Madagascar

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National Marine Ecosystem Diagnostic Analysis (MEDA)

Agulhas and Somali Current Large Marine Ecosystems (ASCLME) Project

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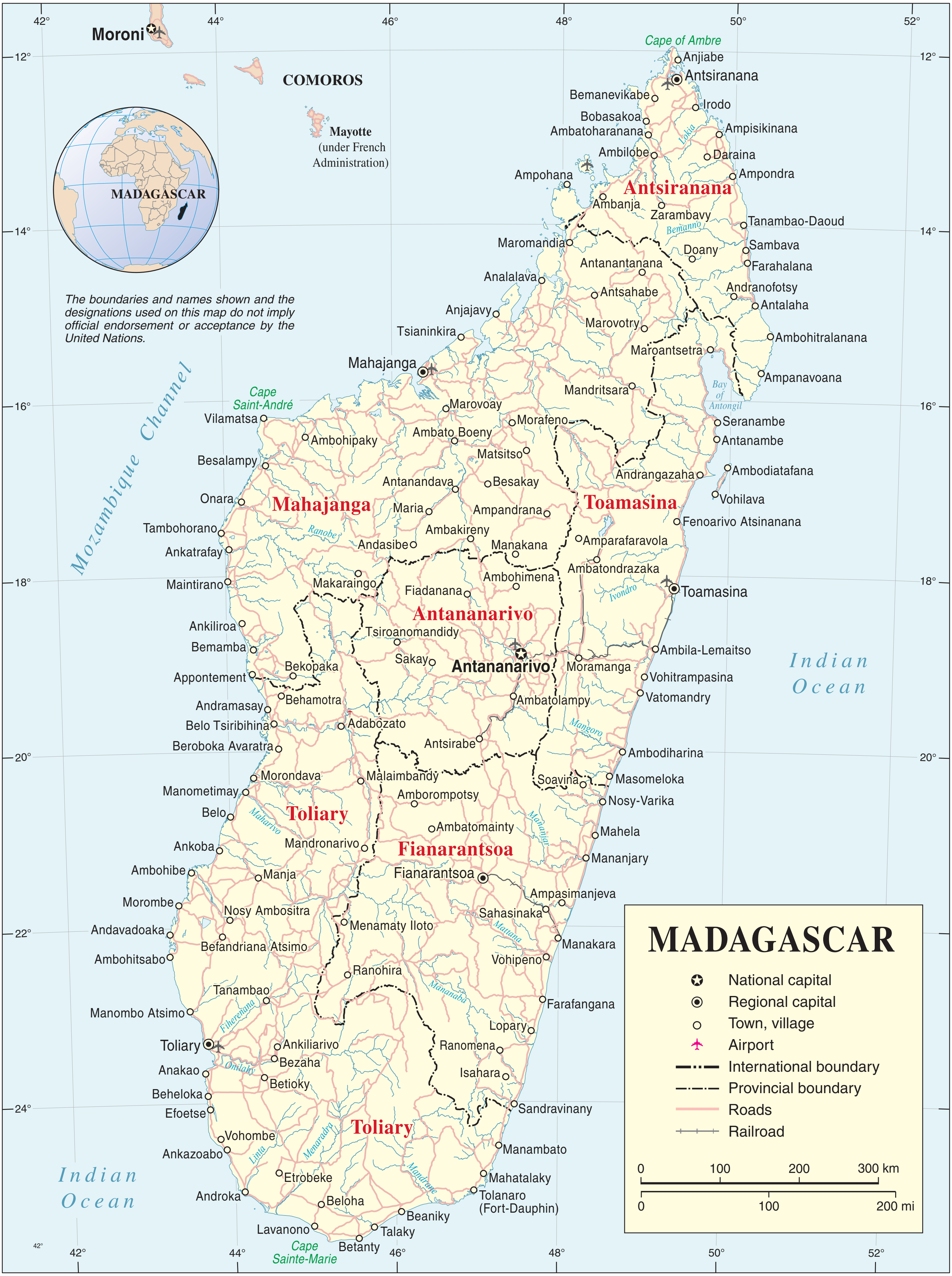

Map No. 4360 United Nations
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EXECUTIVE SUMMARY

The ASCLME Project is approaching the Transboundary Diagnostic Analysis and Strategic Action Plan process initially at the country level through a national Marine Ecosystem Diagnostic Analysis (MEDA)
The MEDA captures essential data and information relating to the coastal and marine environment and identifies areas of concern that will feed into the Transboundary Diagnostic Analyses (TDAs) and the Strategic Action Programme (SAP) for the Western Indian Ocean.

Madagascar has a total surface area of approximately 590,000 km^2 making it the world's 4th largest island. The income per capita is approximately USD 478 (2009) and life expectancy is 66.7 years with a population growth rate of 3% per annum. The key coastal ecosystems supporting livelihood systems include estuaries, mangroves, seagrass beds, coral reefs and offshore marine ecosystem beyond the continental shelf. The mangrove forests occupy about 327 000 ha and the seagrass beds and coral reefs are found along 1 400 km of the coastline. The East coast is very steep compared to the West coast which has gentler slopes. The country experiences tropical climatic conditions with two seasons: a hot, rainy season from November to April, and a cooler, dry season from May to October. There is however, great variation in climate owing to elevation and position relative to dominant prevailing winds.

The island is influenced by the East Malagasy Current, the South Equatorial Current and Mozambique channel eddies. Mesoscale eddies flow southward in the Mozambique Channel and the East Malagasy Current (MEC) flows south-eastward past the south of Madagascar. The South Equatorial Current influences the northern regions of the island. Upwelling occurs in the south in the southern winter and summer. The island experiences semidiurnal tides with tidal range of 3m during spring tides. The sea surface temperature (SST) is on average slightly above 25°C. The maximum of 30°C is usually reached in February and the minimum of 23°C in July.
The coral reefs of Madagascar are very valuable ecosystems with socio-economic and cultural importance. The coral reefs are however subjected to both anthropogenic and naturally driven degradation. In the most populated areas, the impacts on reefs are due to overfishing, sedimentation, coral harvesting and pollution. Degradation due to natural disasters, particularly cyclones, is also very important in addition to coral bleaching. For reefs already under severe stress, the damage done by bleaching is sometimes considered irreversible. Mangroves are another important ecosystem in the island which is still under-exploited. Nevertheless, threats are due to increasing exploitation for fuel wood, charcoal and timber in the regions of Mahajanga and Toliara. The other main threats to mangroves include migration of people to areas adjacent mangrove forests due to drought. Sedimentation is also a major threat to mangroves. As a result of soil erosion due to destruction of vegetation in river basins through burning and farming, 40 to 50 million tonnes of sediments are carried downstream and deposited in mangrove areas each year, causing degradation of the ecosystem.

Madagascar has valuable living marine resources. Among the 123 species of sharks and rays present in Madagascar, 31 are classified by IUCN as threatened, 1 is endangered (the skate *Rostroraja alba*), 17 are vulnerable (the whale shark and endemic skate *Dipturus crosnieri*) and 10 are near-threatened. All three species of sawfishes are classified as "critically endangered" on the IUCN Red List and in Appendix I of CITES. Today, sawfishes are very rare, probably due to shrimp trawling, use of gill nets across rivers and installation of fish barriers in estuaries. Approximately 50 species of sharks and rays of neritic and oceanic deep waters of Madagascar are affected by the industrial tuna fishery (longline and seine fishing), industrial fisheries, industrial shrimp fishery, artisanal and traditional fisheries. Due to their slow reproductive rates, Chondrichthyes are very vulnerable to overexploitation. Official statistics on local production and export of meat and fins show an annual mortality of sharks by various forms of fishing from 200,000 to 600,000 individuals.

In Madagascar, the coelacanth *Latimeria chalumnae,* is mainly reported in the Southwest, near Toliara (Anakao, Tsiandamba, Fiherenamasay) where seven coelacanths have been caught since 1995. Due to their low population, slow reproduction and vulnerability in relation to fisheries, the coelacanth is classified as "critically endangered" by IUCN and in Appendix 1 of CITES. In Madagascar, there is no legal protection, but the export of specimens is controlled by CITES and decrees dating from the colonial period. Currently, 14 species of marine teleost fish present in Madagascar are listed on the IUCN Red List. Tuna are harvested in the industrial seine fishery and longline fishery. Official fisheries statistics indicate catches of 10,000 to 11,000 tonnes per year.

Non-reef sea fishes are targeted by industrial fisheries, the industrial shrimp fishery, artisanal and traditional fisheries. The main target species belong to the Lutjanidae (Two-spot red snapper *Lutjanus bohar*, emperor red snapper *Lutjanus sebae*), Sparidae, Serranidae, Lethrinidae, Carangidae and Thonidae. Small pelagic and demersal fishes are targeted by shrimp trawling in all shrimp fishery zones, by the artisanal fishery, mainly concentrated in the Northwest and by traditional fisheries mainly concentrated along the west coast, in Antongil Bay and in the Southeast. The fishery for reef fish is mainly carried out by traditional fishermen mainly targeting carnivorous fish (Serranidae, Lutjanidae, Lethrinidae, Carangidae), herbivorous fish (Siganidae, Scaridae, Acanthuridae), scavengers (Mullidae and others) and to a lesser degree planktivores such as Caesionidae. Annual yields of fish from the traditional fishery are estimated at around 50,000 tonnes.

Turtle catches in the southwest region have been estimated to be as high as 13,248 turtles per year. Apart from non-destructive fishing practices, sea turtles are affected by the offshore industrial fishery (longline and seine), fishing on the continental shelf, industrial shrimp trawling, fishing nets for shark and the traditional fishery using poison. Industrial trawling for shrimp is also an important cause of accidental catches of turtles, but has never been scientifically evaluated in Madagascar. Approximately 40 species of seabirds are found around the coasts of Madagascar, including albatrosses, petrels, phaetons, frigates, boobies and terns. The main threat to endangered seabirds is egg collection which takes place on many continental islands of Madagascar that are accessible to fishermen.

Climate change is impacting Madagascar. The mean annual rainfall is predicted to decrease by 5% by 2100. However, an increase of 5% to 10% of rainfall in December to February is predicted. The maximum increase of 10% is predicted in Atsimo Andrefana, Anosy and Androy regions. The projections for change in rainfall suggest that the rainfall will increase during summer and decrease in winter. The magnitude and frequency of cyclones has also changed. Although the total number of cyclones per year has not changed, the percentage of intense cyclones has increased and cyclones have become more frequent in northeast and southwest coasts of the island. The sea level is rising at a rate of between 7.2 and 21.6 mm on all coastal zones of the island with impacts such as flooding of low-lying coastal areas, coastal retreat and modification of coastal ecosystems. The impacts of climate change on coastal ecosystems are of great concern in view of the various benefits accrued from them.

The small-scale fishery in Madagascar, which includes subsistence, artisanal and recreational fisheries is largely concentrated on the country's west coast, with total catches estimated to be 107,300 tonnes per year in 2008 as compared to 13,800 tonnes per year in 1950. Small-scale fisheries represent nearly 72% of total fish production largely focusing on export products such as crustaceans, holothurians and cephalopods. In 2003, the small-scale fisheries, as a whole, contributed nearly 26% of the total tonnage of fisheries export production and nearly 9% of the total value of exports, worth an estimated USD 142 million.

Tourism and the hotel sector contributes about 3.7% of GDP and the sector is the second largest source of foreign exchange in the country, contributing between USD 116 million and USD 303 million. The sector also directly employs nearly 27,300 people. Agriculture however, is the main sector contributing 27% of GDP, 70% of the employment and 20% of the total exports.

The governance of the coastal and marine environment is generally weak. The development of the coastal and marine zones of Madagascar is supposed to be guided by integrated coastal zone management (ICZM) but this is largely ineffective. In conclusion, the specific issues identified in the MEDA are:
Declining fisheries and changes in ecosystem structure and function: There is a significant decline of small pelagic fisheries, demersal finfish fisheries, elasmobranchs (sharks and rays), marine turtles, cetaceans and tunas;

Habitat modification: This is evidenced by the degradation of coral reefs, mangroves and seagrass beds which are critical habitats. Also, other habitats such soft sediment seabed, sandy beaches, seamounts, and coastal wetlands are being impacted by both human and natural factors;
Declining water quality: This is particularly due to alteration of river flow, sedimentation, pollution, agro-chemical residues (pesticides and fertilizers) and eutrophication.

Climate change: This is evident through sea level rise, increased magnitude and frequency of cyclones and extreme events such as droughts and floods.

Lack of effective governance of the coastal and marine environment: There is evidence of a lack of capacity for monitoring, surveillance and control. Planning for coastal development is weak and the implementation of relevant legislation is generally limited.

Several recommendations were suggested. These include development of systems for data and information sharing and monitoring, conducting research on climate change adaptation and mitigation measures, developing a list of indicator species for coastal monitoring purposes and developing regional oceanographic models. Other recommendations are on the need to develop refined maps of coastal areas, conducting vulnerability assessments of key ecosystems (mangroves, seagrass beds, coral reefs, etc.), development of a framework for monitoring coastal human population dynamics and building of the capacity of national institutions for effective governance of the coastal and marine environment and use of natural resources.

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ACRONYMS

ADEMA	Aéroport de Madagascar
AIW	Antarctica Intermediate Water mass
AMADA	Association Madagascar Aide au Développement par l'Algoculture
ANDEA	Autorité Nationale de l'Eau et de l'Assainissement
ANGAP	Association nationale pour la gestion des aires protégées
APMF	Agence Portuaire Maritime et Fluviale
AQUALMA	Aquaculture de la Mahajamba
ASCLME	Agulhas and Somali Current Large Marine Ecosystem
BNGRC	Bureau National de Gestion des Risques et Catastrophes
BRGM	Bureau of Geological and Mining Research
CCGRC	Comités Communaux de Gestion des Risques et Catastrophes
CEP	Commission Environnement-Pêche
CEREGE	Centre Européen de Recherche et d'Enseignement des Géosciences de l'Environnement
CITES	Convention sur le commerce international des espèces de faune et de flore sauvages menacées d'extinction
CLGRC	Comités Locaux de Gestion des Risques et Catastrophes
CMS	Convention on Migratory Species (Convention sur la Conservation des Espèces Migratrices Appartenant à la Faune Sauvage)
CNA	Centre National Anti-Acridien
CNDO	Centre National des données océanographique (IHSM)
CNGIZC	Comité National de la Gestion Integrée des Zones Côtières
CNGRC	Conseil National de Gestion des Risques et Catastrophes
CNRE	Centre National de Recherche sur l'Environnement
CNRO	Centre National de Recherches Océanographiques
CNRS-VRA	Endoume Marine Station and Oceanography Centre
CNS	*Conseil National de Secours*
COAP	Code des Aires Protégées
COI	Commission de l'Océan Indien
COPEFRITO	Compagnie de Pêche Frigorifique de Toliara
COUT	Cellule des Océanographes de l'Université de Toliara
CPGU	Cellule de Prévention et de Gestion des Urgences
CRED	*Centre for Research on Epidemiology and Disasters*
CRENA	Centre de REcupération Nutritionnelle Ambulatoire
CRENI	Centre de REcupération Nutritionnelle Infantile
CRIC	Committee of Reflection of Stakeholders in Disaster
CRIC	Comité de Réflexion des Intervenants en Catastrophe
CSP	Centre de Surveillance de Pêche
CTOI	Commission des Thons de l'Océan Indien
CW	Central Water
DGM	Direction Générale de la Météorologie
DGPRH	Direction général de la pêche et des ressources halieutiques
DIANA	Diégo, Ambilobe, Nosy-Be, Ambanja
DLIST	Distance Learning and Information Sharing Tool
DPCO	Department of Physical and Chemical Oceanography
DPRH	Direction de la Pêche et de Ressources Halieutiques
DTS	Droit de tirage spécial
EEZ	Exclusive Economic Zone
EIA	Environmental Impacts Assesment
EITI	Initiative pour la Transparence dans les Industries Extractives
EMC	Composante Environnement Marin et Côtier
ENSO	El Niño Southern Oscillation
ESW	Equatorial South Water Mass
EU	European Union

FAO	Food and Agricultural Organisation (Organisation des Nations Unies pour l'Alimentation et l'Agriculture)
FTM	Foiben-Taosarintanin'i Madagasikara
GAPCM	Groupement des Aquaculteurs et Pêcheurs Crevettiers de Madagascar
GDP	Gross Domestic Product
GEF	Global Environment Facility
GELOSE	Gestion Locale Sécurisée
GLOSS	Global System of Observation of Sea Level
GRC	Gestion des Risques et Catastrophes
HAB	Harmful Algal Blooms
HIV/AIDS	Human Immunodeficiency Virus
HS	Hydrographic Service
ICAM	Integrated Coastal Area Management
ICRI	International Coral Reef Initiative
ICZM	Integrated Coastal Zone Management
IFRECOR	Initiative Française pour les Récifs Coralliens
IFREMER	Institut Français de Recherche pour l'Exploitation de la Mer
IHSM	Institut Halieutique et des Sciences Marines
INSTAT	Institut National de la Statistique
IOC	Inter-Govermental Oceanographic Commission of UNESCO
IOD	Indian Ocean Dipole/Dipôle Océan Indien
IOGA	The Institut et observatoire géophysique d'Antananarivo
IPCC	Inter-Governmental Panel on Climate Change
ITCZ	Inter-Tropical Convergence Zone
IUCN	International Conservation Union
MAEP	Ministère de l'Agriculture, de l'Elevage et de la Pêche
MAP	Madagascar Action Plan
MEC	Madagascar East Current
MEDA	Marine Ecosystem Diagnostic Analyses
MHSA	Holothuria Madagascar SA
MPA	Marine Protected Areas
MPRDAT	Ministère chargé de la Décentralisation et de l'Aménagement du Territoire
MPRH	Ministère de la pêche et des ressources halieutiques
MSY	Maximum Sustainable Yield
NAPA	National Action Plan for Adaptation to Climate Change
NGO	Non-Governmental Organization
NOAA	National Oceanic and Atmospheric Administration
OCHA	United Nations Office for the Coordination of Humanitarian Affairs
OFCF	Overseas Fisheries Cooperation Foundation of Japan
OLEP	Organe de Lutte contre l'Evénement de Pollution marine par hydrocarbure
OMNIS	National Office for Strategic Industries
ONE	Office National pour l'Environnement
ONN	Office National de Nutrition
OPRC	International Convention on Oil Pollution Preparedness, Response and Co-operation
OTU	Office des Travaux d'Urgence
PACP	Projet d'Appui aux Communautés de Pêcheurs
PGRM	rojet de gouvernance des Ressources Minières
PIC	Convention on Prior Informed Consent
PNRC	Programme National de Recherche Crevettière
POP	Persistent Organic Pollutants
PROGECO	Regional Programme for the Sustainable Management of Coastal Zones of the countries of the Indian Ocean (ReCoMaP)
QMM	Qit Madagascar Minerals
RDM	Risk and Disaster Management
RECOMAP	EU-COI Regional Coastal Management Project

SAGE	Service d'Appui à la Gestion de l'Environnement
SAP	Strategic Action Programme
SAVA	Sambava, Andapa, Vohémar, Antalaha
SEC	South Equatorial Current
SECREN	Société d'Etude de Construction et de Réparation Navale
SEPRH	Service de la Pêche et des Ressources halieutiques
SOTEMA	Société Textile de Madagascar
SPAM	System of Protected Areas of Madagascar
SST	Sea surface temperature
SWOT	Strengths Weaknesses Opportunities Threats
TDA	Transboundary Diagnostic Analysis
TED	Turtle Excluder Device
TED	Turtle Excluder Devices
TMP	Tourism Master Plan
TSW	Tropical Surface Water
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNDP	United Nations Development Programme
UNESCO	United Nation Educational Scientific and Cultural Organization
UNICEF	United Nation Children's Educational Fund
UN-ISDR	United Nations-International Strategy for Disaster Reduction
USD	United States Dollar
USTA	Unité de Statistique Thonnière d'Antsiranana
WCS	Wildlife Conservation Society
WHO	World Health Organization
WIO	Western Indian Ocean
WIO-LaB	UNEP-GEF Project addressing land-based sources of pollution
WIOMSA	Western Indian Ocean Marine Science Association
WWF	World Wide Fund for nature
ZICOMA	Zones d'Importance pour la Conservation des Oiseaux à Madagascar

1. COUNTRY OVERVIEW

Madagascar, the world's 4th largest island, is located in the Southwest Indian Ocean with a total surface area of approximately 590,000 km^2. Madagascar is officially divided into 22 regions with 13 coastal regions. The key coastal ecosystems include estuaries, coral reefs and mangrove swamps. The mangrove forests occupy approximately 327 000ha and coral reefs are found along 1,400 km of the coastline. The East coast is very steep compared to the West coast which is gentler. The contrasting physiographic characteristics between the two regions have had a direct impact on drainage patterns with the longest rivers being found on the western side of the island. The eastern region is characterised by relatively short rivers with very steep slopes and numerous waterfalls. Madagascar's climate is very varied, due to the influences of ocean currents, atmospheric processes, latitude and relief.

Due to the high diversity of geographical formations, climates and natural habitats, the island has a remarkable differentiation of animal and vegetation species. Madagascar today is among the top seventeen megabiodiversity regions in the world. Madagascar also has a high coastal and marine biodiversity. The main marine and coastal ecosystems include mangroves, coral reefs, seagrass beds, lagoons, sandy beaches, pebble beaches and rocky outcrops.

The interior of the island is very mountainous and the transport infrastructure is poorly developed, creating difficulties for economic development. In addition, the location of the country makes it prone to periodic intense monsoon and hurricane damage that has wreaked havoc on railways, ports and buildings over the years. The country has a population of approximately 20 million inhabitants (INSTAT 2011), approximately 80% of which live in rural areas. Much of the island of Madagascar is sparsely populated with an average density of approximately 32 inhabitants per km^2. About 34 percent of the population lives within 100km of the coast. The coastal populations are dependent on the ports for communications, supplies and export of agricultural products, handicrafts and fisheries. Tourism is a major source of income, and the island has benefited from the extensive flora and unique animal species.

With a gross domestic product of approximately USD 478 per head (2009), a life expectancy of 66.7 years and a population growth rate of 3%, Madagascar is considered as one of the least developed and poorest countries in the world (placed 145th of 182 countries in the human development index ranking in 2009) (INSTAT 2010). The population is mainly dependent on small-scale agriculture for subsistence. About 3 million ha of land is under cultivation, of which less than 2 million ha are permanently cultivated and only 484,000 ha of agricultural land is irrigated. Some 300,000 km^2 of the total landmass is pastoral grazing land dedicated to cattle-keeping. Other forms of land use in Madagascar are forests, shrub land and urban areas.

Despite the abundant whitesand beaches, Madagascar's tourism sector is currently only partly oriented toward classical beach holidays. Natural landscapes, managed through national parks represent one of the principal resource bases for tourism. Madagascar is one of the major tourist destinations in the Western Indian Ocean.

With 5,603 km of coastline, Madagascar has an enormous potential in marine fish resources which should be a source of income for the country but it is currently poorly managed. The artisanal fishery which has increased in recent years, however, suffers from inefficient and sometimes destructive techniques being employed in fishing.

2. BIOPHYSICAL ENVIRONMENT

Description of the coasts and distinctive features

The island of Madagascar is located in the Southwest Indian Ocean separated from East Africa by the 400 km-wide Mozambique Channel (Chaperon *et al.* 1993). In a general NNE-SSW orientation, it extends over a length of 1,600 km from Cape Amber to Cape Sainte Marie, between latitudes 11°57' S and 25°39' S. The 47° E meridian divides the island into two nearly equal parts. With a total surface area of approximately 590,000 km^2, Madagascar is one of the largest islands in the world.

The coastal zones are mainly formed of sedimentary rock. In the West, there is a wide continental shelf extending outwards to a maximum of about 90 km offshore. The presence of estuaries, coral reefs and mangrove swamps is characteristic of the western part of the country. The mangrove forest swamps occupy between 300,000 and 400,000 ha of land (Perrier de la Bathie 1936, Lebigre 1990). Coral reefs are found along 1,400 km of the coastline. In contrast, the East coast is very steep with a narrow continental shelf and few estuaries. Protective coral reef formations are rare, and swells and waves approach the coast directly.

i) Issues

Coastal erosion affects the coast of Madagascar at several places such as Morondava, Manakara and Mahajanga. In the cases of Manakara and Mahajanga, coastal erosion is a recent phenomenon. However, the city of Morondava has for a long time suffered from coastal erosion. This has led to the construction of breakwaters on the beach in order to control coastal erosion.

In addition, sedimentation is an important problem that is responsible for the modification of shorelines. The most spectacular shoreline changes due to sedimentation are often observed in estuaries and mouths of major rivers. The Bay of Betsiboka is an example of an estuary with serious sedimentation problems. The river carries huge quantities of silt which is deposited in large quantities at the bay. In the Southwest, the same heavy sedimentation occurs at the mouth of the river Fiherenana, resulting in smothering of reef flats and mangrove forests (Bemiasa 2009).

ii) Gaps

Few studies have been conducted on the key estuaries and deltas of Madagascar.
Aerial photos that can be used to study shoreline change are very old and cover only some parts of the island. There is therefore lack of recent aerial photographs for study of shoreline change.
Satellite images are currently available at FTM

General description of the climate

The Climate of Madagascar is conditioned by 4 factors: geographical position, relief, the maritime influence and the mode of the winds. Madagascar is subject to the influence of two major centres of meteorological influence on circulation in the Southwest Indian Ocean: the area of low pressures in the North and the oceanic cell of high pressures, almost permanently centered in the south Mascarene region (Germain and Chaussard 1964, Donque 1975). The climate is also subject to geographical factors, mainly latitude and relief. The combination of these factors creates a wide range of climatic conditions within the island (Robequain 1958, Hood *et al.* 1993).

During Austral summer, the most frequent types of weather are those resulting from the southward shift of the intertropical convergence zone (ITCZ), and cyclonic disturbances in the Indian Ocean and Mozambique Channel. No part of the country is spared tropical disturbances. The degree of exposure and vulnerability of different localities to cyclones is presented Figure 1 below. The movement of air masses in the vicinity of Madagascar is regulated by areas of intertropical low pressure whose meridional movement affects the weather during summer and winter seasons (Chaperon *et al.* 1993).

