of earlier objectives 1 and 2, and the literature, to construct plausible evolutionary mechanisms supporting or rejecting the case for a diversity hotspot in the study region (cf. Roberts et al. 2002, Hoeksma 2007).

Module 5 – spatial aspects of resilience and conservation planning

This final item will synthesize the findings of the previous modules to assess the evidence for a biodiversity center in the WIO, potential changes to reef health and diversity patterns based on latest regional climate change projections, and application of these findings to regional conservation planning. This work will build on the foundation provided by the marine eco-region planning processes undertaken by WWF through the East African Marine Ecoregion (EAME) and Western Indian Ocean Marine Eco-region (WIOMER) programmes.

Key regional and national partners:
The following regional organizations are supportive of the project objectives and will collaborate with the work programme:

- EAME/WIOMER –East Africa Marine Ecoregion and Western Indian Ocean Marine Ecoregion programmes.
- Agulhas and Somali Current Large Marine Ecosystem programme (ASCLME) – collaborative research cruise in the Comoros basin..
- IUCN Eastern and Southern Africa Regional Office
- IUCN Climate Change and Coral Reefs working group
- Reefs at Risk.
- WIOMagnet – Western Indian Ocean Marine Genetics Network.

A number of national partners were involved in development of the project proposal, and will play a formal role as project host and participating in research and student capacity building:

- Department of Biological Sciences, University of Edouardo Mondlane (Adriano Macia)
- Centre for Coastal and Marine Environment Research (CEPAM). Pemba, Mozambique (Hermes Pacule).
- University of Dar es Salaam (Albogast Kamukuru)
- WWF Madagascar (Fidy Olivier Ralison).

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