The climate of Madagascar is dominated by the southeastern trade winds that originate in the Indian Ocean anticyclone - a center of high atmospheric pressure that seasonally changes its position over the ocean. Madagascar has two seasons: a hot rainy season from November to April; and a cool dry season from May to October. There is however, great variation in climate owing to elevation and position relative to dominant winds (Donque 1975). The east coast has a subequatorial climate with heavy rainfall, averaging as much as 3500 mm annually. This region is notorious not only for a hot, humid climate in which tropical fevers are endemic but also for the destructive cyclones that occur during the rainy season, approaching from the direction of the Mascarene Islands (Figure 1). Because clouds discharge much of their moisture east of the highest elevations on the island, the central highlands are appreciably drier and, owing to the altitude, also cooler. Thunderstorms are common during the rainy season in the central highlands and lightning is a serious hazard (Donque 1975). Table 1 lists tropical storms and cyclones that struck Madagascar from 1968 to 1999, Table 2 lists the 10 most important natural disasters in Madagascar and Table 3 lists the floods affecting Madagascar from 1968 to 1999.

Antananarivo receives practically all of its average annual 1400 mm of rainfall between November and April. The dry season is pleasant and sunny, although somewhat chilly, especially in the mornings. Although frosts are rare in Antananarivo, they are common at higher elevations. During this time, the blue skies of the central highlands around Antananarivo are considered by many to be among the clearest and most beautiful in the world.

The west coast is drier than the east coast and the central highlands because the trade winds lose their moisture by the time they reach this region. The southwest and the extreme south are semi desert. Toliara in the south receives as little as one-third of a meter of rain falls annually. Overally, surface water is most abundant along the east coast and in the far north, with the exception of the area around Cap d'Ambre, which has relatively little surface water. Amounts diminish to the west and south, with the driest regions being found in the extreme south.

i) Issues

- Floods following heavy rainfall which often accompany cyclones usually affect low-lying areas, such as river basins and slums in cities. Flood in rivers and coastline have also been observed.
- Tropical Storms and Cyclones
- Drought and famine

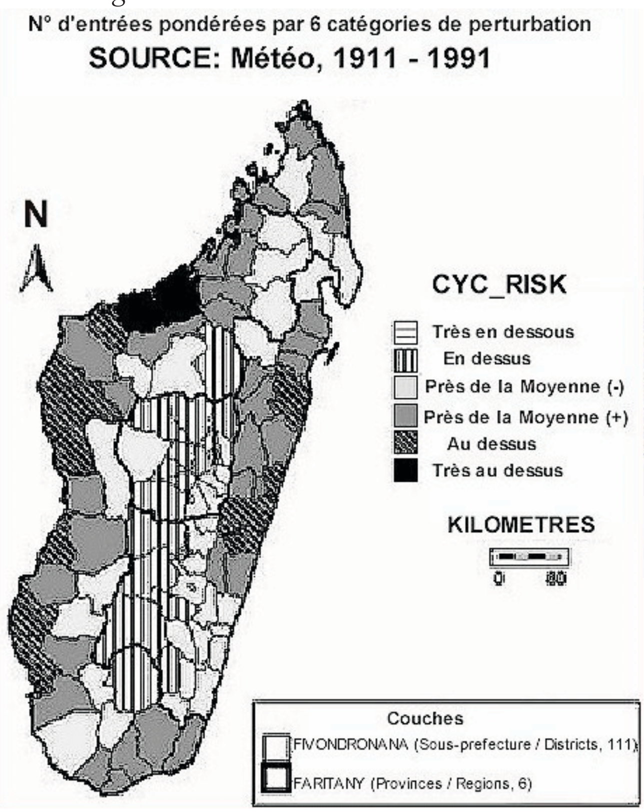


Figure 1: Vulnerability of different regions of Madagascar to tropical disturbances. The indexes were calculated for the period 1911-1991 (Meteo 1991)

Drought indexes are presented in Figure 3, and Figure 4 shows the distribution of rainfall around Madagascar.

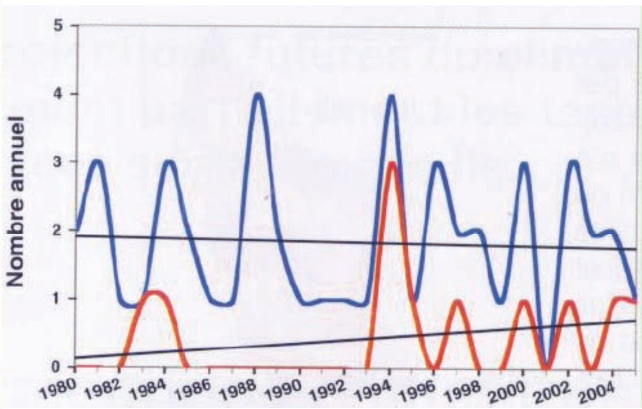


Figure 2 indicates the average number of cyclones having touched Madagascar ( ) and the average number of cyclones with an intensity > 200km/h ( )between 1980 and 2005 (FTM 2008).

Figure 2: Average number of cyclones having touched Madagascar

Table 1: Tropical storms and cyclones that struck Madagascar from 1968 to 1999 (EM-DAT 2000 www.md.ucl.ac.be/cred)

Year	Name	Number of deaths	Number of injured	Number of homeless	People Affected	Total affected	Damages (in US$)
1968	-	29	-	10.000	65.000	75.000	3.100
1969	-	81	40	3.000	40.000	43.040	5.000
1970	-	70	-	-	10.000	10.000	11.400
1972	-	91	56	10.000	2.500.000	2.510.056	12.420
1975	-	7	50	-	10.000	10.050	-
1976	-	16	26	8.850	500.000	508.876	17.000
1977	-	10	-	-	30.000	30.000	350.000
1978	-	70	-	-	18.000	18.000	29.000
1981	-	107	-	50,000	118,000	168,000	250,000
1982	-	100	-	117,000	-	117,000	-
1983	-	42	100	-	13,560	13,660	25,000
1984	-	68	215	-	100,000	100,215	250,000
1986	-	99	424	-	83,885	84,309	150,000
1989	-	46	-	1,050	55,346	56,396	-
1991	Cynthia	36	0	125,000	125,000	250,000	-
1994	Daisy	200	43	40,000	500,000	540,043	10,000
	Geralda						
1994	Nadya	12	8	-	-	8	-
1994	Litanne	-	-	-	-	-	-
1996	Bonita	9	-	-	100,000	100,000	-
1997	Gretelle	140	-	80,000	520,000	600,000	-
1997	Josie	34	-	-	-	-	-
	Total	1,267	962	444,900	4,788,791	5,234,653	1,112,920

Table 2: The 10 most important natural disasters in Madagascar (www.md.ucl.ac.be/cred)

Disaster	Date	Number of deaths	People Affected
Tropical storm	February 2, 1994	304	357,217
Famine	March 15, 1992	200	-
Tropical storm	January 13, 1994	200	540,043
Tropical storm	January 24, 1997	140	600,000
Tropical storm	December 20, 1981	107	168,000
Tropical storm	February 14, 1972	91	2,510,056
Drought	1981	-	1,000,000
Tropical storm	May 22, 1992	-	950,000
Drought	January 10, 1976	16	508,876
	December 16, 1990	-	250,000

Table 3: The floods affecting Madagascar from 1968 to 1999

Dates	Affected Regions	Caused by / Characteristics	Effects
March 12-23, 1975	Antananarivo Manjakandriana	Cyclone Inès ; rise in water level of 370 m³/s	Low zones, railway line, 740 ha of rice fields, road damaged
February 12, 1977	Antananarivo	Cyclone Emilie ; rise in water level of 350 m³/s	
January 1982	Antananarivo	Centennial rise in water level;	102 deaths, 37 injured, 130,705 homeless, 47 missing
March 26, 1986	Antananarivo	Cyclone Honorinina	28,223 affected people, with thousands homeless, hundreds flooded houses, dyke breaking at Ikopa, Andromba and Sisaony
1987	Antananarivo	Torrential rain, continuous	40,220 affected people and 2 deaths
February 4, 1994	Antananarivo and eastern part of the country	Cyclone Geralda	
February 1998	Antananarivo, Fianarantsoa, Mahajanga and Toliara	River floods	20,000 homeless, damaged roads and blocks

Sources:
1- Conseil National de Secours (CNS) – Madagascar (March 1998)
2-EM – DAT : The OFDA / CRED International Disaster Database - www.md.ucl.ac.be/cred – Université Catholique de Louvain – Brussels – Belgium / juillet 2000.

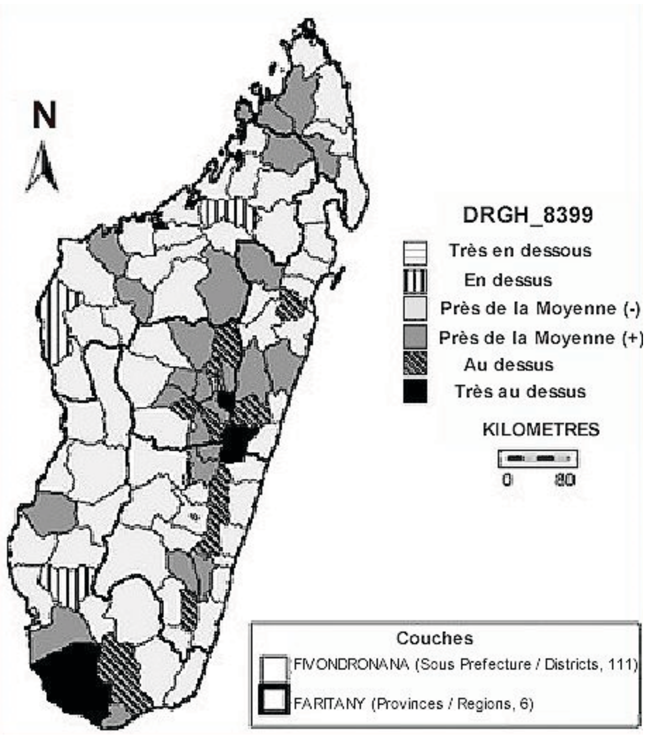


Figure 3: Drought index map of Madagascar. The indexes were calculated over the period 1982-1999 (NOAA, 1982-99).

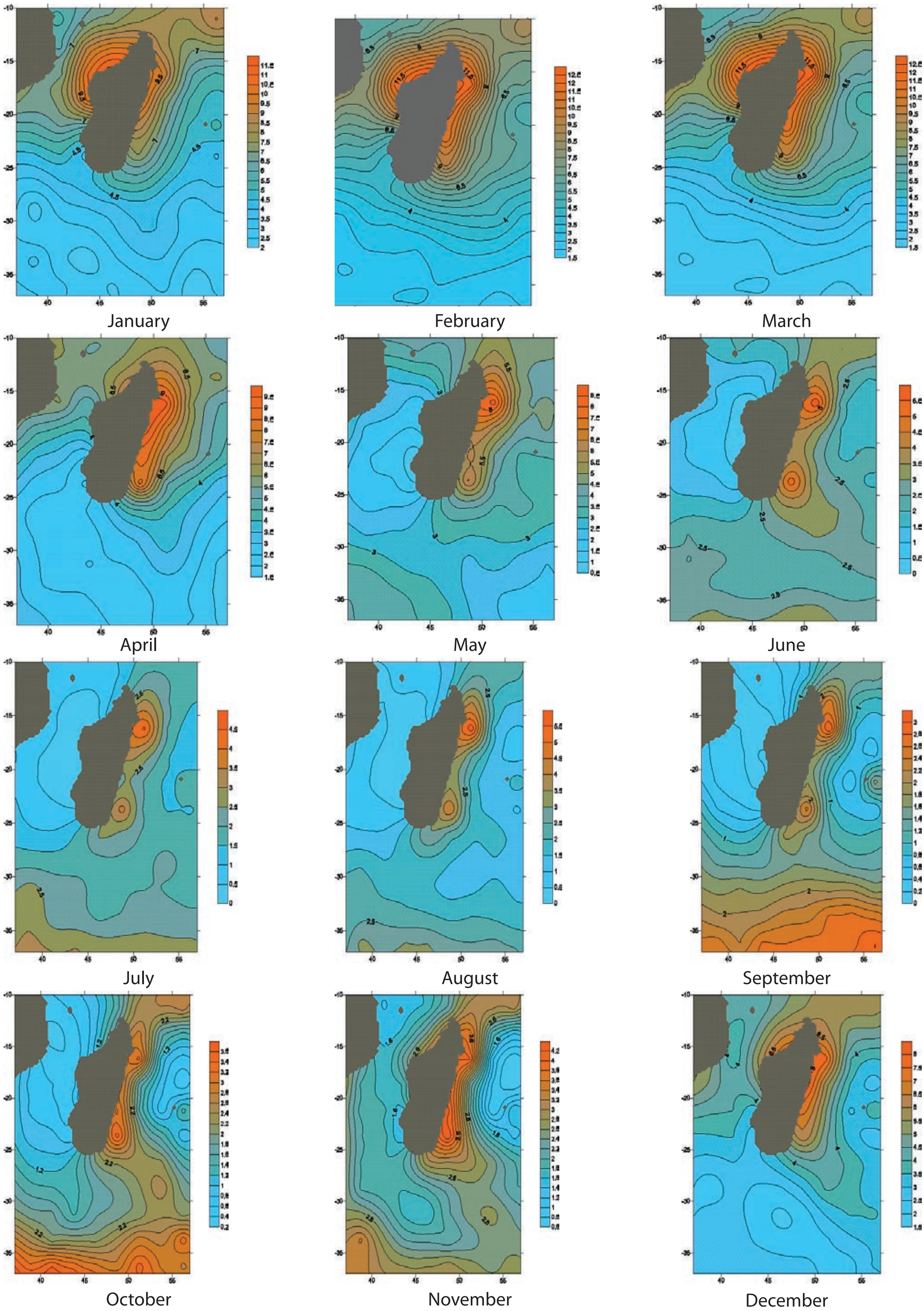


Figure 4: The distribution of rainfall in Madagascar. Rainfall averages calculated over the period 1957-2004 (Bemiasa 2006). The unit are x100mm.

Marine and coastal geomorphology and geology

From the Cretaceous period, marine transgressions and regressions succeed one another leading to the formation of continental then marine deposits, alternating with numerous changes of facies. It is also during this period that large effusions, mainly basaltic fissure spread to the periphery of the bedrock. This has been widespread from Iharana to the Bay of Antongil including the massif of basalt and cryolite of Androy Region, the basaltic layers of the West in Toliara region, south of Cape St. André and in the Mahajanga basin (Kornicker and Thomassin 1998). Sedimentary rocks form a wide band on the West Coast of the island. There are also a few isolated patches on the East Coast but these have not been subjected to significant orogenic action (Besairie 1946).

Geomorphology of the East coast

The eastern region of Madagascar can be divided into three regions:

1. From Taolagnaro to the Isandra River: This zone consists of a relatively narrow zone with fairly large depressions and valleys separated by a mountain chain occurring parallel to the coast. The main mountain peaks (Isakatelo, Vohimena) reach between 1 200 and 1 300m above sea level. The zone quickly approaches the Indian Ocean by a narrow zone of gently undulating lateritic hills.
2. Between the Isandra River and the mouth of Mangoro: This zone consists of a vast peneplain lying against the eastern steep slope resulting from an ancient erosion surface, more or less affected by a new cycle (Besairie 1954). The shape of the basin shows rectangular tectonic direction or circumvented orientation striking west-east.
3. North of Antongil Bay: In this zone, the foothills of Tsaratanana approach very close to the sea, leaving only narrow alluvial plains interrupted by basalt effusions. From north to south there are series of small swampy depressions isolated from each other by low hills. The rivers discharge into a lagoon system, parallel to the coast (Figure 5).

In detail, the relief of the sedimentary cover appears as relief cuestas resulting from alternating hard and soft layers with a generally low dips towards the sea. Between Morondava and Toliara, there is one last cuesta shaped in Tertiary marine limestones (Battistini 1967). Throughout the West, from North to South, the sedimentary rocks are disrupted by Cretaceous igneous intrusions, creating Manongarivo, Ampasimbitika, Ambereny, Fonjay and Analavelona massifs (Mauge 1976).

Soil types and permeability have been studied for a long time in Madagascar. These include, among others, the works of Bourgeat *et al.* (1973) and those of Riquier (1951). The first describes the relationships between landforms, soil types and their suitability for cultivation in the highlands of Madagascar. The second focuses on the classification of lateritic soils of Madagascar according to topography. With a particular focus on the highlands, part of the forest of eastern and coastal dunes, Riquier (1951) classified 21 types of soils.

It should be noted that more recent information obtained following the implementation of the PGRM is currently available.

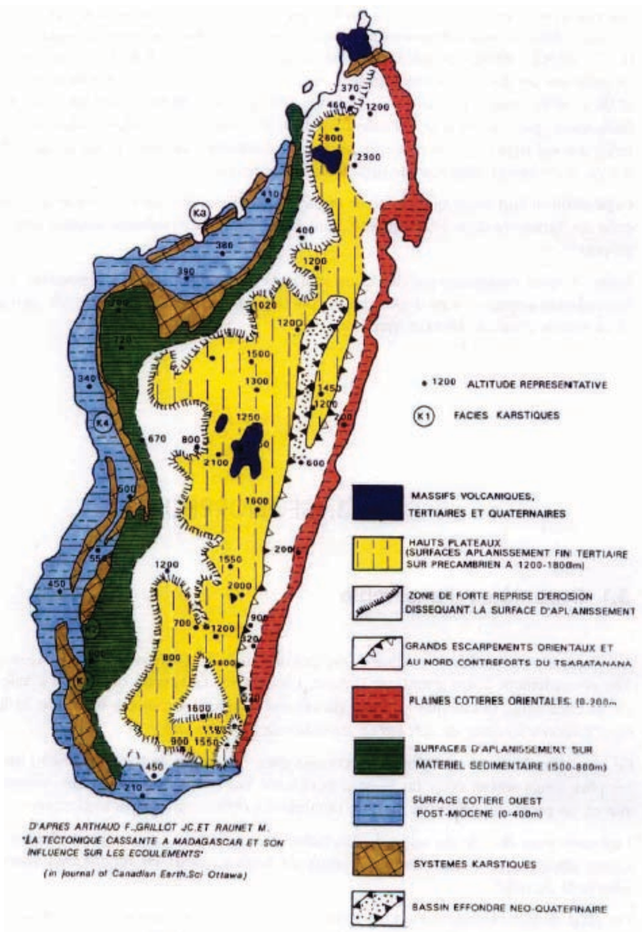


Figure 5: Geomorphological regions of Madagascar (Arthaud *et al.* 2003).

Freshwater resources and drainage

On the eastern side of Madagascar, the main rivers and streams that flow into the sea are the Mananara and Mangoro from the Central Highlands. Rivers flowing through the Central and East coasts to the sea include the Maningory that has its source in Lake Alaotra. Other rivers are the Bemarivo, Ivondro and Mananjary. Flood flows of these rivers are usually very high because of the steep drainage gradient. This provides important hydroelectric potential which in some cases has been harnessed. The specific median peak flow is between 300 and 1200 l/s/km^2, and between 1000 and 2700 l/s/km^2 for decennial flows. High flow rates are observed in small basins on the extreme southern slopes (e.g Efaho 2200l/s/km^2, median and 4 900 l/s/km^2, decennial) (Figure 6) (Chaperon *et al.*1993).

In the western side of Madagascar, the river basins include Sambirano, Mahajamba, Betsiboka (the port of Mahajanga is located in the mouth), Mania, south and north Mahavavy, Mangoky and Onilahy. The Mangoky watershed occupies 50,000 km^2. The Ikopa River which crosses Antananarivo feeds Betsiboka River. Ikopa and Betsiboka rivers have drainage areas of 18,000 and 11,000 km^2 respectively. The Mandrare River in the south has 12,435 km^2 of watershed, but it is intermittent.

The rainfall distribution in the drainage basins depends on the topography. The highest rainfall (100 to 200 mm/month) occurs on the eastern slopes of eastern highlands and western slopes of Tsaratanana highlands. The intermediate rainfall (50 to 100 mm) occurs in the western and southern sectors of the highlands. Those in the Southwest (e.g. Mangoky River) receive relatively lower rainfall ranging from 25 to 70 mm per month. Finally, in the south, these reserves are more-or less non-existent (Chaperon *et al*. 1993).

Five major units of hydrological regime can be identified in Madagascar (Chaperon *et al.* 1993):

1. The regions of the North, particularly: i) the extreme North and Amber Mountain, ii) the Tsaratanana massif, and iii) a northeast between these two massifs.
2. The eastern slope region,
3. The Highlands region: i) the central highlands between Tsaratanana in the north and Andringitra in the south, ii) the Southern Highlands between Andringitra in the north, Ivakoany in the south, Ambalavao in the east and Isalo in the west.
4. The western slopes region: i) the Northwest and West from Maevarano Basin in the north to Tsiribihina in the south, ii) the Southwest from Morondava Basin in the north to Mangoky bsasin in the south.
5. The South region from lower Mangoky basin to Mandrare basin (Figure 7).

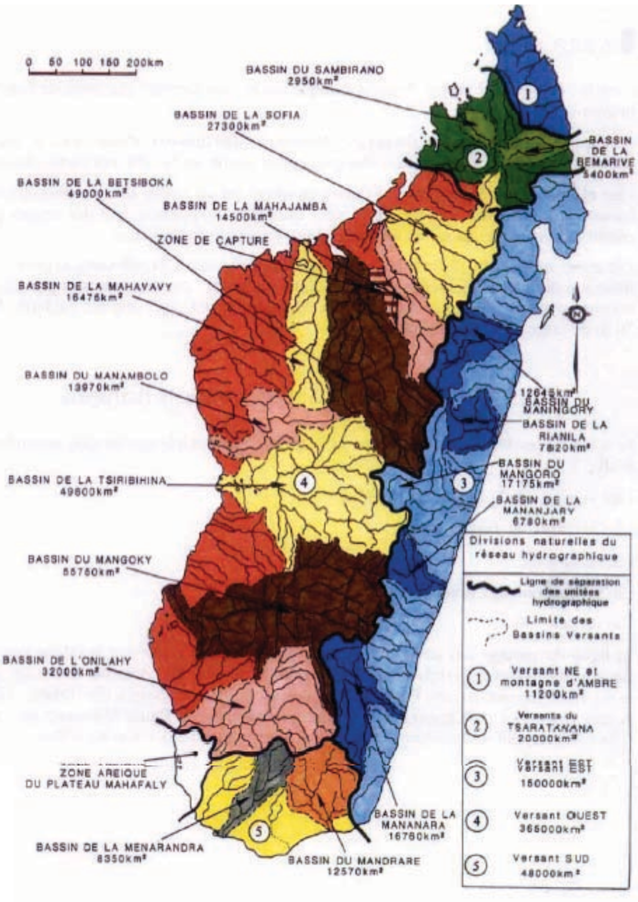


Figure 6: Drainage basins and major watersheds of Madagascar (Chaperon *et al*. 1993)

Coastal erosion and sedimentation

Coastal erosion, which is more serious along the west coast of Madagascar in Mahajanga, Maintirano, Morondava and Manakara regions, is a result of changes in coastal hydrodynamics conditions. Coastal erosion is particularly serious in the northwest coast of Madagascar.

Sedimentation is common in the Betsiboka estuary which drains the largest rivers in Madagascar. The spectacular growth of mangrove swamps in this zone is attributed to sedimentation due to soil erosion taking place in the hinterlands. During rainy season, reddish soils eroded from land are transported by the rivers to the coast. Seen from air, it has been said that "Madagascar bleeds" into the ocean. The estuary of Betsiboka illustrates this phenomenon which is particularly intensified during the passage of a tropical cyclone (Gafilo 2004).

ii) Gaps

Most of the hydrometric stations in Madagascar have short-term observations. This is due to remoteness and inaccessibility of the regions where stations are located. Other reasons are poor hydraulic conditions resulting from significant instability of control sections; insufficient gauging and inability to establish calibration curves. Also, most data are based on occasional studies for a specific development projects.

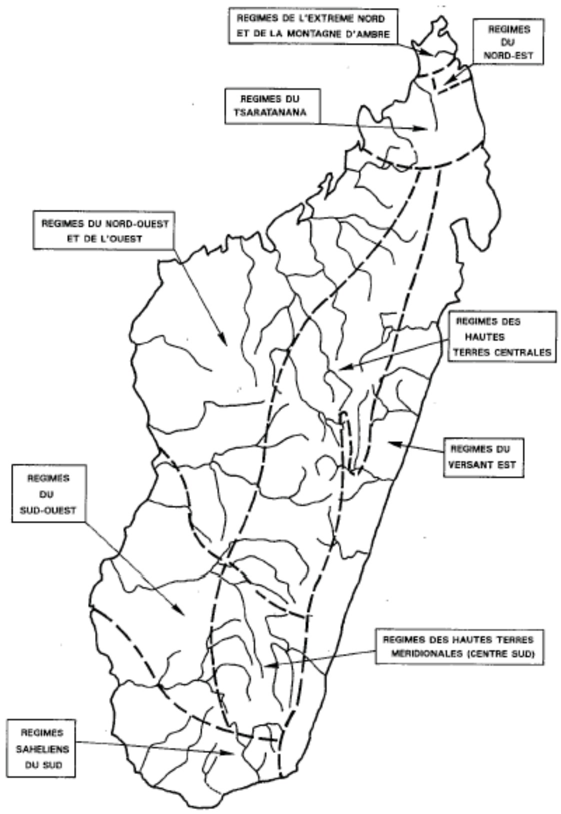


Figure 7. The major hydrological regimes of Madagascar (Chaperon *et al*. 1993).

Physical Oceanography

Currents (coastal hydrodynamics and system of offshore currents)

Madagascar is influenced by the East Malagasy Current, South Equatorial Current and Mozambique channel eddies. The Agulhas current (Figure 8) which originates from the narrowest part of the Mozambique channel at 17°S moves southward (Quartly and Srokosz 2004). The Malagasy East Current (MEC) flows south-eastward past the south of Madagascar.

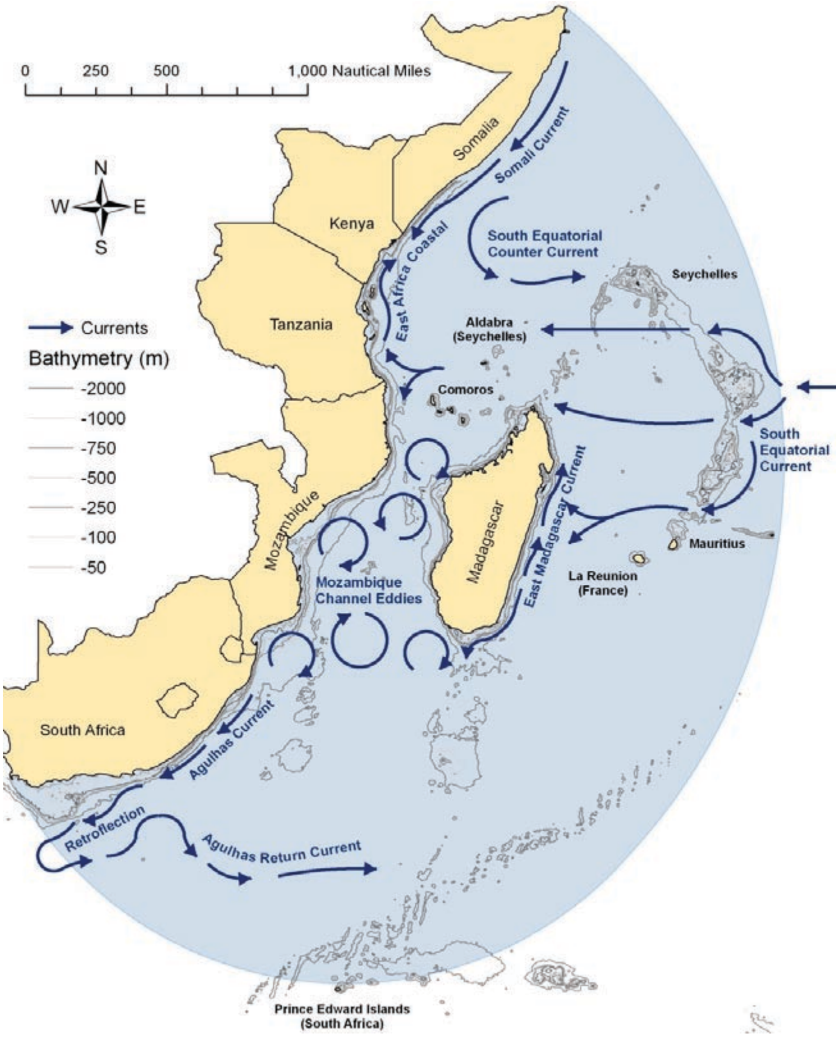


Figure 8: Currents and water movement around Madagascar

Upwelling zones are found in the South of Madagascar. The upwelling in this region is enhanced in austral winter except in 1999 and in austral summer except in 2001. Upwelling borders the Malagasy East Current (MEC) in the east and south. The southward transport of MEC is of the order 41 × 10^6 m^3 s^{-1}. In the south of Madagascar, an intense warm, shallow eastwards flow occurs immediately south of Cape St. Marie. The narrow East Madagascar Current has the characteristics of a minor western boundary current. South of Madagascar, MEC cast off eddies and occasionally acts as a source current to the Agulhas Current. During the southern winter, the MEC waters crosses south of Mozambique Channel in the direction of the African coast, but it is often deflected northward along the Malagasy west coast (Lutjeharms and Machu 2000, DiMarco *et al.* 2002).

The sea surface temperatures around Madagascar are higher than expected in the subtropical location of the southern part of the island. These high sea temperatures are due to the South Equatorial Current (SEC) whose warm waters flow past Madagascar. Off the coasts, the annual average sea surface temperature ranges from 22°C in the south to 28°C in the north, with local seasonal extremes ranging from 19°C to 33°C in shallow areas.

Frontal zones and eddies

Quartly and Srokosz (2004) showed that the eastern part of the Mozambique channel is characterized by the presence of cyclonic eddies, particularly in the far south of Madagascar. Although there is still doubt as to the local origin of these eddies, it is clear that coastal waters, extremely rich in chlorophyll, move West-Southwest with these eddies. Although data analysis of chlorophyll does not show the existence of anticyclonic eddies, it does show the presence of retroflexion of the MEC and that surface waters transported by the MEC can reach the African continent when there is no retroflexion. Cyclonic eddies originate from offshore zone of the south continental shelf of Madagascar. These eddies then move westward down the Mozambique Channel to feed the Agulhas current, together with other eddies.

Dynamics and extension of the Malagasy south upwelling

Bemiasa (2007) studied the long-term variability of the southern upwelling off Madagascar and its interaction with the Malagasy East Current (MEC). Except for 1999 and 2001, the upwelling in the south of Madagascar is usually active during winter and southern summer. The current generated by the upwelling flows along the east and south coasts of the Island.

Hoerner (1986) points out particularities which suggest the occasional existence of a sub-polar cold current off Madagascar. These includes the discovery of dead penguins towards 21°S in the west coast of Madagascar; the air temperature which falls below 10°C in southern winter, often linked to the strong wind of the South " Tsiokatimo " and rough inter-seasonal transitions. This periodic cold current could account for the occasional arrivals of huge number of anchovy along the Malagasy Southwest coast in the period between October and December. These anchovies are particularly abundant in the local fishery (Hoerner 1986). This was witnessed after a drought in the Toliara region in 1990-91 in which there was a high abundance of anchovy and young pelagic species in addition to abnormally cold waters in coastal zones. This phenomenon of massive arrival of anchovies was also noticed in 2002 by Bemiasa (2009).

A new current discovered by altimetry

Lutjeharms (2006) discovered a counter current of the South Indian Ocean which flows eastward from Madagascar at approximately 25° S. This current is the counterpart of a current found close to Ecuador, which flows in the opposite direction (Lutjeharms 2006). While it is not always visible, the average current speeds in the region show it clearly (Figure 9).

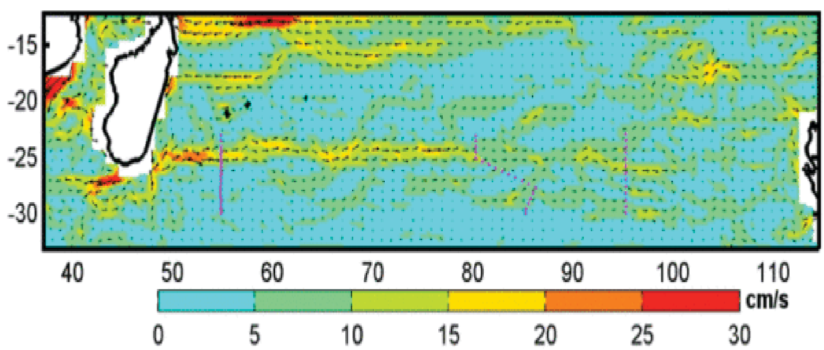


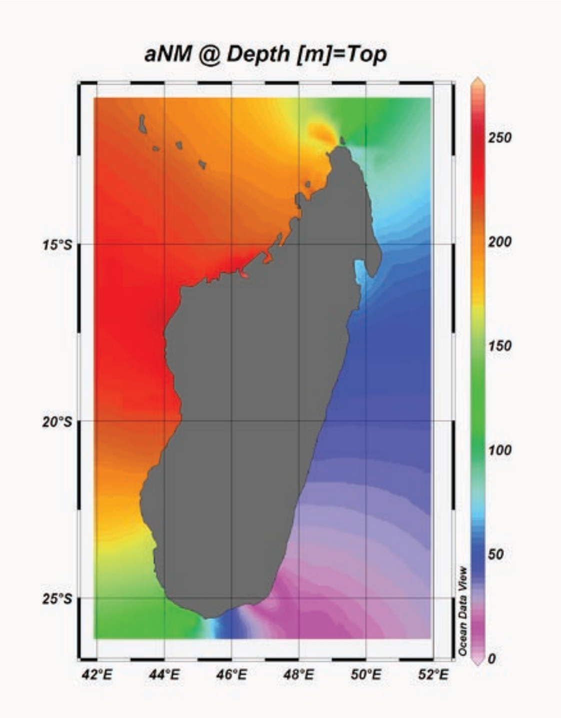
Figure 9: Average geostrophical speeds (deducted from the absolute dynamic topography) [altimetry] over 5 years (in August, 2001 - in May, 2006) in the east of Madagascar. The pink lines represent *in situ* observations (Woce data programme), which confirm the existence of this current (Rouault and Lutjeharms 2006).

i) Issues

ii) Gaps

- Lack of current data on drifting buoys.
- Lack of data on native knowledge.
- Tidal regime

The tides in Madagascar are semidiurnal with two low tides and two high tides a day with approximately equal amplitudes. The western coast is characterized by relatively higher tidal ranges (Figure 10a). In the vicinity of Toliara, the tidal range can reach 3m during spring tides. Strong tidal currents ensue from it, particularly between the Grand Reef and the coast.



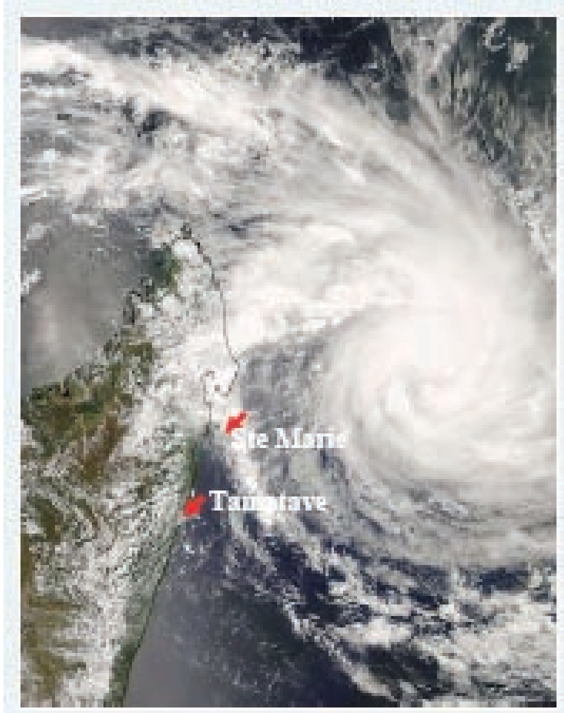


Figure 10: Average level of tidal range in Madagascar in cm (left) and tropical storm Ivan, February 16, 2008, 06h45 Z (right). (Bemiasa 2008).

Floods, Extreme Waves and Storm Surges

The wind regime (monsoons, trade winds) in Madagascar significantly affect the state of the sea. The western side of the island is protected from the influence of trade winds. The sea in the west coast is therefore calm compared to the East Coast where hydrodynamic conditions are very rough, especially during cyclones (Bemiasa 2008). The cyclones which affect Madagascar are formed in two main regions. The first region is located to the Northeast of Madagascar within the Indian Ocean. In this region, cyclones move in a westward direction at first, and then their trajectory moves southeastwards. The second area of cyclone formation is the Mozambique Channel. The cyclones formed in this area are generally smaller and less violent. They mostly move eastward and may cross Madagascar in the southeast (Bemiasa 2008).

Cyclones are common on the East Coast during the rainy season. They cause storm surges and a temporary sea level rise. Also, they regularly cause floods in the coastal zones. Figure 10b shows the location of the cyclone Ivan on February 16th, 2008 when it reached the northeastern coast of Madagascar. The cities of Toamasina and Ste Marie were affected by floods during the passage of Ivan (Bemiasa 2008). Data on water level and atmospheric pressure during the passage of the cyclone were acquired at Beautemps-Beaupré hydrographic station near Tamatave (Bemiasa 2008).

Storm surges associated with cyclones are common occurrences in Madagascar. The maximum sea surge measured at Tamatave during cyclone Ivan was 0.979m on February 17th, 2008 at 06h50 UT (Figure 11).

Sea level variation

During the colonial period, the Hydrographic Service (HS) of France was responsible for maintenance of tide gauge stations in many ports of Madagascar. Tide gauges were established to monitor water levels for depth sounding purposes. The activities of the HS in Madagascar continued until mid 1980s when Madagascar became a member of the Global System of Observation of Sea Level (GLOSS) (Razakafoniaina 1999). Four tide gauge stations have been operating in Madagascar since the end of the 1980s. The last operating tide gauge station was stopped in 2003. During this period, some data were collected in the main ports of the country.

The tide gauges installed at Antsiranana, Hell-Ville, Toamasina, Toliara and Taolagnaro were supplied and installed by FTM (Foibe Taon-tsarintanin'i Madagasikara) which shared the responsibilities of their maintenance with the National Center of Oceanographic Research (CNRO). The tide gauges at Hell-Ville and Taolagnaro were under the responsibility of the CNRO, whereas the FTM took care of those located in Toliara. The employees of local ports and agencies were trained on maintenance and daily reading of data from tide gauges.

Until 2002, the follow-up and analysis of sea level data from Hell-Ville were entrusted to the Department of Physical and Chemical Oceanography (DPCO) of the CNRO, which acquired software for the analysis of data from tide gauges. This software was supplied by the University of the Hawaii who also trained CNRO staff. The trained staff later ensured regular dispatch of sea level data to the University of Hawaii Sea Level Center for other more advanced analysis.

Trends of the mean sea levels

The mean annual sea levels were calculated from hourly daily levels data. Only two ports which have long temporal data series were retained for the calculation. These are ports of Hell-Ville and Antsiranana. The sea level data that has been analyzed covered the periods 1958-1998 and 1902-1972, respectively (Figure 12). The analysis of some tide gauge series shows that the mean sea level rise around Madagascar is consistent with sea level rise trends observed in the Western Indian Ocean (WIO) region. There is an increase in sea level at Antsiranana and a decrease at Hell-Ville. These trends must be considered with a certain caution because the data series are not long enough to allow a more reliable long-term trend to be established. Also, missing data on some series of measurements does not allow for validation.

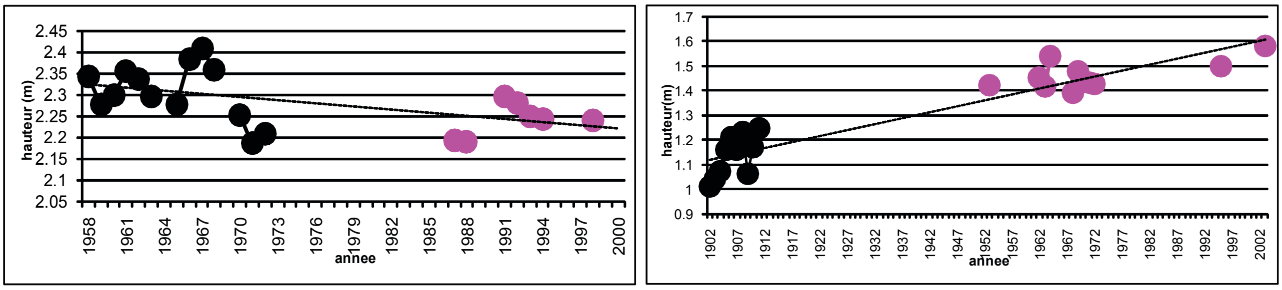


Figure 12: Annual evolution of the mean sea level at Hell-Ville (left) and Antsiranana (right) over the periods 1958-1998 and 1902-1974 (CNDO 2003); black dots are validated data; pink dots are unvalidated.

Sea temperature

The sea surface temperature (SST) is on average slightly above 25˚C. The maximum of 30˚C is usually reached in February and the minimum of 23˚C is observed in July. SST range from 22 to 27˚C during cold season in April to September and range from 25 to 29˚C during warm season in October to March.

Studies on paleoclimatology were done by Zinke *et al.* (2004) on the south-western reef of Madagascar. The study found that the period 1675–1760 was the coolest with temperature anomalies of 0.3–0.58°C. The warmest periods occur in the period 1880-1900 and 1973–1995. Strong Indian Ocean subtropical dipole events, occurring during austral summer, are evident in past records. The study also revealed that the impact of ENSO on SW Indian Ocean SST and atmospheric circulation was strong in the period 1680–1720 and 1760–1790. The results of the study also demonstrated that the impact of ENSO cycles in the SW Indian Ocean region has changed significantly since 1970. This is due to warming of southwestern Indian Ocean surface waters.

i) Issues

- The coral bleaching caused by high water temperatures, in particular that of 1998, affected the reefs of the south-west coast of Madagascar. As the area is one of the most exploited reef areas, the effect of ocean warming was devastating. There are large areas where the coral colonies were killed and these are now covered with algal turf. This indicates that the degradation is not mechanical but is due to change of water temperature (Maharavo 2009). This has affected fisheries productivity. Other associated issues are fish kills and loss of seaweed colour, and hence value in seaweed products.

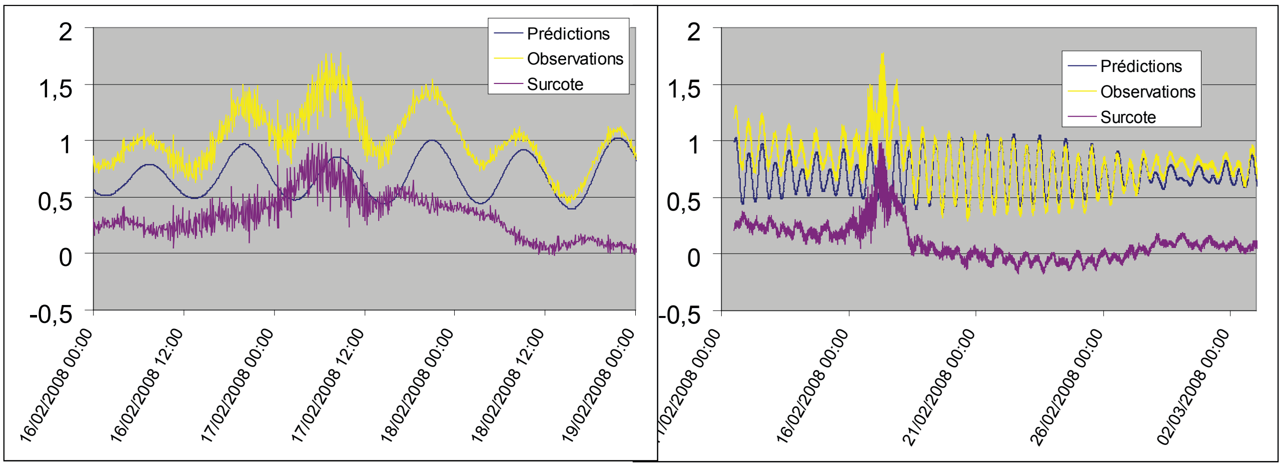


Figure 11: Observations of sea level (in meters) in Toamasina and Sainte Marie from 02/16/2008 to 02/19/2008 during the passage of the cyclone Ivan (CNDO 2008)

ii) Gaps

- Lack of data on the mortality and other effects of temperature rise on fish and other organisms.
- Lack of data on loss of color and hence value to algae products.
- Lack of data on in situ temperatures (UTR and thermister chains).

Salinity patterns

A series of oceanographic data from the period 1950-2006 were analyzed in order to establish profiles of temperature, salinity and oxygen in waters around Madagascar. These are presented in Figure 13.

The plot of temperature – salinity data derived from CTDs shows an existence of Equatorial South Water Mass (ESW) relatively rich in oxygen, high temperature and salinity ranging between 34.5 - 35.4 PSU. This warm water mass has its origin in the Subtropical Indian Ocean to the east of 58°E and between 15° and 35°S (Wyrtki 1971). It reaches the Southwest Indian Ocean in the southern tip of Madagascar where it comes into contact with the Tropical Surface Water (TSW) with low salinity (<35.0 PSU), which propagates southward in the Mozambique Channel (Duncan 1970). The superposition of the Tropical Surface Water on the Tropical Subsurface Water produces a maximum subsurface salinity of water to a depth of 150-200m. At this depth, temperatures range between 15 and 20˚C in the contact area in the Agulhas Region.

Between 300m to 600 m, the T-S correlation shows a perfect linearity at a temperature of between 9°C and 12°C and salinity of between 34.80 and 35.10 PSU. This zone consists of Central Water (CW) mass (Sverdrup *et al.* 1942). At a depth of 1,000 m, three types of water masses are evident - low salinity Antarctica Intermediate Water mass (AIW) seeping northward in the southern Indian Ocean and returning to the south in the opposite direction in an anticyclonic direction (Clowes 1950, Duncan 1970). The other type of water mass has a temperature of between 6.5°C and 4°C, and salinity higher of 34.70 PSU reaching a maximum of about 34.78 PSU (Donguy and Piton 1969).

Ocean-atmosphere interaction

In tropical regions, studies of ocean-land-atmosphere are essential in the understanding the dynamics of climate change on a global scale. However, the interactions between the water cycle on the continents and major forcing climatic factors such as ocean temperatures remain unclear. In Madagascar, studies on the ocean-continent interactions are being undertaken with a special focus on the variability of the discharge of large rivers. These studies have been conducted by CEREGE2 on the lake Ihotry, but their details were not available for presentation in this report. Data on heat flux, carbon exchange, cyclogenesis, evaporation, Indian Ocean Dipole, etc are also not available for Madagascar.

i) Issues

- Madagascar is influenced by ocean-atmosphere processes. Unfortunately, very little research has been carried out in this area. The country also experiences extreme climatic events such as droughts and floods which are yet to be studied extensively. There is also the issue of ocean acidification which is currently poorly understood as no studies have been carried out on the same in Madagascar.

ii) Gaps

- There is a major gap in research on ocean-atmosphere interaction is concerned. Also, limited studies have been carried out on the physical processes of waters surrounding the island. There is a need to fill this gap by implementing comprehensive oceanographic research programmes.

Biological and chemical oceanography

Nutrients

Nutrient data for Madagascar are presented in atlas form (Stephens *et al.* 2002, Boyer *et al.* 2002, Locarnini *et al.* 2002, Conkright *et al.* 2002 and World Ocean Atlas 1998 (WOA98) series. Among others, data from research conducted by Malagasy scientists are also available for some areas of the island, mainly in the South (Lope 2009). In the same way, a recent study undertaken by CNRE and IHSM in 2009, during the WIO-LaB Project, is also available for two sites, Nosy Be and Mahajanga.

Lope (2009) has shown that three lagoons, Ambinanibe, Andranasy and Andrantoloharano have high concentrations of nutrients throughout the year. This nutrient enrichment is due to flooding of the Ifaho River. The average ammonium concentrations differ between the lagoons, with 1.2 ± 0.6 mol/l at Ambinanibe, 2.9 ± 2.0 mol/l at Andranasy and 4.8 ± 3.1 mo/l at Andrantoloharano. The nitrate enrichment begins in January in the Ambinanibe lagoon and spreads gradually to the other lagoons after an interval of one month. After a period of high floods, there is a peak in nitrate concentrations, with some significant variations between the lagoons. The nitrate concentrations of the surface water range from 0.4 to 158.5 mol/l at Ambinanibe, 1.7 to 299.7 mol/l at Andranasy and 0.6 to 123 mol/l at Andrantoloharano. The nitrite concentrations for the three lagoons Ambinanibe, Andranasy and Andrantoloharano were 0.15 ± 0.10 mol/l, 0.12 ± 0.07 mol/l and 0.21 ± 0.15 mol/l, respectively.

i) Issues

- The rivers draining the Madagascan Highlands are important sources of nutrients brought to the coast. Nutrient enrichment can be enhanced due to use of fertilizers in agriculture and also due to accelerated soil erosion within the river basins. Nutrient enrichment causes eutrophication and occurrence of harmful algal blooms (HABs).

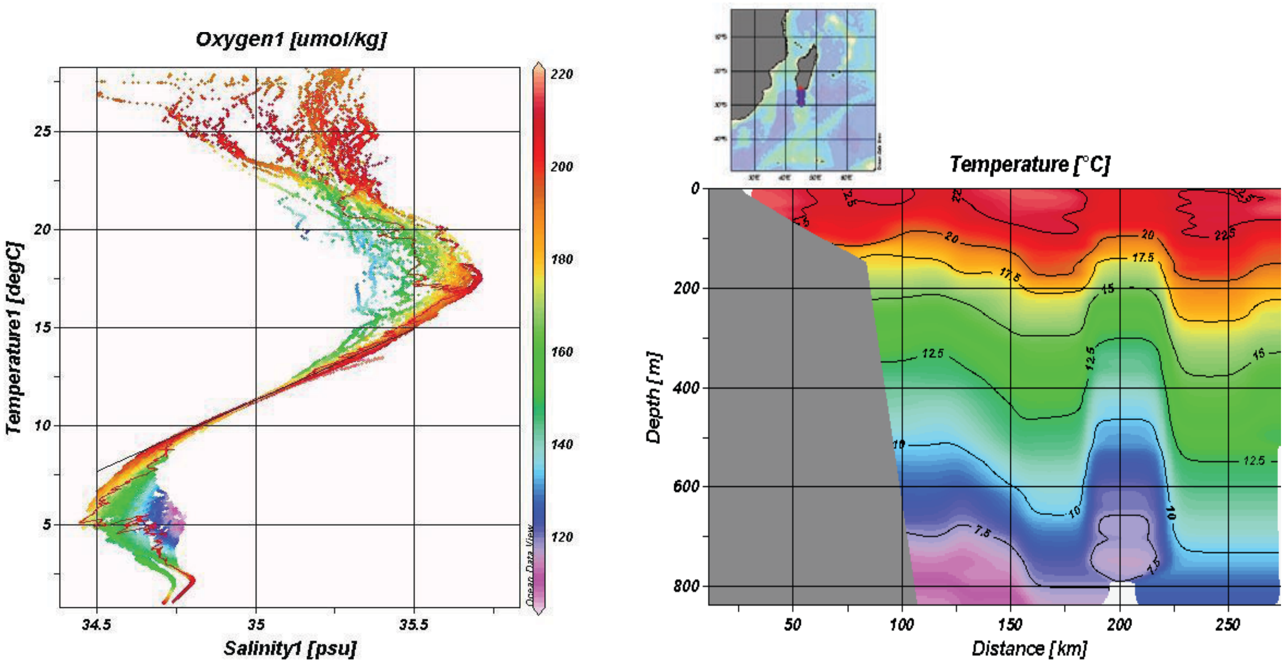


Figure 13. T-S-O profile and hydrological section (temperature of seawater) in upwelling area in the south of Madagascar

ii) Gaps

- Except for data from recent oceanographic campaigns conducted by international research vessel (*Fridtjof Nansen* in 1993, 2008, 2009, Pelagia 2001), few *in situ* data have been collected on nutrients: nitrate, nitrites, and phosphates. Data from these surveys are archived in various data centres located in Norway, Madagascar, South Africa and Japan. There is a need for repatriation of data archived in foreign institutions which are not easily accessible to the Madagscan institutions.

Persistent organic pollutants

In Madagascar, the pollution of the marine and coastal environment is due to industrial, agricultural, port and mining activities whose importance and consequences are not well quantified. Most pollutants are biodegradable but there are also persistent organic pollutants (POPs) such as highly toxic insecticides such as DDT used in malaria control. There is also pollution due the increase in waste production (domestic and industrial) in urban areas such as Toliara. The high rates of sedimentation associated with Fiherenana River are also considered to be important sources of pollution. The sedimentation is especially high in the rainy season, during which the river flow can reach 3000 to 4000 m^3/s compared to 40 to 60 m^3/s in the dry season.

In Madagascar, the sources of pollution are either point-based or diffuse and are often due to the discharge of effluents from industries, oil refineries, shipyards and mines. The oil refinery at Toamasina and the shipyard at Antsiranana, whose effluents contain naphthenic pollutants, sulfides and thiophenols, are examples of point sources of pollution. It is the same case with mining zones whose pollutants are made up of solid waste and sludge mineral suspensions. It is important to note that industries in coastal zones, which account for 34% of all industries in Madagascar, are among the major sources of pollution load. This sector is dominated by the food industry (38.4%) and wood industry (34.8%).

Primary production

Research on phytoplankton has been conducted in the northwestern part of Madagascar by the Hell-Ville Station (CNRO) team. The results of this research are available as scientific publications (Anon 1954, 1964a, b). Travers (1965) studied the phytoplankton in the region of Toliara in the Southwestern coast of Madagascar. In the Ampasindava Bay, the average concentration of chlorophyll a is 0.7 mg/m^3 in the period July - March. At the end of the rainy season in April, phytoplankton blooms occur with a chlorophyll a mean value of 3.9 mg/m^3 and maximum value of 10 mg/m^3 at a depth of about 20 m. This situation maintains stable conditions in nutrients levels which vanish only one month later in June, when the chlorophyll a concentration drops to 0.7 mg/m^3.

The analysis of the chlorophyll-concentration variability (primary production) around Madagascar shows a higher level off the West and South coasts (Figure 14). Generally, the south of Madagascar (latitude 24°S 26°S) is richer in chlorophyll-a than the north and west. In the East Coast, high chlorophyll a concentrations (0.10 - 0.30 $mg.m^{-3}$) are only observed at latitudes 21°S -23°S and 25°S and along the mouths of large rivers. The analysis of interannual changes between latitudes -20° and 26°S along the Southwest coast, shows that the year 2002 experienced intensification of phytoplankton bloom in the southern area of Madagascar (Bemiasa 2009).

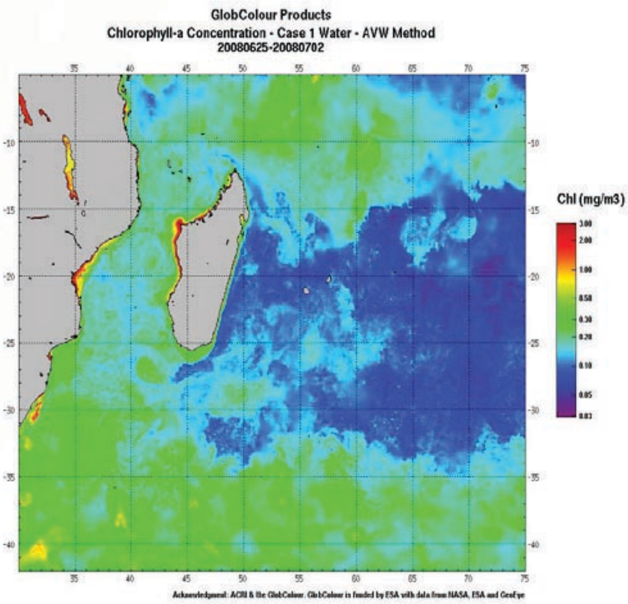


Figure 14: Composite representation of chlorophyll-*a* concentration ($mg.m^{-3}$) around Madagascar (Ocean Color Image, GlobeColor Products)

Recent studies on seasonal phytoplankton blooms in the Madagascar Basin have uncovered a hitherto-unnoticed phytoplankton bloom of 3000×1500 km, occupying the Madagascar Basin in late austral summer (**Longhurst 2001**). The bloom was attributed to the seasonal deepening of the mixed layer within a strong mesoscale eddy-field and the consequent entrainment of nutrients into the photic zone. The bloom did not develop in 1998, the second year of a two-year ENSO episode, when anomalously weak Southeast trade winds failed to deepen the mixed layer as in other years.

A study was conducted by Southampton University Scientists in 2005 around Madagascar, with the main objective of explaining the massive blooms of microscopic marine algae–phytoplankton–in the seas around Madagascar and its effect on the biogeochemistry of the southwest Indian Ocean. Their findings can be summarized as follow: '*Previously, it has been thought that the large-scale autumn bloom that develops in this region is driven by nitrogen-fixing blue-green algae, or cyanobacteria, called* Trichodesmium, *colonies of which the researchers found to be abundant. However, the 2005 bloom was dominated by a diatom – a type of phytoplankton – the cells of which play host to another nitrogen-fixing cyanobacterium called* Richella intracellularis, *with* Trichodesmium *apparently playing second fiddle. Diatoms have relatively large cells, and when they die they sink down the water column, carrying with them carbon that is ultimately derived from carbon dioxide drawn from the atmosphere though the process of photosynthesis*'. The researchers believe that their findings will have an impact on modelling and satellite studies of the Madagascar bloom. Future research will need to account for the carbon export associated with diatoms and their nitrogen-fixing guests in the southwest Indian Ocean.

i) Issues

- Dead zones are associated with nutrient enrichment due to increased nutrient supply from the river basins. Also, there is the issue of Harmful Algal Blooms (HABs) and Ocean acidification. The latter is poorly studied and its effects on the coastal and marine ecosystems of Madagascar are not well understood.

ii) Gaps

- Lack of data on primary production, harmful algal blooms and oceanic acidification. There is a need for research in these areas.

Secondary production

In Madagascar, research on zooplankton begun in 1925. The results of various studies are available as publications in various journals (Mosse 1925, 1954, 1956a, b, Cressey 1958a, b, 1959a-c, Cressey and Gooding 1958, Frost 1963). Other more recent data have been collected during oceanographic campaigns conducted in Madagascar's territorial waters by the research vessel, Pelagia (Netherlands) and Dr. Fridtjof Nansen (Norway) between 2001 and 2009. Most of the data from these surveys are still being analyzed. In addition, secondary production data have been collected by the Malagasy National Oceanographic Centre and need to by analysed.

i) Issues

- A lot of data on secondary production collected in various oceanographic cruises is yet to be analyzed in order to understand trophic relationships. The capacity of Madagascar to carry out independent oceanographic studies is limited.

ii) Gaps

- There is a need for oceanographic research on primary and secondary productivity in waters surrounding Madagascar.

Coastal zone and continental shelf

Description and extent of marine and coastal habitats

The coastline of Madagascar is approximately 5,603 km. The shallow regions of 0 to 10 m are characterised by the growth of coral reefs and mangroves, which are mainly located in the western part of the island. In some places, the continental shelf is very narrow, particularly in the region of Toliara, where depths reach 200m near the coast (Figure 15) (Battistini 1964).

The coastal continental shelf of Madagascar has an average slope of between 0.6 and 1%. This is followed by a broad but gentle sloping submarine plain with gradient of between 0 and 3.5%. This zone occupies most of the extended continental shelf of the southern part of the island between Toliara and Taolagnaro (Battistini *et al*. 1969). The continental shelf is narrow between Mangoky Delta and Androka and wider in the region between

Cape Ste Marie and Cape St André. In the North, the continental shelf width diminishes again.

Figures 16 and 17 show the distribution of coral reefs and mangroves along the coast of Madagascar. The island is a part of the tropical Indo-Pacific domain where coral reefs constitute the typical coastal marine ecosystem. The coral reefs of Madagascar extend along the coast for a distance of about 1,400 km with an estimated surface area of 2,400 km^2 (Cooke *et al.* 2000).
Deep canyons are known to incise the continental shelf, some formed by former river valleys which were submerged as the sea level rose. A good example is in the case of Onilahy canyon which is found directly adjacent to Onilahy River (Battistini 1975). Another important submarine canyon appears in front of the Fiherenana river mouth.

i) Issues

- The main issues are coral bleaching, acidification, destructive fishing practices, coral mining, sand mining, seagrass clearing/beach cleaning, urban expansion, and nutrient loading.

ii) Gaps

- Insufficient data on coral bleaching, acidification, sand mining and nutrient discharge.

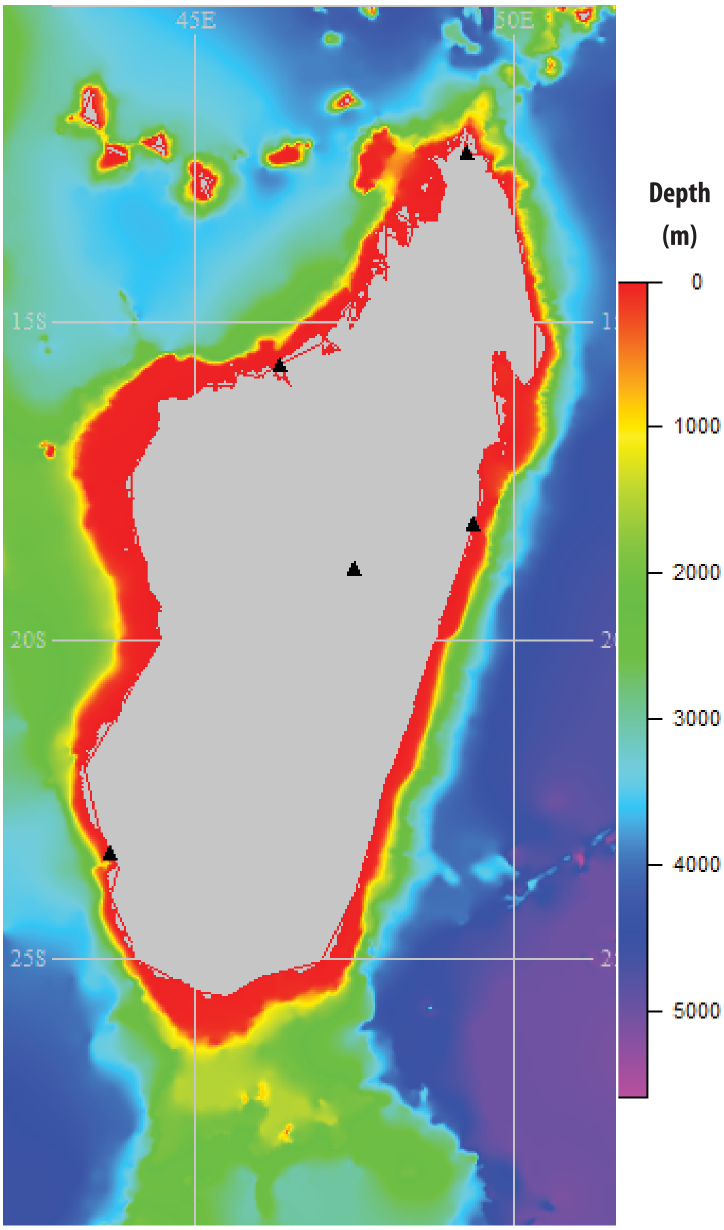


Figure 15: Bathymetric map of Madagascar showing the continental shelf area (Bemiasa 2009)

Productivity of the coastal zone

Many studies on coral reefs and mangroves in Madagascar have been carried out by various researchers (e.g Gabrie *et al.* 2000, Maharavo 2002, Perrier de la bathie 1912, 1953, 1954, Pichon 1963a, b, Mireille 1963, 1964).

a) Coral reefs

The coral reefs of Madagascar are very valuable ecosystems with biological, socio-economic and cultural importance. By the diversity of the biotopes (hard, sandy, muddy substrates), the coral reef ecosystems have a very great faunistic and floristic richness. As an illustration, more than 6000 sp are inventoried in Toliara's coral reef complex, among which there are 700 reef fish species, 700 shellfish species and 1000 mollusc species (Ranaivomanana 2006). Thirty families of corals are observed among which the most abundant are the Acroporidae, Agaricidae, Favidae, Fungiidae, Mussidae, Oculinidae, Pociloporidae and Poritidae.

The reports from several scientific meetings (ICRI 1996, WIOMSA 1997, Pre-IOC Workshop 1998, IFRECOR 1999) show that the coral reefs are currently under severe pressure due to overexploitation. The coral reefs of Madagascar are undergoing several types of anthropogenic and natural degradation. In the most populated areas, the reefs are impacted by overfishing, sedimentation, over-harvesting and pollution. Degradation due to natural disasters, particularly cyclones is also very important in addition to coral bleaching. For reefs already under severe stress, the damage done by bleaching is considered irreversible. In fact majority of most accessible coral reefs in Madagascar are already damaged (Maharavo 2009). However, there are still few well protected places with maximum coral cover which are very important for conservation of biodiversity. These places are located in isolated areas where coral reefs are found at a depth of 20m. The scarcity of resources in accessible areas is forcing fishermen to venture into the protected places which are generally rich in fishery resources. Thus, the future of coral reefs in Madagascar appears to be uncertain unless urgent management measures are put in place.

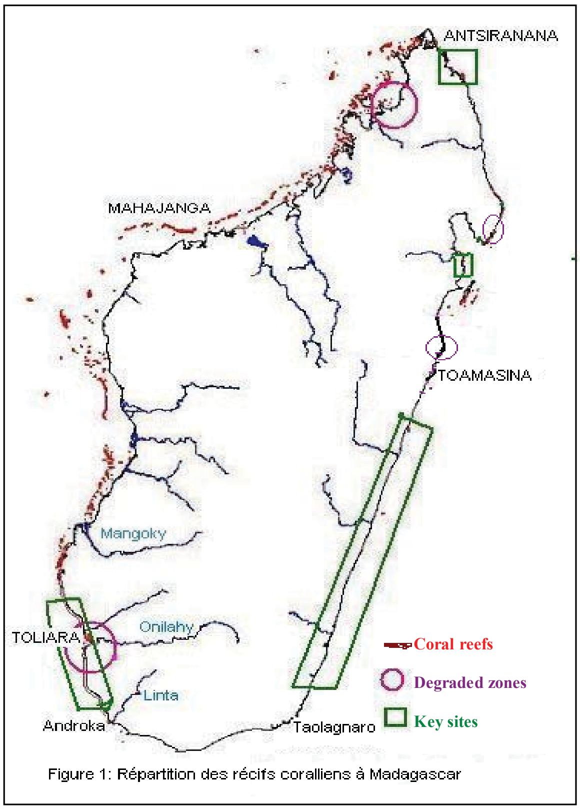


Figure 16: The distribution of coral reefs in Madagascar (Maharavo 2002)

As human populations grow, the pressures on the reefs increase and trends suggest that there will be a significant overexploitation of marine resources in the coming decades, to feed the growing human population. Nowadays, fisheries resources are already overexploited beyond the tolerances of various reef sites. In recent years, reefs have been raided for coastal resources that could be cashed or consumed such algae, corals, shellfish, sea urchins, sea cucumbers, octopus and fish, which resulted in rapid decline in some species. Massive corals in lagoons are exploited for manufacture of lime or as building materials (Maharavo 2009). This may subsequently cause an imbalance in the functioning of the reef ecosystem as a whole.

To the north and south of Toliara, a large number of fishermen (150 000) have destroyed the corals due to trampling during collection of *Eucheuma* algae during low tides. In 1995, 140 000 fishermen invaded the Great Reef near the islands of the South Horn and in the process damaged corals while collecting algae (*Pers. Comm.* Prof. Pierre Vasseur).

Increasing anthropogenic pressure is undermining the recovery of reefs that were damaged by bleaching. This is making reefs even more vulnerable to temperature increases due to global warming. The phenomenon of coral bleaching is no longer only related to ENSO events. Observations show that corals are no longer able to tolerate a slightest increase in temperature at the limits of their range of tolerance. The combined effects of global warming, overexploitation, sedimentation and physical damage due to trampling would most probably lead to gradual disappearance of many coral reef areas in Madagascar (Anon 2009, Maharavo 2009).

b) Mangroves

Mangroves are still under-exploited in Madagascar. Nevertheless, threats result from the exploitation of mangrove wood for fuelwood, charcoal and timber in the regions of Mahajanga and Toliara. Fishing in mangroves is mainly artisanal but this has no damage to the mangroves. Shrimp aquaculture in mangrove areas is being encouraged in Mahajamba, with high possibility of destruction of mangrove forests for the development of fishponds (Roger 2007).

Migration to areas adjacent to mangrove ecosystems has increased dramatically. Villagers in the hinterland have migrated to the coastal zone to ensure their survival. Drought was one of the main factors driving this migration due to the loss reduction in the productivity of farms. These migrants have converted from being farmers to temporary fishers without proper equipment. As the number of fishermen on the reef flats who are involved in overfishing increases, the productivity of the mangroves decreases. This forces the population to change activity again, turning to the exploitation of mangrove wood. Traditionally, mangrove resources were used for timber

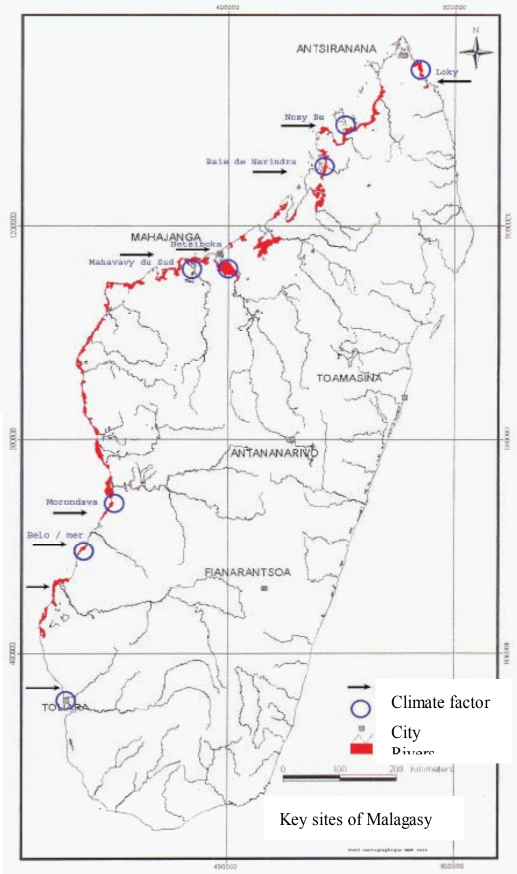


Figure 17: Distribution of mangroves in Madagascar (Maharavo 2002)

for house and boat construction, in traditional medicine, for collection of crabs and fish and for firewood. However, rapid population growth in coastal zones has affected this balance leading to uncontrolled and irrational human activities that are threats to mangrove ecosystems. Also, installation of villages in suburban areas around the mangrove forest zones have led to dumping of garbage and other waste into mangrove forests leading to their degradation. A good example is the case of Mahajanga (Miasa 1992).

Sedimentation is also a major threat to mangroves in Madagascar. As a result of soil erosion due to destruction of vegetation through burning and farming in the highlands, 40 to 50 million tonnes of topsoil is carried downstream and deposited in the mangrove areas each year (Rabesandratana 1984). This sedimentation causes an ecological imbalance in the mangroves due to smothering of mangrove roots with silt and sand leading to the death of mangroves (UNESCO 1985).

Illegal harvesting and overexploitation is also a major threat. Mangroves are in high demand due to rot-proof properties of its timber. Mangrove trees are used for the construction of traditional huts, fencing fields (*baiboho*) and construction zebu pens. Usually farmers harvest lower seedling diameters ranging from 1.5 to 2.5 centimeters thus slowing down mangrove regeneration. The mangrove wood also produces high heat values when burnt which encourages overharvesting limestone and charcoal production. The demand for these products is usually high in cities. The production of salt also threatens mangroves in Madagascar. Indeed a significant quantity of mangroves is exploited for the salt production.

Other pressures on mangroves are cattle grazing near mangrove areas (Miasa 1992). At low tides, zebus eat mangrove seedlings thus affecting natural regeneration. Other pressures are clearing for rice fields (case of Tsiribihina Delta and North Morondava, Tomitsy), fishing using toxic plant products from *Euphorbia laro* (in the case of Belo sur Mer), economic pressure, and uncontrolled tourism development.

The exploitation of mangroves is also driven by economic reasons. For instance, in the common economic area, there is competition between trawlers, artisanal and semi-industrial fishermen (Case of Menabe) with the artisanal traditional fishermen losing the battle and being forced to exploit mangroves in order to survive (Rabesandratana 1984). Also, closure of some factories such as SOTEMA Mahajanga, cement works of Amboanio, Filatex of Tulear and others, forced most of the coastal population to become fishermen. Their source of income depends largely on fishing. However, the reduction in fisheries production due to overfishing inevitably forces villagers to focus on the harvesting of mangroves for their survival.

The protection of mangroves in Madagascar is limited by political and institutional constraints. Territorial disputes as it happened in Morondava, holds back the effective implementation of mangrove conservation and management systems (Roger 2007).

Microfauna and meiofauna

Very few studies have been done on the microfauna of Madagascar. Most of these studies were devoted to Foraminifera, Ostracoda and Pteropoda and have not covered the entire territory. The best studied sites are located in the northern part of the island. The most relevant information was observed in the city of Antsiranana, at a place named Abattoir, and about 40 km from Antsiranana further to Southeast. Ammonites have been the subject of palynological and micropaleontological studies (Herngreen 1982, Herngreen *et al.*

1982, Randrianasolo 1989, Randrianasolo and Anglada 1989).

Babinot *et al*. (1996) established the ostracodes associations of geological strata in Antsiranana Region. Table 4 summarizes the distribution of encountered species. Ostracod associations from the region of Antsiranana, formerly Diego-Suarez, in the north of Madagascar, were studied in systematic level. On average 29 species belonging to 21 genera have been recognized with 10 new species, one new genus (*Malagasyella*) and one new subgenus (*Hemiglenocythere*). The Albian and the Early Cenomanian are characterized by well-differentiated associations. From paleoecology, sequence of ostracode faunas shows a gradual decline in sea level, from basin in Albian to an environment of outer shelf in Turonian. During this period, the ostracod faunas of Madagascar show strong affinities with those of India (Rajasthan); it leads to the proposition of the existence of Indo-Madagascan faunal province (Babinot *et al.* 1996).

Associations of Danian ostracods from Mahajanga region, north-western Madagascar were described. Twenty-five species were recognized including five new ones: *Cytherelloidea furcafera, Keijcyoidea antekeiji, Haughtonileberis postfissilis, Dutoitella dinglei, Paragrenocythere alfuraihi*. One species seems to identify with *Occultocythereis arabica,* known north of Indian Ocean, but none are close to contemporary Guinean species (Guernet *et al*. 2001).

In the Southwest region, Kornicker and Thomassin (1998) studied the composition of the ostracod fauna (Myodocopina) in the Toliara reef complex, based on their systematics and distribution on the reefs. Twenty-four species - 16 of these new species, representing five families of Myodocopides with one species remaining in the nomenclature, were described and illustrated from collected specimens in the Toliara reef complex. Samples were collected by the staff of the Endoume Marine Station and Oceanography Centre (CNRS-VRA No. 41), Marseille, France, between the periods 1969 to 1972. The distribution of Myodocopina in the area and the similarities with other populations living in various parts of the reef (Simpson index), was discussed (Table 4).

Table 4: Simpson's index on the similarities of fauna between localities based on species (diagonal above) and genus (diagonal below). The numbers in the list correspond to localities in left column (Kornicker and Thomassin 1998).

Species	Locations							
	1	2	3	4	5	6	7	8
1. Coral Flagstone	-	69	71	63	46	44	38	40
2. Spur-and-Groove Zone	69	-	71	75	57	56	46	80
3. Reef-flat microattoll	71	71	-	57	43	43	57	40
4. Coral sand reef-flat	71	86	57	-	63	63	75	60
5. Lagoon and sandy bottom reef-flat	55	73	43	71	-	89	62	60
6. Residual Pools Reef Flat	50	63	43	71	88	-	89	60
7. Lagoon bottom	50	70	57	67	80	86	-	80
8. Caye beach of Nosy Ve	50	75	50	75	75	75	100	-

Frontier (1960) analyzed the overall distribution of plankton populations, Heteropoda and Pteropoda based on the study of 54 samples of plankton in the vicinity of Nosy-Be between October and December 1960. The species collected can be divided into three groups:

1. Those species which were regularly present in the harbour such as *Atlanta gaudichaudi*, *Atlanta lesueuri*, *Limacina inflata*, *Limacina trochifonnis*, *Creseis acicula*, *Creseis virgula* and *Cavolinia inflexa.*
2. Those species which are from the open sea: *Atlanta fusca*, *Limacina bulimoides*, *Cuvierina columnella*, *Styliola subula*, *Euclio pyramidata* and *Cavolinia inflexa.*
3. Those species found in the intermediate zone or pelagic species more tolerant than those of previous group and occasionally carried into the coastal zone: *Oxygyrus keraudreni*, *Atlanta helicinoides*, *Atlanta inclinata*, *Atlanta inflata*, *Atlanta peroni*, *Atlanta turriculata*, *Firoloida demaresti*, *Hyalocylix striata*, *Diacria quadridentata*, *Desmopterus papilio* and *Clionina longicaudata* (Frontier 1960).

i) Issues and Gaps

- Data and information on mesofauna are rare and in most cases not available. Very few studies have been undertaken on algal blooms except those made by Coquerel (1854).

Macrofauna

Invertebrates

Biodiversity and genetics

Many invertebrate species are commercially exploited in Madagascar, some of which are important to conservation (Table 5).

Table 5: Marine invertebrate groups and species important to conservation identified in Madagascar.

Name	Scientific name	CITES	Nairobi Convention	National law
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 corals (all species)	*Stolonifera / Tubiporida*	App II	-	-
Black corals (all species)	*Antipatharia*	App II	-	-
Black coral (one species)	*Antipathes dichotoma*	App II	App 2	-
Spiral wire corals (spp.)	*Cirripathes spp.*	-	App 2	-
MOLLUSCS				
Giant clams (tall 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
CRUSTACEAN/SHELLFISH				
Coconut crab	*Birgus latro*	-	Annex 2	-

Sponges

Only some research projects on bioactive substances- a non-regulated activity, exploit sponge species. These species are not of international, regional or national conservation concern.

Cnidaria

Cnidaria are not exploited except in isolated cases where hard and black corals (Antipatharia) are exported for jewellery. Hard corals and Antipatharia species are listed in Appendix 2 of CITES. Antipatharia species and spiral wire corals are listed in Annex 2 of Nairobi Convention Protocol on Flora and Fauna.

Hexacorallians (scleractinaria)

In 2002, a rapid assessment of marine biodiversity conducted by Conservation International, identified 323 species of hard corals in north-western Madagascar (McKenna and Allen 2005), more than doubling the number of species known in Madagascar (Pichon 1971, Sheppard 1998). Although no endemic genus was listed for Madagascar, *Horastrea* (Siderastreidae) was considered confined to East Africa, Madagascar and Mascarene Islands.

Back corals (antipatharia)

Eight antipatharian species at least have been identified for Madagascar on the reefs of Toliara, Nosy Be and Mananara (Pichon 1978, Vasseur 1981, Randriamanantsoa and Brand 2000). Black corals are exploited on a small scale for jewellery sold in the tourist market.

Shellfish/Crustaceans

Thomassin (1978) identified 779 crustacean species were identified on the reefs of Toliara (Thomassin 1978). Several crustacean species are commercially exploitated in Madagascar, including penaeid shrimps, crawfishes

(Panuliridae and Homaridae) and crabs (Ocypodidae and Portunidae). Only one species of crustacean, the coconut crab *Birgus latro* is of conservation concern as stated in Annex 2 of Nairobi Convention Protocol on Fauna and Flora. Its presence in Madagascar, including the West Coast islands is not scientifically confirmed.

Decapoda (shrimps, crawfishes and crab, etc.)

Penaeid shrimps

During 1958 to 1960, nine species of commercial penaeid shrimps were caught along the west coast of Madagascar. These are *Penaeus monodon*, *Penaeus semisulcatus*, *Fenneropenaeus indicus*, *Marsupenaeus japonicus*, *Metapenaeus monoceros*, *Trachysalambrica curvirostris*, *Parapenaeopsis acclivirostris*, *Sicyonia lancifer* and *Sicyonia trispinosa* (Crosnier 1965). The main wild species caught in industrial fishery catches are: *Penaeus indicus,* the Indian white prawn, which represents approximately 70% of annual catches, *Metapenaeus monoceros* the Speckled shrimp, representing about 20% of catches, *Penaeus semisulcatus* the Green tiger prawn, representing about 10% of catches and *Penaeus monodon* the giant tiger prawn, making up about 5% of catches. *P. monodon* is the favourite species in aquaculture.

Deep-water shrimps

Studies onboard the research ship Vauban in 1974, identified 24 deep-water shrimp species of commercial interest. These are *Penaeus teraoi, Parapandalus narval, Parapenaeus fissurus, Metapenaeus andamanensis, Parapenaeus sextuberculatus, Plisionika longirostris, Panaeopsis serata, Hymenopenaeus lucasi, Plesionika indica, Heterocarpus wodmasoni, Heterocarpus ensifer, hymeopanaesu sibogae, Panaeopsis rectacuta, Plesionika martia, Aristaeomorpha foliacea,* two *Aristeus* spp., *Heterocarpus tricarinatus, Plesiopenaeus edwardsianus, Heterocarpus dorsalis, H. laevigatus, Plesionika alcocki* and *Acanthephyra armata* (Piton and Poulain 1974). The only areas that may currently be commercially exploited by trawling are in Northwestern Toliara, in front of Mahajanga, Morombe and South Maintirano. The northwest area of Toliara, an area of 900 km^2, could produce 500 tonnes of deep-water shrimps per year for export, while the potential annual productivity of deep-water shrimps was estimated at 1,000 tonnes at national level.

Neritic crayfishes

The Malagasy littoral crayfish is an important fishery resource, mainly represented by the genus *Palinurus*. It is characterized by the diversity of its species with *P. Homarus* occurring on the South, Southeast, Northeast and Northwest Coasts, *P. japonicus* or *P. longipes* off the West, Southeast and Northeast Coasts, *P. penicillatus* off the South and East Coast, *P. versicolor* off the West Coast, *P. ornatus* off the West and East Coast and *P. dasypus* off the North Coast. These species occupy rocky and coral reefs all around the island. However, each species has its particular area of distribution.

The slipper lobsters (Scyllaridae) are a frequent catch around Nosy Be, especially *Scyllarides squamosus*. They were caught in industrial trawl fishery around Mahajanga in early 2000s. Another species of slipper lobster, *Ibacus indicus* was identified in southern Madagascar in 2008 up to 250m depth (Mara 2009). The mud lobsters (Thalassinidea: Callianasssidae) like *Callichurus* are common on sandy bottoms, as far south as Nosy Tanikely at Nosy Be (Laboute and Maharavo 1998)

Deep-water crayfishes and dublin bay prawn

The area with significant concentrations of *Palinurus delagoae* (Gilchrist) is located in southern Madagascar. The potential productivity of green prawns was estimated at 1000 tonnes/year (Ralison 1991, Andrianaivojaona *et al*. 1992). On Walter Banks, a new species of giant lobster weighting 18 kg was discovered. Named *Palinurus barbarae*, this lobster was 50 cm and could possibly live to 50 years old (Griffith and Groenveld 2006).

True crabs (Brachyura & Anomura)

Three hundred and forty four (344) species of true crabs are found in Madagascar, including 153 species belonging to the family of Portunidae - the highest number of all countries in Western Indian Ocean (Crosnier 1962). Crosnier (1965) listed 41 species of Grapsidae and 19 species of Ocypodidae. The ghost crab (*Ocypode madagascariensis*) is one of the very rare endemic marine species in Madagascar. Studies on Xanthidae, Trapezeiidae, Carpeleiidae and Menippidae family indicate more than 200 species (Jenkins 1987).

Neritic crabs
Among neritic crabs, only the mangrove swamp crab *Scylla serrata* is exploited. This resource is targeted by traditional and industrial fisheries. Bautil *et al*. (1991) studied crab fishery in Mahajanga and estimated the annual potential productivity from 1.66 to 1.8 tonnes/km^2, or approximately 7,500 tonnes/year for the whole of Madagascar. Official data indicate an annual production of approximately 1500 tonnes, especially in the region of Mahajanga.

Molluscs
Cephalopoda
Three species of octopus were caught around Toliara among which were the day octopus *Octopus cyanea*, the marbled octopus *Octopus aegina* and the less common long-armed octopus *Octopus macropus* (FAO 1998). The pelagic deep water or common squid (*Loligo*) is also a food resource in Toliara and Nosy Be. The species *Sepiatheulis lessoniana* is the most important. The cuttlefish *Sepia* sp. is a less common fishery product and *Sepia zanzibarica* is common on sandy bottoms around Nosy Be (Laboute and Maharavo 1998). *Octopus cyanea* is important for fisheries in the Southwest.

Gastropoda
In Madagascar, most of the big gastropods are edible. Shells of large gastropods such the great green turban (*Turbo marmoratus*) are used for the manufacture of pearl buttons, while others such as porcelain shells, helmeted snails and cone shells are highly desired as curios. Near cities such as Toliara, large ornamental species of gastropods have become rare. Such a species of gastropod found in Madagascar, the queen conch *Strombus gigas*, is on Appendix II of CITES. Two other species, the triton *Charonia tritonis* and *Trochus niloticus*, are listed in Annex 2 of the Nairobi Convention.

Ornamental gastropods
In 1997, it was reported that 138 species of gastropods were for sale in shellfish markets at Toliara. Among the rarer and more valuable species are the spider conch *Lambis truncata*, the Mauritius island cowry *Cypraea mauritiana*, the helmets *Cassis cornuta, Cypraecassis rufa*, the giant triton *Charonia tritonis*, the shell tun *Tonna canaliculata* and various cone shells *Conus* spp. (Romaine 1997). There is no legislation controlling the exploitation of gastropods in Madagascar.

Bivalves
The best known are food species such as clams (*Anadara antiquata*), oysters and mussels. Several species of food bivalves are overharvested. All species of giant clams are listed in Appendix II of CITES, including three species listed in Annex 2 of the Nairobi Convention. The pearl oysters (*Pinctada* spp.) are listed in Annex 2 of the Nairobi Convention.

Echinoderms
Some species, including sea cucumbers (Holothuroidea) and to a lesser extent, edible sea urchins (Echinoidea), have a considerable economic value. Sea cucumbers are an important export product for Madagascar. Echinoderms are not considered important for conservation although some sea cucumbers are endangered by overharvesting.

Starfishes (Asteroidea)
Asteroids have not been commercially exploited in Madagascar except for very small scale exploitation as ornamental species. They are not among the species of conservation concern.

Sea urchins (Echinoidea)
The only exploited species is the edible priest-hat urchin, *Tripneustes gratilla,* which is abundant in seagrass beds. The sea urchins are not listed among species of conservation concern in Madagascar. Fisheries of edible species are not regulated.

Sea cucumbers (Holothuroidea)
Cherbonnier (1988) described 122 species of sea cucumbers for Madagascar, including 47 new species from specimens collected in Toliara, Nosy Be and various other sites. About 40 species are reported in waters around

Nosy Be and at least 28 species of sea cucumbers live in shallow water in the region of Toliara, 25 of which are fished for sale (IHSM 1997). In the sea towards Islands Radama, 19 species are exploited (Metcalf *et al*. 2001). To date 11 species are known for Masoala (Andrianarivelo *et al.* 1998) and 11 for Mananara (Randriamanantsoa and Brand 2000). The sea cucumbers are not among the species of conservation concern although some species are locally overexploited (Mara *et al.* 1997).

Exploited key species/groups

Key invertebrates targeted by fisheries are:

1. Decapod crustaceans, including penaeid shrimp, crayfish, slipper lobsters (Scyllaridae) and the mangrove crab, *Scylla serrata* (traditional fisheries), with a potential for the harvest of deep-water shellfish;
2. Molluscs, especially cephalopods (octopus, squid) and both edible and ornamental large gastropods and bivalves (shells);
3. Echinoderms, including sea cucumbers (trepangs) that are the subject of intensive traditional fishery along the West Coast and edible sea urchins (*Tripneustes gratilla*) that are traditionally fished in the Southwest.

According to official statistics, the national annual production of invertebrates is about 20,000 tonnes. Precise data only come from the industrial fishery. The traditional and artisanal catches are unknown (DGPRH Statistics Unit, Table 6).

Table 6: Fishery production (tonnes) of invertebrates in the period 2002-2006 (DGPRH 2008)

Fishery Type / resource	2002	2003	2004	2005	2006	2007
Industry fishery	9 478	8 545	7 185	5 312	5 442	4 679
- Shrimps	9 328	8 545	7 155	5 312	5 442	4 679
- Deep-water shrimps	150		30			
Artisanal fishery	490	726	590	572	490	401
- Shrimps	490	726	590	572	490	401
Traditional fishery	10 580	11 700	11 750	11 795	12 050	11 170
- Shrimps	3 450	3 450	3 450	3 450	3 450	3 450
- Crabs	1 400	1 450	1 500	1 525	1 600	1 370
- Crayfish	400	450	450	500	550	380
- Trepangs	830	850	850	820	850	470
- Others (eels, Cephalopoda, shellfish…)	4 500	5 500	5 500	5 500	5 600	5 500
Total (invertebrates)	20 548	20 971	19 525	17 679	17 982	16 250

The hard corals in particular are threatened by climate change, especially in the region of Toliara, where environmental conditions for reef development are marginal (McClanahan *et al.,* 2009) and reef degradation by fishing, sedimentation and global warming are more advanced. Invertebrates are threatened by trawling, particularly shrimp trawlers and, more recently, by deep-water trawling on the continental slope.

i) Issues

Excessive harvesting of invertebrates

Crustaceans

Shrimps

Artisanal and traditional fisheries joined the industrial fishery after some years of delay. With fairly stable industrial catches in the early 1990s, the first decline in industrial catch was observed in 1999 and a significant drop was noticed from 2002 (Figure 18). In order facilitate better stock recruitment, the members of GAPCM proposed the seasonal closure of the shrimp fishery.

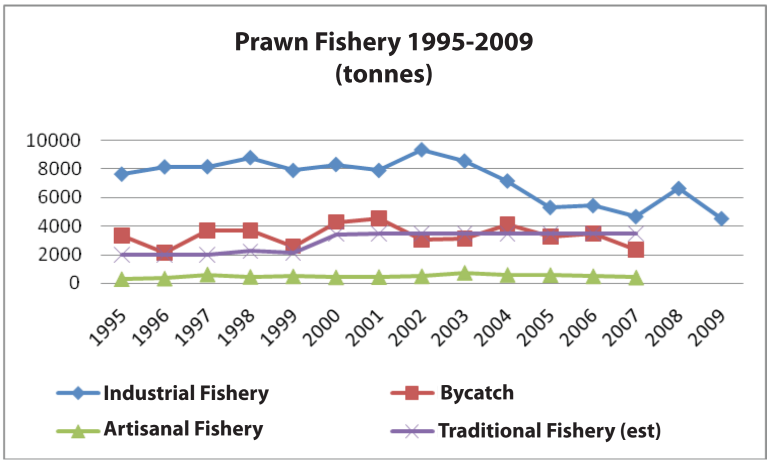


Figure 18: Annual production of shrimps 1995-2009 (MPRH)

Crayfish fishery

The crayfish fishery practices are still traditional and include trap fishing, diving and fishing with torches (Mara 1993). Recently, fishermen have started to use nets to trap crayfishes. *Panulirus homarus* and *P. japonicus*, the dominant species in the South and Southeast are caught while diving or in some instances there are caught using traps or nets. A bio-statistical monitoring of the fishery is necessary in order to assess stocks and allow for simulation of changes in fishing effort and determine the effectiveness of management systems.

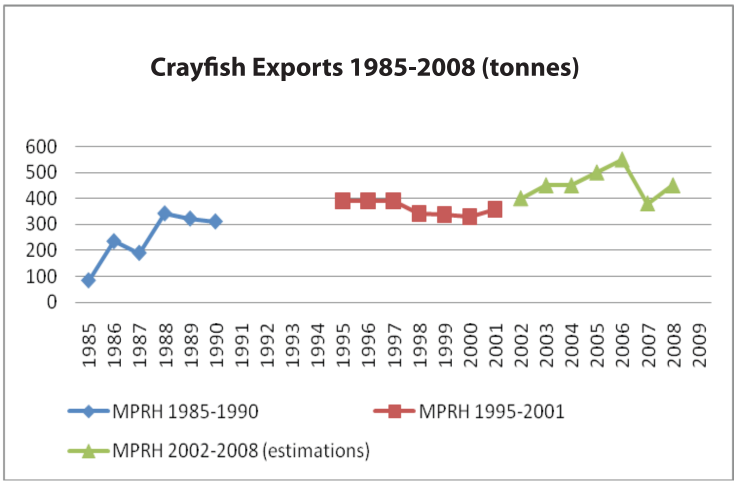


Figure 19. Annual export of crayfishes 1985-2008 (MPRH)

An assessment of crayfish fishery in Taolagnaro in 2000, based on statistics for the period 1988-1996 (Rabarison 2000) reported that yields remained constant around 250-300 tonnes per year although the average size of animals has decreased. The study concluded that the exploitation of *P. homarus* approaches the maximum sustainable yield (MSY). The main problem was identified as a tendency for fishermen to catch too many juveniles and pregnant females, which threaten the stock recruitment (Rabarison 2000).

Crab fishery

The crab fishery is mainly limited to the collection of the mangrove crab *Scylla serrata*. It is mainly practiced between Mahajamba Bay and Cape St Andrew. Bautil *et al.* (1991) studied the fisheries near Mahajanga and estimated the potential sustainable yield at between 1.66 and 1.8 tonnes/km^2 /year or 5.500 tonnes/ year for whole of Madagascar. The production of crabs steadily increased from 500 tonnes in 1985 to 1,500 tonnes in 2007. Mangrove areas near coastal cities are subject to overharvesting, while more remote areas still support fishable stocks. To avoid overfishing for crabs, regulations were introduced in 2006 by Decree N° 16365/2006.

Molluscs

Octopus fishery in Toliara

With only 50 tonnes of production in 1994, the production in Toliara region reached more than 700 tonnes in 2002. Today, the fishing area for octopus stretches 400 km, between Fanambosy and Morombe reefs, and involves some 60 fishing villages. In 2005, the first decrease of catches was noticed. Consequently, the Ministry of Fishery announced a closed season between December 15 and January 31 and imposed a minimum size of 350g. Meanwhile, an initiative of COPEFFRITO and Blue Ventures Conservation Andavadoaka showed the advantage of longer closure period which can lead to the commercially preferred octopus size of 500g (Humber 2006).

Gastropoda fishery

The main Gastropods targeted are the edible and ornamental species. Mangroves are exploited for mangrove gastropoda *Terebralia* (= *Pyrazus*) *palustris*, whose shells are used in making lime. In Toliara, at least 138 species of gastropod are exploited for ornamental shell trade (Romaine 1997). Many are considered threatened, including helmets (*Cassis cornuta* and *Cypraecassis rufa*) and porcelain (Cypraeidae). Turbo (*Turbo maromorata*) and pearl oysters (*Pinctada margaritifera*) are exported for the manufacture of buttons and other pearly objects. Between 1989 and 1991, one Indian exporter from Toliara annually exported 8,000 kg of ornamental shells and 50 tonnes of industrial shellfish (WWF 1993).

Echinodermes

Sea cucumber fishery

Sea cucumber harvesting is very common in Madagascar (Laroche and Ramananarivo 1995, Rasolofonirina and Conand 1998, McVean *et al.* 2005) and natural populations are overexploited (Conand *et al.* 1997). This is due to a significant increase in the market for sea cucumbers in China and the Eastern Asia region.

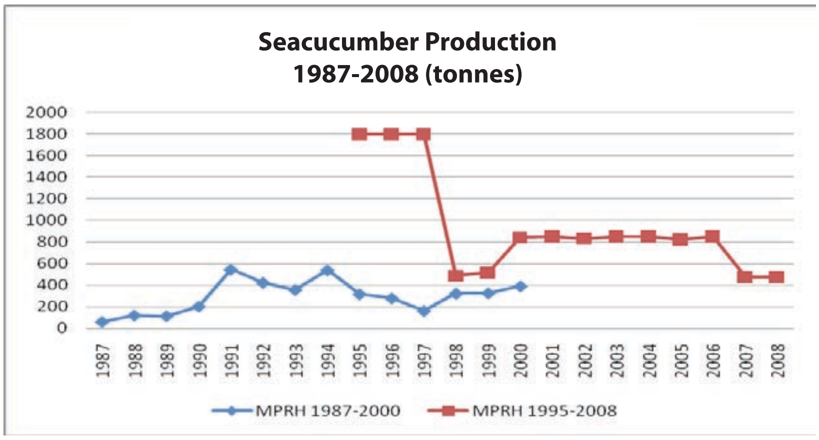


Figure 20: Dried sea cucumber production (tonnes) 1987–2008 (MPRH 2009)

In the Northwest, the sea cucumber harvesting is almost industrialised with 'mother' ships and many teams of divers diving off small boats to collect sea cucumbers at considerable depths (Metcalf and Gray 2001). In other regions, the collection is traditional but still intensive. To address the problem of sea cucumber overfishing, a project of the IHSM in the1990s aimed at developing techniques for sea cucumber aquaculture. After twenty years of technical assistance by Belgian University Cooperation for Development, Copefrito and IHSM established in 2008 a company called Madagascar Holothurie SA -, the first commercial entity centred on sea cucumber aquaculture in Madagascar (Eeckhaut *et al.* 2009).

Sea urchin fishery

The sea urchin fishery only targets edible species, *Tripneustes gratilla*, mainly in the region of Toliara.

Exotic/invasive species impacts on invertebrates

Invasive seaweeds

Turbinaria is invasive in the coral reefs of South West Madagascar in Toliara region. This has contributed to the degradation of reef in addition to other factors such as overfishing and bleaching events (McClanahan *et al.* 2009). While the effects of *Turbinaria* invasion have not been studied yet, the reduction of light might have negative effects on coral growth.

Invasive Cnidaria

Sometimes jellyfish blooms occur, particularly in the region of Toliara during the warm season (Vasseur *pers. comm.*). Blooms have also been observed near Anjajavy in Northwest coast in May 2009. (*Pers. obs*, A Cooke)

Invasive Echinodermata

In southwest reefs, spiny sea urchin blooms occur (*Diadema* spp.) probably due to overfishing which results in the removal of sea urchins predators and herbivorous fish that are competitors for the algae. In the region of Nosy Be, in the late 1990s, industrial shrimp fishermen reported proliferation of sea urchin *Salmaciella erythracis*, whose thorns contaminated their catch.

Pollution

In terms of impact, pollution by sedimentation is probably the most important since Madagascar is still industrially undeveloped and chemical pollution is limited. In the Toliara region, the reefs receive large quantities of sediment carried by the Onilahy and Fiherenana rivers. The sediment has led to the reduction of water transparency and deposition of terrestrial sediment on the lagoon floor (Randriamanantsoa 1997). The reduction of water transparency has reduced the level of "irradiance" and, consequently, the growth rate of hermatypic corals and calcareous algae which are the main coral reefs developers. High rates of sedimentation in coastal zones around the Onilahy river mouth in 1990s was linked to poor farming techniques leading to soil erosion.

Destructive fishing practices affecting invertebrates

The main destructive techniques affecting invertebrates are trawling in the Northwest region, shrimp trawling practiced on the West, Northwest and Northeast coasts, use of mosquito seine fishing in the West and Northwest coasts, use beach seines often with nets, especially in the region of Toliara, use of poison from plants such as *Euphorbia Laro* as practiced in the Southwest, fishing on foot on reef flats targeting octopus and shellfish in the Southwest and finally the use non-selective gear by traditional shrimp fishermen. Five main types of gear are used which include: *Periky*, a set gillnet, *Kaokaobe* a haul seine off a boat, *Valakira* a dam or fish lock, *Pôtô* a stownet or foreshore rigged trawl and cast nets. It is thought that the low selectivity of traditional gears could have a negative impact on stock recruitment.

Impacts of aquaculture on invertebrates

In recent years, the aquaculture activities have developed considerably in some mangrove forests of Madagascar. Except for shrimp aquaculture which is well established with an annual production of 8,000 tonnes, some experimentation has been done on other species such as milkfish *Chanos chanos*, oysters, *Artemia* and penaeid shrimps. These have been tested and proved to be successful in salt basins in Toliara.

Effects of draining aquaculture ponds

The main impact of fish farms on environment is the periodic draining of wastewater ponds. This water is rich in phosphates, nitrates and organic matters and may also contain pathogens, antibiotics and pesticides. During the last five years, diseases emerged in wild populations of shrimp but the link to aquaculture has not been established (Z. Kasprzyk *pers. comm*).

Effects of aquaculture on invertebrate habitats

The construction of fish farms in the west coast of Madagascar has benefited from the presence of bare soils in mangrove swamps. Most of the construction of aquaculture ponds is made in these zones, without significant loss of mangroves. The amplification of tides due to development works can destabilize channel banks, and thereby affect the ecological niches and shelters.

Effects of fishing on foot on reef flats

Fishing on foot is practiced on most exposed coral reefs at low tide. Breaking the coral blocks to expose octopus and other targeted species is particularly destructive. On the Great Reef of Toliara, the density of collectors can exceed 36 persons per km^2 and it was estimated that they can destroy 22-36% of the reef flats annually (Randriamanantsoa 1997). In Masoala, the reef is already damaged due to the collection of live corals in order to hide fish traps (McClanahan and Obura 1998).

ii) Gaps

Table 7: Major concerns and gaps

IDENTIFIED CONCERN	INFORMATION REQUIREMENTS
Unclear reduction of shrimp catch since 2002	Evaluation of the causes of decline in stocks – ecological and economical and their relative importance
Potential negative effects of non-selective traditional fishery	The assessment of the effects of traditional fishery
Negative effects of trawling on shrimp stocks	The assessment of the effects of traditional fishery
Decline of crayfish fishery in Taolagnaro	Evaluation of factors responsible for the decline (ecological and economical) and their relative importance Taking management measures together with appropriate monitoring of the effectiveness of measure taken
Mangrove crab overexploitation	Crab stocks re-assessment in suburban and remote zones, including the assessment of new regulation effects Assessment of the effects of current regulation on fishing
Overharvesting of octopus	Develop useful information for optimal fishing
State of gastropod resources and effects of collection	Exhaustive evaluation of shell fishery, stock status and proposed regulations
Decline of sea cucumber resources and over-exploitation	Reassessment of production and export figures and stock status
Negative effects of sedimentation	Assessment of the impacts of sedimentation on coral reefs
Harmful effects of bottom fish trawling on invertebrates	Assessment of ecological effects (to integrate with the overall assessment of fishery)
Harmful effects of shrimp trawling on invertebrates	Assessment of ecological effects (to integrate with the overall assessment of shrimp trawling)
Harmful effects of non selective traditional gears on shrimp stock-recruitment	Assessment of the effect on shrimp fishery (to integrate with overall assessment of shrimp fisheries).
Negative effects of mangrove degradation on invertebrates	Assessment of mangrove state and vulnerability

Fish and fish resources

a) Biodiversity and genetics

Chondrichthyans

Sharks and rays

Among the 123 species of sharks and rays present in Madagascar, 31 are classified by IUCN as "threatened", 3 "critically endangered" (the sawfish), 1 "endangered" (the skate *Rostroraja alba*), 17 "vulnerable" (the whale shark and endemic skate to Madagascar, *Dipturus crosnieri*) and 10 "near threatened".

Sawfish of Madagascar

Three species of sawfish have been identified in Madagascar; the largetooth sawfish *Pristis microdon*, the green sawfish *P. zijsron* and the knifetooth sawfish *Anoxypristis cuspidata* (Petit 1930). Sawfishes are classified as "critically endangered" in IUCN Red List and on Appendix I of CITES.

Today, sawfishes are very rare, probably due to shrimp trawling, use of gill nets across rivers and installation of fish barriers in estuaries. They can be affected by sedimentation of their habitat caused by upstream deforestation and soil erosion. Recent field studies and reports suggest that the sawfish still exists in the West and Northwest around Nosy Be and in Mahavavy Delta, Tsiribihina and Mangoky rivers (Cooke 1997).

Coelacanths

In Madagascar, the coelacanth *Latimeria chalumnae* is mainly reported in the Southwest, near Toliara (Anakao, Tsiandamba, Fiherenamasay) where four coelacanths have been caught since 1995. The fish is locally known as *fiandolo* or "fish ghost". In 2006 a coelacanth was caught from Barren Islands, Maintirano in the west of Madagascar and in 2009 sixth coelacanths were caught near Morondava. Due to their low population size, slow reproduction and vulnerability in relation to fisheries and catch of specimens, the coelacanth is classified as "critically endangered" by IUCN and in Appendix 1 of CITES. In Madagascar, there is no legal protection for coelocanths, but the export of specimens is controlled by ancient decrees dating from the colonial period.

Teleost fish

Currently, 14 species of marine teleost fish present in Madagascar are listed in IUCN Red List (Table 8).

Table 8: Finned marine fishes found in Madagascar listed in IUCN Red List of threatened species.

Species	Names	Presence in Madagascar	Habitat	IUCN	CITES
Epinephelus lanceolatus	Giant grouper	Rare, present in all reef zones of Madagascar	Reefs, 0 to 100 m	VU	-
Epinephelus marginatus	Dusky grouper	Uncertain (UICN); present acoording to FishBase; non identified by local research	Reefs, 0 to 300 m	EN	-
Epinephelus fuscoguttatus	Brown-marbled grouper	Present in NW and SW reefs of Madagascar	Reefs, 0 to 60 m	NT	-
Cephalopholis boenak	Indian grouper	Present overall coral reef zones of Madagascar	Reefs, 0 to 50 m	LC	-
Dermatolepis striolata	Smooth grouper	Unknown presence according to IUCN but locally identified in NO and SW	Reefs, 0 to 15 m	DD	-
Cheilinus undulatus	Humphead wrasse	Wide distribution in coral reefs, but less common	Reefs, 0 to 60 m	EN	Ann II
Bolbometopon muricatum	Double-headed parrotfish	Rare, identified in NNE, NW coral reef and coral zones in SW	Reefs, 0 à 50 m	VU	-
Argyrosomus hololepidotus	Madagascar meagre	Endemic in S/SE Madagascar (estuariane & marine) ; identified in large numbers in the South in 1983	Coastal waters	EN	-
Thunnus maccoyii	Southern bluefin tuna	All around Madagascar, particularly in southern zones of EEZ	Pelagic 0-50 m	CR	-
Thunnus obesus	Bigeye tuna	Wide distribution, but mainly present in south and east waters	Pelagic 0-250m	VU	-
Eurypegasus draconis	Short dragonfish	Reported by IUCN overall coasts but not reported by local research	Reefs, 0 to 90 m	DD	Ann II
Hippocampus borboniensis	Reunion seahorse	Not reported in Madagascar but possibly present because it is present near Reunion Island	Demersal, 0-60m	DD	Ann II
Hippocampus fuscus	Sea pony	Not reported in Madagascar but possibly present given its wide distribution	Demersal, 0-10m	DD	Ann II
Hippocampus kuda	Spotted seahorse	Presence reported by local research in NW and SW	Reefs and lagoons	VU	Ann II
Syngnathoides biaculeatus	Alligator pipefish	Presence reported by local research in SW	Reefs and lagoons	DD	Ann II

Scombridae

The skipjack tuna *Katsuwonus pelamis* is mainly caught around the north and west of Madagascar, where it represents 75% of the catch by industrial seine fishery. It also prevails in fish catches around the island of Juan de Nova. The bigeye tuna *Thunnus obesus* has a bimodal distribution, with the main concentrations in a southern belt around 30°S and another concentration in a band located between 10°S and the equator (Doumenge 1998). However, Bigeye tuna is almost absent in the Mozambique Channel (Rene *et al.* 1998).

The yellowfin tuna *T. albacares* has a unimodal distribution extending from the equator to Toliara in the west and Toamasina in the east of Madagascar. It is allopatric with the similar species, the albacore, which seems to prefer the southern oligotrophic waters (Doumenge 1998). The yellowfin tuna reproduces in the Mozambique from April to June Channel (Rajoharison and Conand 1995). The albacore *T. alalunga* has a wide southern distribution and therefore appears more often in fisheries in the southern part of the island.

The dogtooth tuna *Gymnosarda unicolor* and the mackerel tuna *Euthynnus affinis* are coastal species. Dogtooth tunas often form shoals on reefs west of Nosy Be and are also common outside Toliara coral reefs in the period between March and April when their sixe averages 1 m (WWF 1993). Large shoals of sub-adults mackerel tuna are found outside of Toliara coral reefs in December-April period (WWF 1993) and are also abundant in Antongil Bay at the same period.

Mackerels, in particular the narrow-barred Spanish mackerel *Scomberomorus commerson* and the wahoo *Acanthocybium solandri*, known locally as *lamatra* or *angoho*, constitute important elements of coastal fisheries. Important concentrations of rake gillat mackerel *Rastrelliger kanagurta* are present near Nosy Be in August and September (Laboute and Maharavo 1998). The same species is common in Antongil Bay between February and August.

Only one species of Scombridae is critically endangered in Madagascar. This is *Thunnus maccoyii,* the southern bluefin tuna. This species may be present in the southern part of the EEZ at 200 miles, where it is targeted by Asian longline fishermen.

Deep-water fishes

Continental shelf and slope surveys carried out by NO Vauban in 1974 in the Northwest identified almost 20 species of commercially important deep demersal fish. These are Lethrinidae (*Lethrinus coerulues*, until 150m), Denticidae (*Cheimerius nufar*, up to 120m, *Polysteganus coeruleopunctatus* up to 150m), Sparidae (2 *Argyrops* at 150m, 2 *Pterogymnus* between 100 and 300m, 1 *Pagellus* species up to 1 250m), Priacanthidae (2 species at 150 and 250m), Branchiostegidae (1 species captured between 100 and 300m), Triglidae (4 species between 100 and 450 m), Sciaenidae (1 unidentified species between 450 and 475m), Brotulidae (1 species between 400 and 500) and Gadidae (1 *Merluccius* sp. between 600 and 720m).

The RV Fridtjof Nansen expedition in 1983 performed experimental trawling in three zones (Southwest, Southeast, East) where approximately 50 species were discovered, mainly Sciaenidae (including the mulloway *Argyrosomus hololepidotus* in Zone A), Sparidae, Mullidae, Nemipteridae, Pomacentridae, Serranidae, Lethrinidae and Lutjanidae. Abundance and diversity were higher in the South than in the East (FAO 1998).

Coral reef fishes

Reef fish including large carnivorous families such as Serranidae, Lutjanidae and Lethrinidae, and herbivores, Acanthuridae, Scaridae and Siganidae are exploited by traditional fishery. Some species of reef fish are of an international concern for conservation, including some groupers (Serranidae), the humphead wrasse, *Cheilinus undulatus* (Labridae) and the double-headed parrotfish *Bolbometopon muricatum* (Scaridae).

Deep-water teleost fish (> 500 m)

Deep-water fishes have not been studied except for the splendid alfonsino *Beryx splendens* which has been studied by a South African Society in South Taolagnaro, where it was found on a seamount in the Ridge of Madagascar. The *Hoplosthethus atlanticus,* the Orange Roughy and *Epigonus telescopus,* the blue-eye or deepsea cardinal fish were identified in catches.

b) Exploited key species fish

Fishing zones

Fishing in Madagascar is largely concentrated along the West Coast due to a combination of factors including higher primary productivity, low winds and swells, high diversity and large area of shallow marine and intertidal habitats and the presence of extensive trawling grounds. The main exploited key groups and species in Madagascar are:

Chondrichthyes, in particular sharks for fins (by industrial, artisanal and traditional fisheries),
Scombridae and big oceanic and pelagic fishes (by industrial offshore fishery),
Small pelagic fishes, including small Scombridae, Clupeidae and Engraulidae (by industrial shrimp fishery, artisanal and traditional fishery),
Continental shelf fishes (by industrial fishery fishes and artisanal fisheries),
Reef fishes (by traditional and artisanal fisheries),
Deep-water fishes (by a new industrial fishery of splendid alfonsino).

Other affected fish species consist of all species from deep and shallow waters that are impacted by habitat degradation, especially non-target species in reefs and in trawling areas.

i) Issues

Stock overexploitation

Chondrichtyans

Approximately 50 species of sharks and rays of neritic and oceanic deep waters (including 2 or 3 species of sawfish) of Madagascar are affected by industrial tuna fishery, industrial fish fishery, industrial shrimp fishery, artisanal and traditional fisheries. Due to their slow reproductive rates, chondrichthyes are very vulnerable to overexploitation. Sawfishes in particular, seem to be close to extinction. Official statistics on local production and export of meat and fins show an annual mortality of sharks by various forms of fishing ranging from 200,000 to 600,000 individuals (Cooke *et al*. 2003).

Tunas and big pelagic fishes

Tuna are fished by the industrial seine fishery (under two agreements with Anabac and EU) and longline fishery (under three agreements - the EU, Korea -Dae Young, and Japan- Japan Tuna). Official fisheries statistics indicate catches of between 10,000 and 11,000 tonnes per year (Source: Unité de Statistique Thonnière d'Antsiranana (USTA).

Sea fishes

Non-reef fishes are targeted by the industrial fishery, the industrial shrimp fishery as well as the artisanal and traditional fisheries. In 2004, experimental fishing under the SEPRH-OFCF (Overseas Fisheries Cooperation Foundation of Japan) agreement assessed the relative abundance of sea fishes along the northwest continental slope of Madagascar. The main species were found to belong to Lutjanidae family (Two-spot red snapper, *Lutjanus bohar*, emperor red snapper *Lutjanus sebae*), Sparidae, Serranidae, Lethrinidae, Carangidae and Thonidae (Source: SEPRH – extracts from the OFCF project report).

The main interest of demersal resources is the very high value of large noble fishes belonging to Lutjanidae and Serranidae families, especially those located along the continental slope at relatively accessible depths (e.g. 50 m and more). However, overharvesting could have negative impacts on stock-recruitment. In addition, the techniques of bottom trawling, targeting demersal fish can cause physical damage to bottom habitats and significant by-catch.

Small pelagic fishes

Small pelagic and demersal fishes are targeted by shrimp trawling in all shrimp fishing zones, by artisanal fishery, mainly concentrated in Northwest and by traditional fishery mainly concentrated along west coast, in Antongil Bay and in the Southeast. The most common species belong to Sciaenidae, Leiognathidae, Trichiuridae and Mullidae families (PNRC 2006). The reduction of incidental catches and discards remain major environmental and socio-economic concern. The most affected species by traditional and artisanal fisheries are small Scombridae, often called "small tunas", such as the eastern little tuna *Euthynnus affinis,* the wahoo *Acanthocybium solandri*, the narrow-barred Spanish mackerel *Scomberomorus commerson*, the Indian mackerel *Rastrelliger kanurgata* and *Auxis* spp., Sphyraeindae, Carangidae, sardines (Clupeidae), anchovies (Engraulidae), Hemirhamphidae, Belonidae and others (Anon 1982).

Reef fishes

Fishing for reef fish is mainly done by traditional fishermen operating from dugout canoes. This is a multispecific fishery mainly targeting carnivorous fish (Serranidae, Lutjanidae, Lethrinidae, Carangidae), herbivorous fish (Siganidae, Scaridae, Acanthuridae), scavengers (Mullidae and others) and to lesser degree planktivores such as Caesionidae. In Toliara, the percentage of Serranidae in catch has been reduced to 2.5% (Gabrié *et al.* 2000). Annual yields of fish from traditional fishery are estimated at around 50,000 tonnes (DPRH, annual reports). The major concern is the decline of resources due to overfishing and irrational exploitation. Widespread effects on fisheries due to coral reefs degradation, including climate change, are also a major concern.

Deep-water fishes

In 2007 a pilot fishery for alfonsino *Beryx splendens* was launched by a South African company using deep trawling techniques. This fishery was able to catch 7 tonnes with a single vessel within a period of several months. The fishing site consists of seamounts in the south of Madagascar located at approximately 26˚S 46˚E (Centre de Surveillance des Pêches 2007).

Effect of invasive species on fish

There is the problem of toxicity due to the proliferation of micro-organisms such as microalgae, bacteria, cyanobacteria or diatoms, mainly during the warm season (Rabarison 1994).

Pollution affecting fish

Terrigenous sediment pollution, including pollution from domestic waste and ship discharges at sea could have effects on fish and their habitats. However, marine pollution levels are still limited in Madagascar due to low level of industrial development (Rakotoarinjanahary *et al*. 1994).

Destructive fishing practices

Destructive industrial practices:

Longline industry

While longline gears do not physically destroy the environment, their impacts on ecosystems and vulnerable species such as turtles, seabirds, sharks and whales are a matter of concern.

Deep industrial trawling

Bottom trawls are able to deflect rocks weighing several tonnes and destroy large areas of underwater habitat, particularly on seamounts or continental slopes and shelves. These gears are being used in Madagascar in a pilot fishery for alfonsino (CSP 2007).

Shrimp trawling in shallow water

Shrimp trawls in mud flats leads to the destruction of bottom micro-habitat, affecting ecological niches and therefore the diversity of fish communities and other species. The long use of trawls in Madagascar (since 1967) has modified the majority of natural habitats and replaced them with muddy habitats with poor biodiversity. The creation of closed areas is important in that it would allow assessment of the impacts of trawling. Habitat destruction by trawling is thought to be responsible for recent decline of shrimp catches in Madagascar.

Fishing using poison

In the Southwest, fishermen in some villages use the latex of *Euphorbia laro* in catching fish. This method is non selective and it affects other species.

Beach seine

Beach seining is widespread in Madagascar and is largely used in Toliara lagoons including many other sites in Madagascar. Together with mosquito nets, this gear is somewhat selective and destructive to sea bottom habitats.

Effects of tourism on fish resources

The effects of tourism on fisheries are mainly confined to sport fishing targeting large pelagics. Spear fishing, although rarer, often targets vulnerable large fish such as groupers. A local indirect effect of tourism is the high consumption of fish in tourist hotels and resorts. One study showed that tourists eat five times more by weight of fish than a local fisherman and this is increasing pressure on the fisheries through over-exploration (Tanner 2000).

ii) Gaps

Table 9: Main concerns and gaps related fisheries in Madagascar

Identified concern	Information requirements
Vulnerability and decline of chondrychtyans (sharks, skates, sawfishes)	Implementation of the action plan (NPOA) with adequate data collection on fishing effort, catches, production and exports of sharks and their products Information on incidental catches by industrial fisheries, particularly tuna fishery and industry trawling National study on sawfishes and conservation plan
Uncertain state of stocks of tuna, associated fishes, incidental catches and ecosystem impact of fishing	Review of raw data and modification of catch statistics Implementation of adequate monitoring system Regional sharing of catch data Regional stock assessment Evaluation of incidental catches and ecosystem impacts
Vulnerability of demersal fish stocks and their habitats	Environmental impact assessment of industrial fishery Instituting a monitoring system by species / group of species Ensuring the economical monitoring of the sector (fish cost on international markets)
Environmental Impacts of industrial fishery for shrimps	Environmental impact assessment of fishery (incidental catches, waste, physical damage on ecosystem) Improving the incidental catch monitoring by fish category
Coral fish decline and their habitat degradation	Introducing traditional fishery licensing system in shrimp fishery Developing traditional fishery information system Developing an effective management system based on suitable information system Ensuring simple monitoring of reef ecosystems and effects on fish populations
Vulnerability of deep fishes and their habitats	Assessment of potential environmental impacts of deep sea fishing (ecosystem effects and physical impacts of gears) Ensuring rigorous monitoring of deep sea fisheries.

Marine mammals

i) Issues

Overexploitation of marine mammals

Cetaceans (dolphins, whales) are affected by several different fisheries including the industrial tuna fishery, through longlining and seine netting, the industrial fishery, the industrial shrimp fishery and traditional hunting. Sirenia (Dugongs) are mainly affected by traditional hunting and indirectly by loss of seagrass habitat due to damage caused by industrial shrimp trawling. While evidence shows a massive decline of dugong (Rafomanana and Rasolonjatovo 2004), evidence for cetacean decline in Madagascar is limited.

Impacts of industrial tuna fishery on cetaceans

The industrial seine fishery has recorded some incidental catches of small cetaceans. Apart from catch and direct interactions, the industrial fishery can have negative impact by decreasing the availability of prey for cetaceans. However, the importance of this effect has not been assessed. The effects of industrial tuna fisheries are a matter of particular concern, but its importance is difficult to determine without research.

Hunting and incidental catches of cetaceans

The main threats to coastal cetacean populations are intentional fishing and accidental capture by nets. Intentional hunting of dolphins is common in several fishing communities along the western and eastern coasts of Madagascar, including the South West region, particularly Anakao (Andrianarivelo 2001, Andrianarivelo

2004, Razafindrakoto *et al.* 2009). Table 11 summarizes information on the numbers of dolphins caught in three locations in the West Coast between 1975 and 2009, and in the region of Antongil Bay, in the period between 2006 and 2009.

Table 10: Number of individuals of coastal dolphins caught in 4 regions from 1975 to 2009 (Razafindrakoto et al. in prep)

Years	Andavadaoka	Anakao	Iles Barren	Baie d'Antongil
1975-1980	-	3	-	-
1980-1985	-	6	-	-
1985-2000	2	3789	-	-
2000-2005	135	1441	-	-
2006-2009	-	-	14	4

More in-depth studies have been done on direct hunting in the Anakao area. Dolphin species inhabiting shallower coastal areas are most commonly exploited, including the bottlenosed dolphin *Tursiops truncatus*, the Indo-Pacific humpbacked dolphin *Souza chinensis* and the long-nosed dolphin *Stenella longirostris* (Andrianarivelo 2001, Razafindrakoto *et al.* 2009). At Anakao, the annual catch was estimated at 150 spinner dolphins, with smaller catches of large dolphin and Risso's dolphin *Grampus griseus* (Razafindrakoto *et al.* 2009). According to an earlier report, between 1991 and 1993, about 100 to 150 dolphins were caught every year by fishermen at Anakao (COUT 1994).

Accidental catches of marine mammals are made by various fisheries (commercial, artisanal and traditional) in Madagascar but there is scant of information on the magnitude of the problem. Cetaceans are accidentally caught by different gears, mainly *jarifa* (shark nets). Drift nets and longlines take coastal species of dolphins (bottlenosed dolphin, Indo-Pacific humpbacked dolphin, long-nosed dolphin) (Razafindrakoto *et al. in prep*).

Hunting and incidental catches of dugongs

Dugongs are rarely hunted by traditional fishermen around Madagascar. Hunting of this species was very common in early 1980s until 1990 off small island coast of Vohémar (Rafomanana and Rasolonjatovo 2004) and also off Cape St. Andre (16°11'S, 44° 27'E) (WCS, unpublished data). Accidental catch by driftnets also poses a threat to dugongs in traditional fishery sector. Habitat loss due to trawling for shrimp and associated noise pollution are matters of real concern for dugongs.

Impact of gill nets on all marine mammals

Accidental catches of marine mammals in the artisanal sector is mainly by gill nets, although the total impact of these gears remains unknown. It is recommended that it is necessary to quantify the impact of incidental catches by gill nets on marine mammal populations. There is also a need to implement effective mitigation measures (CTOI 2008).

Pollution effects on marine mammals

Noise pollution

In Madagascar, where coastal shipping is still limited, noise pollution is localized around major ports. It is also caused by specific activities that produce underwater noise, particularly industrial shrimp trawling and seismic and sonar studies undertaken during oil exploration. Noise pollution disrupts the orientation, feeding and communication ability of cetaceans, causing interference which may lead to strandings and physical damage to the ear of the animals if they are close to the sourceof the noise.

Effects of aquaculture on marine mammals

Up to now, no interaction has been established between aquaculture and marine mammals. However, the creation of aquacole farms could change the local hydrodynamic regime that could in turn change local conditions for seagrass ecosystem sustainability. However, the effects are small when compared to other impacts.

Effects of habitat destruction on marine mammals

Human activities such as overfishing in addition to climate change effects can have significant impacts on ecosystems that are essential for marine mammals. For coastal cetaceans (including humpbacked dolphin) and dugongs, the destruction of their foraging habitats could have major impacts.

Effects of tourism on whales and dolphins

The humpbacked whale is the main attraction for sightseers in Madagascar in the period between June and October. Dolphins are observed during diving, fishing and marine tours. In 1998, 12 tour operators attracted 4,000 tourists and this number grew to15,928 tourists by 2008 (WCS unpublished). Collisions between ships and cetaceans and harassment - whether intentional or accidental, is increasing in coastal waters. While there are reports of harassment in Ste Marie Island and Antongil Bay, no collisions have been reported in Madagascar in the recent past. A code of whale watching has been adopted in Ste Marie Island (C. Webster *pers. comm.*).

ii) Gaps

Gaps includes lack of knowledge and information that could enable comprehensive understanding of major issues and formulation of strategies on how to address key problems and concerns (Table 11)

Table 11: Main concerns and gaps related marine mammals in Madagascar

IDENTIFIED CONCERN	INFORMATION REQUIREMENTS
Massive decline of dugongs	The dugong population decline is a major concern, but the relative importance of the causes is relatively well known. Studies of current habitat and impacts are needed
Effects of industrial tuna fishery on cetaceans	Assessment of the effects of Tuna industrial fishery
Impacts of sea mammal hunting and incidental catch by traditional fishery	More complete assessment of the impacts of traditional hunting of small cetaceans
Important but not quantified impact of gill nets on marine mammals	Assessment of the impacts of Gillnets on marine mammals
Loss of dugong habitat due to industrial trawling for shrimp	Assessment of the impact of industrial trawling on dugongs
Humphbacked dolphin habitat degradation	Assessment of the impact of coastal habitat degradation on humpback dolphin
Negative impact of oil exploration on cetaceans	Sonar and seismic campaign impact assessment on cetaceans in Madagascar Assessment fulfillment on electra dolphin beaching in the Bay of Loza in 2008
Negative impacts of beaching on cetaceans	Assessment of causes of cetacean beaching in order to determine if mitigation measures are possible

Marine reptiles

Sea turtle overexploitation

Traditional hunting of turtles is carried out using harpoon or spearguns. Catches estimated along a 800 km of coastline in the Southwest are as high as 13,248 turtles per year (*Chelonia mydas* 51%, *Eretmochelys imbricata* 15%, *Caretta caretta* 15% and *Lepidochelys olivacea* 18% (Hughes 1971). The catch of the threatened *E. imbricata* is estimated to be 2,500 individuals (Hughes 1973). Rakotonirina and Cooke (1994) estimated the national annual catch of turtles in traditional fisheries to be 11,276 individuals. In 1998, 2.9, 8.5 and 4.9 tonnes of turtle meat were sold on the markets of Toliara, Morombe and Taolagnaro, respectively (MPRH regional data unpublished). For Maintirano region, the annual catch in 2006 was more than 350 individuals (Leroux 2007). Traditional hunting of turtles has continued despite the promulgation of the Decree 2006-400 that makes it illegal to catch turtles.

The capture of female turtles in spawning condition is relatively easy. Since females are naturally numerically dominant in spawning areas, the equivalence or predominance of males in catch is an indicator of an overfished population (Hughes 1971). There is a predominance of young turtles and males in catches of green turtles in the Toliara region since the early 1990s (Rakotonirina, *pers. comm.*). In conclusion it can be stated that *C. mydas* and *E. imbricata*, and probably also *L. olivacea* and *C. caretta* are overexploited in Madagascar.

Turtle nests are systematically poached in sea turtle zones (Petit 1930, Rakotonirina 1989, Rakotonirina and Cooke 1994, Sagar 2001, Metcalf and Grey 2001). The pillage is practiced even in remote or isolated areas where there is no tradition of turtle exploitation, such as the Masoala peninsula (Rakotonirina 1989). The decline of sea turtles nesting in Madagascar has been observed all over the country (Rakotonirina 1989, Rakotonirina and

Cooke 1994). Recent observations in the Southwest suggest that many ancient turtle nesting beaches identified by Rakotonirina (1989) are no longer in use (A. Harris, *pers. comm.*).

The effects of pollution and diseases on sea turtles

Sea turtles may be affected by various forms of pollution such as marine debris, oil pollution, sedimentation, noise pollution and light pollution. Marine wastes such as plastic bags are a threat to turtles which feed on jellyfish, particularly *D. coriacea* and *C. caretta*. Abandoned fishing gear such as cast nets can trap and drown all species of turtles. The impacts of marine wastes on marine turtles are at regional and global scales and require analysis and action at regional and global levels.

Oil pollution may in the near future become a risk as the oil industry grows. Sedimentation could affect the water quality and sand deposition in nesting beaches located near river mouths. No studies on the impacts of sedimentation on sea turtles have been carried out in Madagascar. Sea turtles are also sensitive to noise, especially between 50 and 1000 Hz. Turtle reaction to noises includes an increase in swimming speed and diving in an attempt to escape from the source of noise. In the case of seismic campaigns, turtles can flee 1 to 2 km from the source. It is recommended that seismic campaigns are avoided near turtle nesting sites (LGL 2007).

Female turtles generally spawn at night and can be disturbed by the presence of lights on the beach, inducing them to leave the premises without laying eggs. Electric lights can also affect new hatches, inducing them to approach the light instead of moving toward the horizon to the sea. The importance of these effects is inadequately understood in Madagascar.

The effects of turtle diseases -turtle fibropapillomonas

The turtle conservation project in the Maintirano region, coordinated by the Museum of Natural History in Geneva and supported by WWF, found a high incidence of Fibropapillomatosis among sea turtles caught for research purposes around Maroantaly Island. This disease caused by a type of herpes virus, causes tumors in soft parts of the turtle. As they grow, tumors restrict movement of neck and limbs and can ultimately cause death by suffocation or immobilization. The disease affects approximately 25% of captured green turtles and can be a significant cause of mortality among sea turtles. Fibropapillomonas affects green turtles globally. Links to environmental factors such as pollution or global warming are suspected but not proven.

The effects of destructive fishing practices on sea turtles

Apart from non-destructive fishing practices, sea turtles are affected by offshore industrial fishery (longline and seine), fishing on the continental shelf, industrial shrimp trawling, fishing nets for shark and traditional fishery with poison. Industrial trawling for shrimp is an important cause of accidental catches of turtles, but has never been scientifically evaluated. In 2000, a trawler captain in Toliara estimated accidental catch at 300 turtles per ship per year. Most of these turtles were alive when landed, but were subsequently killed by shipmates. This data seems exaggerated. With 50 trawlers around Madagascar, incidental catch of sea turtles could be several thousands per year, and could have decimated turtle populations since the beginning of industrial shrimp fishery in 1967. Before 2003, some operators voluntarily installed Turtle Excluder Devices (TEDs). In the early 2000s, the installation of TEDs became mandatory for shrimp trawlers, which reduced the number of accidental catches. One operator expressed some disappointment in the sense that catching turtles, which is rarely fatal, allowed the identification and banding of animals and turtle monitoring is not possible anymore after the installation of TEDs (fishing company agent in the East Coast, *pers. comm.*).

Artisanal and traditional fishermen fishing for sharks use gill nets of more than 100 m in length known as *jarifa*. This destructive and non-selective gear can catch several different species, including sea turtles which often drown in the net that is usually left overnight. Traditional fishing with poison is limited to the southwest of Madagascar where fishermen use the latex of *Euphorbia laro* called *famata* in protected waters of reefs where they occasionally manage to kill turtles (Rakotonirina and Cooke 1994).

Destruction or modification of breeding and spawning sites

Turtles breed in the sea near nesting areas. While the marine environment is not subject to physical destruction, the nesting beaches are affected by urban development, construction works such as ports, dams, mining and oil installations and constructions for tourism and development.

Little is known about the location and historical importance of turtle nesting sites in Madagascar. Besides rough indications of nesting sites in old works (Petit 1930), the first study of nesting sites was made by Rakotonirina (1989), and again by Rakotonirina and Cooke (1994), followed by several more localized studies (Ramamonjisoa 1997, Andriantahina 1999, Soafiavy 199, Metcalf and Gray 2001, Rafaelarisoa 2001, Sagar 2001, Leroux 2007). The studies confirm that the most important turtle nesting sites are on small islands in the west of Madagascar (particularly the north west of Madagascar). Nesting is less frequent on mainland beaches, and is absent in mainland areas near coastal towns.

Sea turtle eggs are often found in the sea. The phenomenon of abandonment of eggs in the sea may be due to nesting site destruction. This happens when a nesting female cannot get into the beach to build their nests because of a new element present at its breeding place, such as light on the beach or morphological change by new construction. General decline in spawning frequency has been observed (Rakotonirina and Cooke 1994), but the role of habitat destruction in this decline is not known. The general decline indicates that the main cause is not the localized destruction of habitat, but rather factors that are large in scale such as overfishing or raiding of nests.

Effects of climate change on sea turtles

Climate change can have several effects on sea turtles. First, the rising sea levels reduce or modify the nesting beaches. Rising temperatures may affect embryo development, causing sex ratio bias toward females. An increase in seawater temperature could have negative impact on foraging areas, particularly on turtles depending on coral reefs. Finally, the increased influx of terrestrial sediments, due to an increase in extreme rainfall events, soil erosion due to poor land use and upstream deforestation, can change the shape and characteristics of the sandy beaches. This may discourage females from nesting or inhibit young turtles from digging their way out of the nest. This last effect was observed in Masoala region (Randriamanantsoa, *pers. comm.*). None of these effects has been studied in details in Madagascar. In conclusion, climate change effects are matters of general concern, but there is still no assessment of their impacts on sea turtles in Madagascar.

Table 12: Main concerns and gaps related marine turtles in Madagascar

IDENTIFIED CONCERN	INFORMATION REQUIREMENTS
Overexploitation of sea turtles by traditional fishery	Carry out an assessment of impact of hunting particularly on catch sex ratio
Poaching of sea turtle nests and general decline of egg laying frequency	Assess the impact of poaching on sea turtle populations, including other factors causing decline in spawning
Impacts of tuna industrial fishery on sea turtles	Assesss the impact of tuna industrial fishery on sea turtle populations
Impacts of shrimp industrial trawling on sea turtles	Survey of the industrial fishery to determine the historical bycatch rates of sea turtles and estimate the levels of previous abundance of turtles and impacts of industrial fishery
Impact of coastal development (including beach lights) on sea turtles	Use satellite images, determining the percentage of nesting beaches affected by beach modification or light "pollution"
Impacts of hunting and bycatch in traditional fishery	Carry out a more complete assessment of the impact of traditional hunting on sea turtles in order to better understand the scale and nature of the problem

Effects of tourism on sea turtles

Tourism may have three main effects on sea turtles:
1) The promotion of turtle hunting due to availability of a ready market for hand made turtle shell products.
2) The modification of nesting beaches particularly through beach lights overlooking the sea.
3) The direct interference with turtles nesting through setting of tourist camps in nesting sites.

The modification of nesting beaches, in particular by electric lights, could be a factor handicapping turtles in some places. Despite this risk, some new beach hotels in remote areas continue to install powerful lights that directly overlook the beaches. To the contrary, some other hotels are aware of risks and have taken measures to hide their lights from the sea.

In the past, there have been cases of setting of tourist camps on the island of Nosy Iranja and tourists sometimes set fires directly into turtle nest craters. However, these camps have disappeared with the private management of the island. Such tourist camps are not frequent but may become common in future as coastal tourism reaches remote areas of the island.

Birds

Approximately 40 species of seabirds are found along the coasts of Madagascar. These include albatross, petrels, phaetons, frigates, boobies and terns. Terns are best represented with 17 species including terns the sooty tern *Sterna fuscata*, the lesser crested tern *Sterna bengalensis*, the roseate tern *Sterna dougallii*, the common tern *Sterna hirundo* and a smaller number of crested tern *Sterna bergii* tern and the black-naped tern *Sterna sumatrana*. By far, the most abundant species is the sooty tern with about 3 million pairs in the Mozambique Channel.

There are also migrating frigate birds (the greater frigatebird *Fregata minor* and the lesser frigatebird *F. ariel*), the non-migratory booby species (red-footed booby *Sula sula*, brown booby *S. leucogaster*, masked booby *S. dactylatra*), the phaetons (white-tailed tropicbird *Phaethon lepturus*, red-billed tropicbird *P. aethereus* and red-tailed tropicbird *P. rubricauda*) and the wedge-tailed shearwater *Ardena pacifica* which nests on north and east islands of Madagascar (NPWS Factsheet, http://www.montagueisland.com.au/download/factsheets/wedgetail_factsheet.pdf).

About 13 species of seabirds breed on the coasts and islands of Madagascar, but the population size is low. Also, most colonies are threatened by poaching, including the collection of eggs. The large nesting colonies are limited to steep volcanic islands or remote islands where access is difficult because of strong winds in nesting season (July-August). The largest number of nesting sites is found between Nosy Mitsio and Amber Cape, where there are globally significant breeding populations of *Sterna bergii* and *S. dougallii* as well as populations of brown booby, white-tailed tropicbird and frigates (*Fregata minor* and *F. ariel*). Some exceptions are for the small colony of red-tailed phaeton on the island of Nosy Ve (100 to 150 pairs - Cooke and Randriamaindry 1996) and the large number of terns nesting on Nosy Manitse, south-west Madagascar.

About 3 million seabirds nest on islands located within the Mozambique Channel, and 99% of them are sooty terns (*Sterna fuscata*) that breed on three remote locations - 25% Europa, Juan de Nova, 66% and Glorioso Islands 19% (> 3 million pairs). Other species inhabiting the Channel are the lesser crested tern *Sterna bengalensis* > 8.000 pairs, the greater frigate bird (*Fregata minor*) and the red-footed booby (*Sula sula*) (Le Corre and Taquemet 2005). Several species of seabirds migrate over large distances between breeding areas. Terns are especially highly migratory. The frigates can migrate between sites as distant as island Europa and the Maldives. Seabirds of the Mozambique Channel breed in different seasons depending on location. Sooty terns nest in June and July on Europa Island, in December on Juan de Nova and in March-April on the Glorioso Islands (Le Corre and Taquemet 2005).

Greater frigatebirds *Fregata minor* migrate extensively along areas of high primary productivity which are located around the eddies in the Mozambique Channel, sometimes approaching the west coast of Madagascar, where the eddies often develop. Frigate birds are commonly observed in multi-species groups (with terns and boobies), associated with subsurface predators which force their prey to the surface, such as tuna and dolphins. The frigates feed mainly on small fishes and squids.

Islands are important as nesting sites for seabirds The uninhabited islands are especially important refuges for many species of seabirds such as boobies (Polunin 1979), fish eagle of Madagascar *Haliaeetus vociferoides* (Rabarisoa *et al*. 1997), terns and other species (ZICOMA 1999). While seabirds in Madagascar were classified as 'Least Concern' by IUCN, more than half are listed under the Bonn Convention on Migratory Species (CMS) and most are protected by national legislation (Table 13).

Table 13: Threatened seabird status of Madagascar (IUCN, CMS & national legislation)

Name	Scientific name	IUCN	CMS	National legislation
Black-browed albatross	*Diomedea melanophris*	-	Ann 2	-
Shy albatross	*Diomedea cauta*	-	Ann 2	-
Yellow-nosed albatross	*Diomedea chlororhynchos*	-	Ann 2	Protected
Southern giant-petrel	*Macronectes giganteus*	NT	Ann 2	Protected
Crab plover	*Dromas ardeola*	LC	Ann 2	-
Gull-billed tern	*Sterna nilotica*	LC	-	Protected
Caspian tern	*Sterna caspia*	LC	-	Protected
Little tern	*Sterna albifrons*	LC	Ann 2	-
Crested tern	*Sterna bergii*	LC	Ann 2	Protected
Lesser crested tern	*Sterna bengalensis*	LC	Ann 2	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	*Sterna fuscata*	LC	-	Protected
Sandwich tern	*Sterna sandvicensis*	LC	Ann 2	-
Saunders' tern	*Sterna saundersi*	LC	Ann 2	Protected
Black tern	*Chlidonias niger*	LC	Ann 2	-
White-winged tern	*Chlidonias leucopterus*	LC	Ann 2	-
Red-billed tropicbird	*Phaethon aethereus*	LC	-	Protected
Red-tailed tropicbird	*Phaethon rubricauda*	LC	-	Protected
White-tailed tropicbird	*Phaethon lepturus*	LC	-	Protected

Seabirds are important as indicators of oceanographic variables. The colony of *Phaeton rubricauda* on island of Nosy Ve, Southwestern Madagascar came in 1980 with only two pairs (Langrand 1990) and was enlarged exponentially, with 100-150 pairs in 1995 (Cooke and Randriamanaindry 1996). Today, this colony is monitored by IFREMER in collaboration with IHSM in a regional oceanographic monitoring programme (M Le Corre. *Pers. Comm.*).

Birds of coastal wetlands

Birds of coastal wetlands consist of a large number of species that use wetlands, but are not exclusively limited to these areas (Table 14). The west coast of Madagascar is particularly important for wetland birds. A total of 11 endangered species occurs in the area. The west area is known for the endemic fish eagle of Madagascar, *Haliaeetus vociferoides* (IUCN Red List: Critically Endangered Species), with low number of live individuals. Studies conducted from 1991 to 1995 identified 222 adults in 105 sites, apparently concentrated in three main areas, including the region of Morondava (Rabarisoa *et al.*, 1997). Of the 13 coastal birds and seabirds threatened in Madagascar and assessed by IUCN, the sea eagle is considered critically endangered, four coastal birds and one albatross are considered threatened, and three seabirds and four coastal birds are considered vulnerable.

There is a need for an assessment of the main threats to the threatened coastal wetland birds including an assessment and monitoring of the status of coastal wetland species. It is also important to carry out studies to assess the impact of sea bird egg collection.

i) Issues

Pollution

Seabirds can be affected by marine debris, particularly oil spills where they can be soaked with oil although his is still rare in Madagascar. Birds can also become be entangled in nets and other discarded fishing gear.

Destruction of breeding and nesting sites

The main impact on endangered seabirds is through egg collection which takes place on many continental islands of Madagascar, particularly those that are accessible to fishermen. Harvesting eggs is considered to be a major factor in the decline of seabirds in coastal areas (ZICOMA 1999). However, no systematic study on this subject has been conducted in Madagascar.

Fishing

Albatrosses and giant petrels are sometimes accidentally caught by longlines when these birds dive after the bait on the fish hooks. No studies have been done on the importance of its catches in Madagascar and the level of these effects is unknown. There is no data on the impacts of fishing on seabirds. There is however a need for research on sea bird bycatch by longline industrial fishery including an assessment of the importance of these catches.

Introduced alien species

Introduced brown rats, *Rattus rattus,* in most islands of Madagascar, are thought to be responsible for declining populations of nesting birds. However, there has been no systematic study on this phenomenon and the extent of the effects is therefore unknown. In 2000, rat extermination was conducted in Nosy Ve Island, Southwest of Madagascar. However, no impact was observed on the viability of the *Phaeton rubricauda* nesting colony. The number of nests was the same after extermination (Cooke and Randriamanindry 1996, Frontier 2002).

Table 14: Threatened birds of coastal wetlands in Madagascar (IUCN 2004)

Bird species	Common name	Habitat	IUCN Status
Haliaeetus vociferoides	Fish eagle of Madagascar	Subtropical with dry forest, lagoons coasts, estuaries	CR
Anas bernieri	Madagascar teal	Coastal lands, rivers, coves, estuaries, mangroves.	EN
Anas mellerii	Meller's duck	Lakes in coastal zones	EN
Ardea humbolti	Héron de Madagascar	Coastal lands, rivers, coves, estuaries, mangroves, muds, sand and patches of salt.	EN
Ardolea idae	Madagascar Pond-heron	Coastal lands, rivers, coves, estuaries, mangroves, muds, sand and patches of salt.	EN
Threskiornis bernieri	Madagascar Sacred Ibis	Subtropical forest, tropical mangrove, estuaries, patches of mud.	EN
Amaurornis olivieri	Sakalava rail, Olivier's rail	Lakes near coastal zone, ex. Kinkony lake	EN
Charadrius thoracicus	Madagascar Plover, Black-banded Plover	Mangrove, marshes, intertidal patches of mud, estuaries	VU
Circus macrosceles	Malagasy Harrier	Freshwater coastal lagoons	VU
Glareola ocularis	Madagascar Pratincole	Coves, rocky shores, intertidal marshes.	VU
Tachybaptus pelzelnii	Madagascar Little Grebe	Brackish or saltwater coastal lagoons.	VU
Phoenicopterus ruber	Greater Flamingo	Brackish or saltwater coastal lagoons.	NT
Phoeniconaias minor	Lesser Flamingo	Brackish or saltwater coastal lagoons.	NT

Long-term predicted atmospheric/climate change

ENSO and Indian Ocean Dipole

The fluctuations of ENSO (El Niño Southern Oscillation) directly affect the surface water temperature in Indian Ocean including Madagascar. In 1998 and 2001, associated with El Niño in eastern Pacific, the surface water temperatures were maintained above 29.5°C for several weeks, between March and May, in Western Indian Ocean and Mozambique Channel. Associated with this warming, significant coral bleaching occurred in the Northeast and Southwest of Madagascar.

In the Indian Ocean, there is another phenomenon also involved in sea water temperature increase: the Indian Ocean Dipole (IOD). The IOD is a link between ocean and atmosphere in Indian Ocean. It is independent of El Nino (ENSO) as only 35% of IOD events occur with ENSO, but when the IOD is in synchrony with the ENSO, the two phenomena are strengthened (Tsangandrazana 2007). Temperature variations associated with IOD primarily affect north and east of Madagascar waters (Figure 21).

Changes in Rainfall Patterns

The analysis of rainfall data for the period 1961-2005 indicates that the total rainfall has remained unchanged.

The following spatial and temporal trends were observed:

• In southern part of the island, the rainfall increases with increasing temperature;
• In northern part of the island, the rainfall decreases with increasing temperature;
• The rainfall decreases in highlands and east coast between June and November; and
• Longer dry seasons in the same regions.

Regarding the coastal and marine zones, a downward trend in rainfall has been observed for the periods June-August and September to November (DGM 2008).

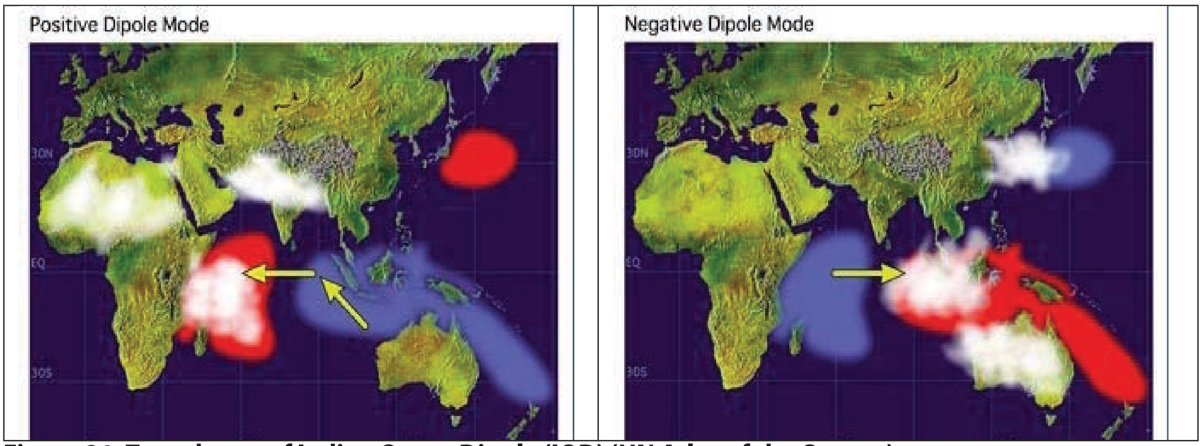


Figure 21: Two phases of Indian Ocean Dipole (IOD) (UN Atlas of the Oceans)

At regional level, reliable levels of rainfall projections from the Intergovernmental Panel on Climate Change (IPCC) are not as satisfactory, and projections do not present sub-regional and seasonal changes. For the whole Indian Ocean, the IPCC projects an increase of 4% [+ 3 to +5%] in mean annual rainfall by 2100 (IPCC, 2007). In Madagascar, the mean annual rainfall is predicted to decrease by 5% by 2100. However, an increase of 5% to 10% in December to February is predicted. The maximum increase (10%) is predicted in Atsimo Andrefana, Anosy and Androy regions. A decrease of 5% to 30% of rainfall could be possible in June to August. A maximum decrease of 20% to 30% is suggested for the same regions (Raholijao and Ramiandrisoa 2007). The projections for change in median rainfall suggest that the rainfall will increase during summer, from January to April. However, during winter in July, August and September, the southern half of the East Coast should be drier by 2050, while the rest of the country should be wetter (Christensen *et al.* 2007).

Changes in Wind Patterns
Prevailing winds around Madagascar result from the influences of permanent high pressure zones, centered over the Mozambique Channel and Mascarene Islands. In general, the winds along the east and south coasts are strong and blow from the south, while on the west and northwest coast, the winds are variable and less strong. Antsiranana in the north and Taolagnaro in the southeast are the windiest coastal sites, while Nosy Be, protected by Tsaratanana highlands is the least windy region. A general increase in the average speed of the surface winds due to air temperature increase is possible.

Changes in the Intensity and Frequency of Cyclones
Analysis of data from 1950 shows that the total number of cyclones per year has not changed but the percentage of intense cyclones has increased and cyclones have become more frequent in northeast and southwest coasts of the island (Raholijao and Ramiandrisoa 2007). In the Indian Ocean, the IPCC projects an intensification of cyclones with stronger maximum winds and more intense rainfall (Petit 2008, Tsangandrazana 2007). The projected paths of cyclones indicate a decrease in cyclones affecting the west of Madagascar, and a tendency for cyclone concentration to the east and north of the island (Figure 22). Models predict that the total number of cyclones affecting Madagascar will remain the same, while the number of those with winds exceeding 200 km/h will increase, especially in the northern and the southwestern parts of the island (DGM 2008).

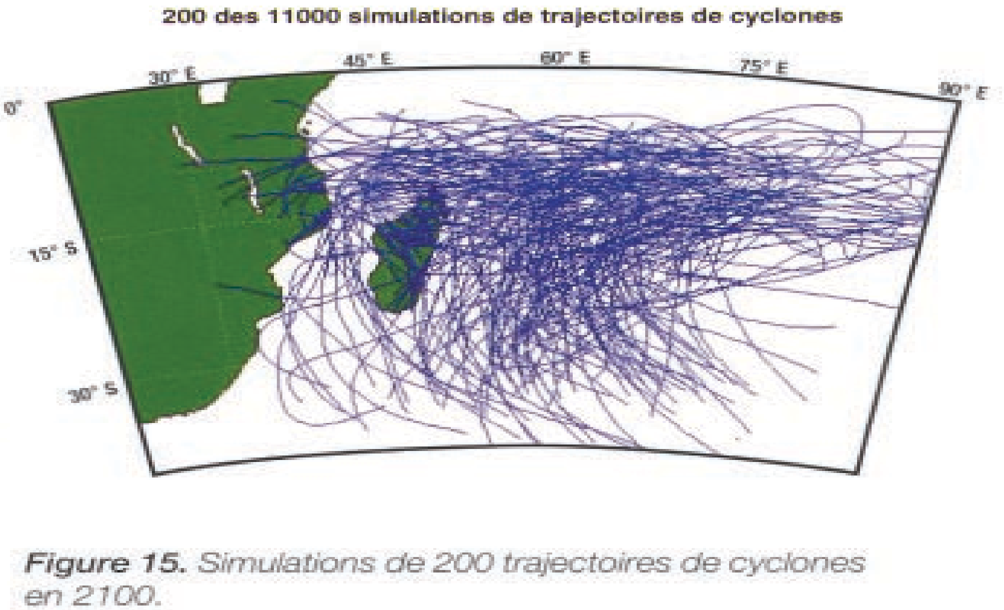


Figure 22: Simulations of cyclone trajectories (DGM 2008).

Changes in Sea Level

Mean sea level

The rate of local sea level rise is influenced by tectonic factors, rates of sediment delivery and local or regional atmosphere conditions, among other factors. The IPCC projects a sea level rise of 0.35 m [+ 0.21 to + 0.48 m] in global average and the same mean elevation for the Indian Ocean by the year 2100 (Petit 2008). It should be noted that on one hand, different models show large differences, which makes the estimates uncertain. Also, sea level rise is not uniform between sub-regions. For example, from 1993 to 2001, significant sea level rise has been observed in Chagos Archipelago, while a significant decrease was measured at Reunion Island (Church *et al*. 2006).

The mean sea level is measured in main ports of Madagascar, and data analysis have been carried out since 1994 (Razakafoniaina 1994). From 1995 to 2003, Madagascar showed a sea level rise of between 7.2 and 21.6 mm (IPCC 2007, Raholijao and Ramiandrisoa 2007). Model results for the coastal city of Morondava located in the southwest coast of the island, showed that an increase in sea level of more than 7 mm will flood an area of 76.99 km^2 by the year 2025, 82.69 km^2 by the year 2050 and 91.29 km^2 by 2100 (Tsangandrazana 2007). The sea level rise will lead to flooding of lowlying coastal areas and thus lead to coastal retreat. This will affect the critical coastal ecosystems.

Relative height of sea surface

Around Madagascar, the currents are mainly driven by winds. So, the average height of the sea is possibly a consequence of climate state. There are no projections on the impact of climate change on relative height of sea surface. However, an accentuation of the differences between various marine regions due to increased average speed of winds can be expected.

Wave height

Madagascar is located in an area of wave average height varying from 4 m in the south to 0.5 m in the north. Sometimes, exceptionally high wave heights are encountered, especially during cyclones which can generate very violent sea conditions. There is no projection of the average wave height in Madagascar. However, an average increase of wave height, following increase of average speed of wind surface can be expected,

Vulnerability of marine and coastal ecosystems to climate change

The potential impacts of climate change on marine ecosystems are diverse and important, but are still relatively unknown and quantified in Madagascar. However, it is known that the coral reefs are vulnerable to sea surface temperature increases. An increase in seawater temperature leads to coral bleaching, CO_2 concentration increase leading to seawater acidification, increased rainfall causing floods with increasing quantity of sediment in coral reefs. Other effects are increased wave energy, winds and cyclones which may limit reef development and sea level rise which may exceed the vertical growth rate of the reef. Reefs are vulnerable to associated ecosystem degradation, such as that in mangroves which trap sediments and thus promote reef development and seagrass beds which stabilizes sediments in lagoons. Reef degradation by fishing and sedimentation makes them more vulnerable to climate change and other environmental factors. Sedimentation is a major threat to the reefs in the southwest of Madagascar (IHSM 2009). Mangrove cutting stops their regeneration capacity, including their capacity to migrate landward in response to sea level rise. Smothering of seagrasses with sediments reduces their capacity for regeneration including their ability to adapt to climate change.

Effects of Atmosphere/Climate Change

Effects of high atmosphere temperatures

The increase in atmosphere temperature has no direct or immediate impact on marine ecosystems. In long term however, increases in air temperature could cause warming of the sea. However, in the short term the air temperatures may affect some marine species that use land or air, particularly sea turtles and seabirds. Turtle sex depends on the temperature of incubating eggs. A rise in temperature in nesting beaches modifies the conditions for egg incubation and increases the percentage of female embryos (Godley *et al.* 2002). The importance of this effect on turtle survival is unknown. It is also possible that ambient temperature has an impact on seabirds whose egg development is inhibited by high temperatures. The importance of this effect is however unknown.

Effects of high sea surface temperature

The effects of increased temperature in surface waters are predicted to be different along the coast of Madagascar because of the natural variation in surface temperature which will be very important in the Southwest compared to the Northwest and Southeast of the Island. Therefore, the risk of coral bleaching will be higher in the Southwest of the island than in the Northwest (Maina and Obura 2008, McClanahan *et al.* 2009). It is expected that high temperatures would have impacts on highly migratory species such as cetaceans, sea turtles and tuna. Given the importance of these species in wildlife conservation and fishing, such impacts would be a potential concern, but sufficient data to assess its importance are lacking (Anon 2008).

Effects of rainfall change

The main impact of rainfall regime change is the increased frequency of severe flooding, leading to hypersedimentation in marine and coastal habitats including reefs, seagrass beds and mangroves, causing high mortality of species. The hyper-sedimentation has been reported in Onilahy River estuary (CNRO 2000). High floods could have negative impacts on the breeding of aquatic species that depend on estuarine habitats or lower reaches of rivers, such as penaeid shrimp. Potentially, many species could be affected indirectly including eel which use mangroves as nursery areas. There would also be significant direct effects on mangroves, seagrass beds and other plant communities. Taken together, these impacts are a major concern.

Effects of wind and cyclones

Expected intensification of winds will involve wave energy increase, which could have a significant influence on the development of shallow water ecosystems, including coral reefs, mangroves and seagrass beds which will be reduced or eliminated at the limits of their sustainability zones. In coastal deserts, dune systems may become more dynamic and significant, leading to the siltation of back mangroves and shallow ecosystems such as lagoons and reefs. Cyclones are expected to become more intense and frequent, but more concentrated in the northwest coast of Madagascar. Therefore, Northeast ecosystems are likely to be severely impacted, while in other areas, impacts could be even reduced. Although the frequency of cyclones would be reduced in some areas, flooding will still be important in areas where cyclones increase (Maina and Obura 2008). Cyclones tend to bring heavy rainfall on a broad spatial scale.

Impacts of sea level increase and waves

In 1997, the coastal retreat due to wave erosion was estimated between 5.71 m and 6.54 m. This is likely to reach approximately 225 m by year 2100. The city of Morondava and some parts in the middle West coast of Madagascar are the best known for high rates of coastal erosion. The east coast of Madagascar has also been affected by coastal erosion: a part of the avenue bordering the beach of Toamasina city has been destroyed. At Manakara, a boulevard is also threatened. The evaluation of coastal retreat in 1997 (between 5.71 m and 6.54 m), suggests that over time, a great part of Morondava coastline would be wiped off the current map. Ports, cultural and historical sites located along the coast and tourist beaches are thus exposed to higher risks of loss due to coastal erosion (Tsangandrazana 2007). However, the causes and factors that determine the importance of these phenomena and their potential links to climate change and rising sea level, are still largely unknown.

Table 17: Issues and concerns related to sea level variations in Madagascar

Identified concern	Information requirements
Lack of adequate monitoring systems to empower global efforts and monitor impacts at national and regional level	Development of regional and national monitoring system
Lack of adaptation actions to mitigate climate change effects and ecosystem vulnerability	Identification of effective regional and national measures to implement
Risk of adverse effects on some aquatic and terrestrial species	Information on the relative importance of identified risks (sea turtle breeding, seabirds, etc)
Coral reef bleaching and degradation due to climate change effects	Adequate information on impacts on Madagascar reefs in order to better develop resilient national and regional networks of MPAs
Risk of adverse effects on migratory species	Appropriate monitoring system of species (cetaceans, turtles, tuna, etc)
Impacts of hypersedimentation and river discharges on coastal ecosystems	Setting up simple but effective systems on the incidence of hyper sedimentation; recovery of river flow and sediment load measures, evaluation of impacts on species breeding in estuarine areas
Impacts of cyclones on marine and coastal ecosystems	Adequate monitoring system (see supra)
Impacts of sea level rise	Development of sea level monitoring system; assessment of coastal erosion causes, trend and impacts.
Climate change effects on biodiversity and livelihoods	Establishment of long-term monitoring and data collection networks to document spatial and temporal changes of biological and oceanographic variations. Increased knowledge on the distribution, abundance, behavior and feeding of key marine vertebrates, especially mammals and turtles, while including data of migratory routes. Identification and mapping of variations (e.g. natural variation, anthropogenic impact, climate variability) that contribute to species response to climate change, adaptability - and creating a model of vulnerability to coral bleaching, etc. Develop ocean models for the region including Madagascar, that accurately reflect the current situation and potential changes in future. Prepare a more refined map of Madagascar coastal topography (resolution of less than 1 m) Establish likely changes due to human pressures on marine ecosystems in addition to climate change (e.g. migration from agriculture to the coast)

3. HUMAN ENVIRONMENT

Coastal and island populations: current status and trends

The total population of Madagascar was estimated in 2009 to be 19,600,000 inhabitants (INSTAT 2011). About 34 percent of the population lives within 100km from the coast. They are distributed in 13 coastal regions, subdivided into 43 coastal districts occupying an area of 404,519 km^2. Much of the island of Madagascar is sparsely populated with an average density of approximately 32 inhabitants/km^2. The Melaky region records the lowest population density of 5 inhabitants per km^2, while Vatovavy Fitovinany holds the highest density of 56 inhabitants per km^2. The average density in coastal areas is 22.44 inhabitants per km^2. This density also varies with the migration of coastal populations. The coastal population is very young with 50.25% of the population being between the age of 15 and 59 years. The population growth rate is high (3.03%) with a mortality rate of 11.11%. The infant mortality rate is very high being 75.21%. This is mainly due to the low coverage of basic health services.

i) Issues

The main issues are pollution, accessibility (hospitals, markets), lack of infrastructure, population pressure, poverty and lack of sanitation. Near coastal cities, unregulated coastal activities are increasing considerably especially overfishing, exploitation of mangroves, and tourism. Pollution is particularly noticeable in all coastal areas of Madagascar. This can be due to watershed soil erosion and deforestation or chemical pollution caused by industrial activities, municipal and domestic wastes.

ii) Gaps

There are gaps in information on demography of Malagasy population (evolution, structure, fertility, mortality) and population distribution in coastal and rural regions.

Sites of religious or cultural significance

In the whole of Madagascar, all ethnic groups have set up religious and cultural sites that they jealously guard and protect, as they represent the indigenous modes of expressions of their culture borrowed from their Asian, African or Arab origin. Everywhere, the abundance of places of worship and religious practices reflects the omnipresence of faith based on God as creator but also on ancestors and other divine spirits with whom the living can communicate with indirectly (http://www.reseau_asie.com).

In northern Antakarana and western Sakalava, there is the Tsingy, located respectively in Ankarana massif and Bemaraha Plateau, which for 300 years have been places of worship and religious ceremony for the Vazimba, the ancestors of Malagasy people. The Tsingy of Bemaraha has been classified since 1990 as a World Heritage site by UNESCO (Blanchy *et al*. 2006).

In western, southwestern and southern regions, baobab and tamarind trees are sacred. Their base is used as an altar for worship and offerings given to gods to fulfil wishes. However, they are threatened by diseases and deforestation for the production of charcoal and firewood (Blanchy *et al*. 2006). In the deep south, tombs with their varied original architectural forms are the particularity of Antandroy and Mahafaly culture. Sculptures and drawings show the life of deceased or his requests to his ancestors during his lifetime which were not granted (Blanchy *et al*. 2006).

The sea is the cradle of Vezo culture. According to tradition, the Vezo also called "sea gypsies" are the descendants of the union of a single ancestor and a siren. At all times of their lives (marriage, baptism, circumcision, burial, and the beginnings of fishing), they make offerings to gods that are believed to roam the sea (Blanchy *et al*. 2006). On the East coast, the art of hut building remain a perpetual culture for people. Rites always accompany choice and collection of building materials as well as plan and building orientation. This tradition concerns Bestimisaraka and Tanala. Sainte Marie Island has managed to preserve and maintain its diverse culture through the remnants of pirates and the coming of Christianity between the seventeenth and eighteenth century:

Sacred lakes such as lake in the North Anivorano located between Ambilobe and Antsiranana preserves the history of a whole engulfed village. Traditional legends tell how the village was cursed by an old woman from the Southeast because inhabitants refused to give her water to drink and were transformed into crocodiles (http://www.madagascar-tourisme.com). In Antsiranana, the Montagne des Français contains the vestiges of successive French occupiers since 1885. During French occupation, this mountain was a bastion for the French.

i) Issues
The main issues are accessibility, cultural erosion particularly loss of appreciation of the importance of cultural sites, physical erosion of culturally important sites, and economic pressures.

Human Health

Malnutrition
In coastal areas, infant malnutrition in particular rages in almost all rural areas. It poses a serious public health problem because it contributes to increased death risks especially among young children. According to data from the Demographic and Health Survey (DHS 2003/2004), nearly half of all children suffer from stunting and 45% suffer from malnutrition. Malnutrition increases infant death rates. Out of every 1000 children born alive, 58 die before the age of 1 and out of 1,000 children aged below 1 year, 38 do not reach their fifth year. Consequently, the government, through the Ministry of Health and Family Planning, created Children Feeding Centers (CRENI/CRENA) at municipality level.

Famine
Since the serious crisis of 1992, significant nutritional problems due to series of droughts hit the southeast and south regions of Madagascar. Crops were virtually nonexistent and in the South, the only food resources were red cactus or ashes mixed with tamarind. In 2005, 150,000 people living in 22 municipalities of the Southeast of the island were affected by famine. 14,000 children suffered from severe malnutrition and 3 700 were under critical condition. In 2009, the South, especially the Androy region was severely affected by the prolonged drought that was aggravated by political crisis. The worst was feared because, according to UNICEF, 250,000 children suffered from malnutrition, dehydration and other diseases. The suspension of United Nations assistance through FAO, UNICEF and reduction of humanitarian aid due to political crisis, worsened food insecurity and nutritional status in these vulnerable areas (http://www.unicef.org/french/infobycountry:madagascar).

Malaria
Malaria is also one of the major diseases that rage in Madagascar. The disease shows an alarming increase in all coastal zones. Malaria annually costs the country USD 52 million due to reduction in productivity, school absenteeism, cost of treatment and funerals. This disease kills 80,000 children every year in Madagascar. Recently, the emergence of Dengue and Chikungunya in the East Coast caused panic throughout the island. In the fight against malaria, 10 districts of DIANA and SAVA regions were supplied with 54,000 long-lasting insecticide-treated mosquito nets in 2008 to protect people against the malaria vector the *Anopheles* sp. Thanks to the distribution of these nets, over 7 million people throughout Madagascar are protected. Following the example of nearby islands (Mauritius and Reunion), Madagascar is trying hard, through its National Malaria Strategic Plan, to completely eradicate this disease. The strategy, based on rapid diagnostic tests, therapeutic combinations based on artemisinin and provision of treated mosquito nets, has led to satisfactory results at Sainte Marie Island (Aubry Pierre 2005).

HIV/AIDS
In Madagasacar, 300,000 people were tested and 144 were HIV positive in 2008. Since the onset of the pandemic in Madagascar, 387 people living with HIV/AIDS are subject to medical supervision of which 162 take antiretroviral drugs. In coastal areas, Nosy Be, Morondava, Toamasina, Mahajanga and Toliara areas remain at risk. In the fight against HIV/AIDS, several actions were undertaken by the Ministry of Health including supplying antiretroviral drugs to 8 of 9 reference centers in Antsiranana and Toliara, with contraceptive supplies for youth reception centers. In family planning, only 41% of the population of Antsiranana was found to practice any form of contraception.

Access to drinking water
In 2005, only 1/3 of the Malagasy population had access to drinking water and 2/3 used water from lakes, rivers

and wells. In the same year, UNICEF found that 3% of the rural population and only 34% of urban population had access to potable drinking water. The Atsimo Andrefana, Anosy and Androy regions suffer from lack of water and drinking water is a real luxury. Even in the capital of the South (Toliara), this situation affects 20% of the population. According to a report by the bush doctor association, 50% of infant mortalities are caused by diarrhea from unsafe drinking water (http://www.Madanight.com). As the drinking water is a strategic commodity, the Malagasy State has accorded priority to the drinking water sector and it aims at supplying 56% of the population by 2015.

Literacy

In Madagascar, half of the population can neither read nor write. Among 40% of illiterate adults, 65% are women. About 40% of students do not finish primary school (http://www.unicef.org). Efforts to address this serious problem were launched in the 1980s. This aimed at eradicating illiteracy in Madagascar and also reducing inequalities in access to basic education. The programme has a goal of reducing illiteracy by 50% by the year 2015. Decentralized communities in rural areas and vulnerable target groups are the main beneficiaries of this program which started in 2008 (http://www.jeuneafrique.com/pays/madagascar).

Access to health care

The health care facilities and health indicators are improving in coastal regions of Madagascar:

- The attendance rate to basic health centers, although still modest, increased from 84% in 2002 to 87% in 2007,
- The immunization coverage of children between 0 and 11 months has also increased from 80% in 2003 to 85% in 2007,
- The proportion of births assisted by skilled health staff reached 54% in 2006.

The prevention of diseases, increasing capacity of medical staff, construction or rehabilitation of community health centres has been the major priorities of the Ministry responsible for health since 2004. However, Madagascar is still far from World Health Organization (WHO) standards which set a preferred ratio of one doctor for 5,000 inhabitants. All over the country, the distribution of doctors is uneven. Rural areas have a lower ratio ranging from 1 doctor for 20,000 inhabitants in Androy Region, and 1 doctor for 17,000 inhabitants for Melaky Region. There are a number of basic health centres which have no doctors at all (Ministère de la Santé du Planning Familial et de la Protection sociale, Institut National de Santé Publique et Communautaire, Service statistique sanitaire, Rapport 2006-2007).

i) Issues

The main issues are malnutrition, education – high illiteracy levels, diseases, limited access to drinking water and limited access to health services. These issues have been discussed in the above sections.

ii) Gaps

Much information exists on human health in Madagascar and covers several aspects. However, they are often globalized and nationalized. Only few indicators concern the coastal zones of Madagascar and most of them are incomplete. There is a need to fill this gap in data.

Infrastructure

Roads

The road sector plays an essential role in the state economy. The road network of Madagascar consists of:

- 12,000 km of principle roads with 5000 km paved and 7000 km unpaved.
- 18,000 km of regional roads with 500 km paved and 17500 km unpaved.
- 5,500 km of public highway with 200 km paved and 5300 km unpaved.
- 2,500 km of unclassified roads essentially unpaved.

About 85% of roads in the island are not tarmacked. Most of the roads representing 74 % of the total network are in poor condition. This poor state of the roads is mainly due to climatic conditions, difficult topographies, lack of maintenance and limited finance (Ioly Robinson 2008).

Ports

Madagascar is served by 6 international ports: Toamasina, Mahajanga, Antsiranana, Nosy-be, Toliara, and Ehoala, and 12 ports of coastal navigation: Vohémar, Maroantsetra, Mananjary, Manakara, Taolagnaro, Morombe, Morondava, Maintirano, Port Louis, Antsohihy, Sambava and Antalaha.

Airports

The company ADEMA SA (Airport of Madagascar) was created in 1989, by interministerial decree dated February 26, 1991 which granted a 15 year concession. ADEMA SA manages 12 major airports in Madagascar such as Ivato and 11 landing pads located at Antsiranana, Mahajanga, Nosy-Be, Toliara, Toamasina, Fianarantsoa, Sainte-Marie, Taolagnaro, Currently, Madagascar has 58 airports with paved or unpaved airstrips ranging from 914 m to 3,000 m in length.

Railways

The total rail network of Madagascar stretches 1,030 km. Madarail is the operator with funding from the World Bank. This funding enabled the company to renew a section of 175 km of railway track and improve 235 km of roads, 7 bridges, and to purchase five new locomotives. The rehabilitation of the railway station in Andasibe is also planned. The railway consists of two North and South networks with 4 one-track lines of 1 m, constructed from 1886 to 1936. The coastal railway networks include 2 lines totaling 541 km which is currently only partly exploited.

Telecommunications

The aim of the government is to offer efficient telecommunication networks. There is an effort to increase access to telephones and high-speed connections as well as international connectivity. Actions initiated since 2003 include (i) the "ICT for All" policy; (ii) introduction of fiber optic cables, (iii) creation of ICT Technopole and, (iv) installation of VSAT system. All administrative centres of coastal districts have at least one communication system such as telephone or internet.

i) Issues

The main issues are lack of investment in ICT sector, poor maintenance of telecommunication networks and low level of education.

4. ECONOMY AND COASTAL LIVELIHOODS

A comprehensive coastal livelihoods assessment has been carried out. Chapter summaries are presented below, and the full Coastal Livelihoods Assessment may be found in Annex XII for further information.

General description

Madagascar is among the least developed countries of sub-Saharan Africa with a gross Income per Capita of USD 275. The country is placed 145th out of 182 countries in the human development indicator ranking in 2009. Economic growth rate was 5.6% in 2007. Inflation rate in 2007 was 10.3%. The economy of Madagascar is highly dependent on primary export sectors such as shrimp, vanilla, coffee, cloves and litchis. This sector represents 27% of GDP and 20% of Madagascar exports. The secondary sector accounts for 14% of GDP and 50% of exports. It encompasses the food industry as well as wood and wood products, textiles, clothing and the metal industry. The service sector with 51% of GDP is based on transport, trade, health, communications and tourism which is the second source of currency after fishing. The political situation prevailing in the country since early 2009 has led to an exodus of foreign capital, deterioration of partnerships and a marked absence of tourists. It has also promoted various illicit traffics particularly smuggling of goods. This situation will certainly have a serious impact on the economy.

Coastal Fisheries

The small-scale fishery in Madagascar, which covers subsistence, artisanal/traditional and recreational fishing, is largely concentrated on the country's west coast, making up 36% and 27% of the workforce in the province's of Toliara and Mahajanga respectively. Small-scale fishery total catches were estimated in 2008 to be 107,300 tonnes per year. In 1950, the catches were estimated to be 13,800 tonnes per year. Small-scale fisheries represent nearly 72% of total fish production largely focusing on export products such as crustaceans, holothurians and cephalopods, with men making up 97% of the workforce (Le Manach *et al.* 2011). In 2003, the small-scale fisheries, as a whole, contributed nearly 26% of the total tonnage of fisheries export and nearly 9% of the total value of exports, worth an estimated USD 142 million.

One clear constraint in the sector is the lack of information, data and socio-economic research which is perhaps a reflection of the country's weak institutional capacity. A recent publication (Le Manach *et al*. 2011) tried to provide an overall estimation of the unreported fisheries production in Madagascar in order to fill in the gap between official statistics and real data. The lack of information makes planning and management very difficult, and thus no policies have been designed solely for coastal fisheries. This lack of capacity has also affected the ability to monitor the sector, whereby, over-fishing, particularly of sea cucumber and shellfish, continues to go unchecked. This problem is further magnified due to lack of coordination between the fisheries and environment ministries. Similar constraints can be seen in infrastructure, with massive post-harvest losses being documented as a result of poor storage facilities, particularly in remote areas. Increased fuel prices, and inflation in general, are threats that could intensify these problems.

Overall, despite the multiple problems caused by weak capacity and infrastructure, there are numerous strengths and opportunities in the sector that could be capitalized on. For example, there are lucrative resources such as crab and rock lobster that are not being utilized by the industrial fishery. This is even more promising for the traditional fishery, which requires significantly less expenditure in comparison to other sub-sectors. High demand for fish products should also provide incentive for growth in the sector, particularly in areas associated with mining developments. International demand is also strong, highlighting the potential for increased exports. The ASCLME project itself also has the potential to generate information and facilitate better management in the sector. However, a lack of microfinance, along with inadequate training, could present further obstacles in the sector moving forward.

Particularly, in the traditional fishery category, during the 2004-2005 seasons, 120,762 people were engaged in fishing as their main activity. In terms of regional distribution, fishermen who practice fishing as their principal activity are more numerous in Atsimo Andrefana, and Menabe regions. On the contrary, in Sofia, Analanjirofo and Atsimo Atsinanana regions, fishermen who only rely on fishing as a secondary source of employment are more numerous. In some coastal regions like Diana, Sava and Anosy, fishing activity is concentrated in some specific zones. This is mainly due to the inaccessibility of the coastal areas and/or the existence of more attractive economic activities especially mining or cash crops cultivation. The regional distribution also shows that, contrary to aquaculture, fishing activity is mainly present in coastal regions.

Tourism

Tourism and the hotel sector represented 3.7% of GDP in 2008, an increase from 2.8% in 2003. The sector is the second largest source of foreign exchange in the country, bringing in USD 116 million in 2009, which is, however, down from USD 210 million in 2007 and USD 303 million in 2008. The sector also directly employed nearly 27,300 people in 2009, an increase of over 6,000 people from 2005, which largely correlates to the 5% annual growth rate in the sector as a whole. Antananarivo, Toliara and the national park of Isalo are the most frequented destinations, while France is the largest tourist source market, representing 70% of all arrivals.

Numerous constraints have been identified in tourism, despite the documented growth in the sector. For example, not only does the rainy season correspond to winter in the Northern Hemisphere, but the risk of cyclones and tropical diseases have all been identified as limiting to tourism activities. Poor international accessibility and weak infrastructure also increase costs to visitors particularly in comparison to other tourist destinations in the region. Lack of appropriate facilities has also been highlighted as a weakness in the sector. Despite these challenges, the strengths prevalent in Madagascar's natural landscape and culture are highly conducive to a successful tourism sector. For example, different climate zones, diversified landscapes and ethnic cultures, as well as extensive biodiversity, all highlight the great natural and social vitality present in the country. These natural strengths also have the potential to be accentuated by potential upgrades in infrastructure, the revival of cultural heritage, as well as the diversification of products being offered in the sector.

As a whole, the ability of the tourism sector to generate income outside of the hotel sector, notably in agricultural goods, fishing and sailing, is clearly an advantage, particularly as a means to include local communities who may not be directly employed in tourism. And while the destruction of rainforests and the pressure being placed on natural resources from internal migration are pertinent issues, it is positive to note that a green charter was jointly signed by the ministries of environment and tourism in 2006, which made promotion of sustainable development as a key facet of tourism in the future. Thus, while both political instability and the domestic monopoly maintained by Air Madagascar could continue to be problematic, the opportunity for increases in quality control and service delivery highlight the potential for further growth in tourism in the coming years.
Madagascar's tourism potential is considerable and tourism is one of the most important economic activities, especially in sources of foreign currency (ranked second after fish products). Apart from conventional tourism (beaches, discovery tours), ecotourism, tourism leisure, discovery and adventure sports are gaining in popularity and represents 50% of the demand. To mitigate regional competition which is very strong with Reunion, Mauritius and Seychelles which are popular international destinations, there is a policy which aims to promote cultural diversity and accelerate the development of the tourism sector. Thus, the number of tourists showed a distinct increase from 2001 to 2006, and it is the same for the amount of currency received, which reached 157.7 million DTS in 2009 compared to 124.5 million DTS in 2005 (http://www.instat.mg).

With regards to job creation, a growth rate of 6% compared with 2005 was recorded with 22,409 new jobs in 2008. The first quarter of 2007 also saw the creation of 360 jobs. The major challenges are to promote tourism by:

- Increasing investment in tourism sector in order to provide places for 300,000 international visitors per year,
- Provide reliable and updated information to travel and tourism subscribers (intranet and extranet of the Ministry of Tourism)
- Risk mitigation in places of interest,
- Mitigating the spread of the negative impacts of tourism
- Improving the supply of key services in the places of interest
- Effectiveness of the implementation of the TMP (Tourism Master Plan).

The plan is to increase hotel capacity up to 500 rooms per year in collaboration with Accor (Novotel, Ibis) and Ventaglio groups, rehabilitation of Ivato and Nosy-be airports and development of regional and international routes (to Bangkok, Milan, Gouangzou). All this is evidence of prospects for significant contribution of tourism to national development.

Mariculture

Mariculture is a developing sector in the Malagasy economy with research and pilot projects ongoing in mud crab, sea cucumber, blue-green algae, oyster and eel. There are also commercial activities present, seen with the large scale farming of prawn for export and domestic consumption, as well as small-scale production in seaweed. Prawn farming, in particular, has been very successful in providing employment for rural communities, supplying 4,325 permanent and 30,000 part time jobs in 2003. The sub-sector also has a strong export component worth an estimated USD 62 million.

As it is a developing sector, numerous constraints still remain prevalent in mariculture. For example, improvements in research and development capabilities, as well as wider access to finance, are both required to further develop the sector. Theft and vandalism, as well as a lack of an overarching sector plan, have also become problematic. Environmental degradation has also become an issue. For example, the physical alteration and destruction of mangroves, as well as biosecurity in general, have been highlighted as foreseeable problems in prawn farming. The sustainability of crablet supply, as well as juvenile harvesting, have also become issues in the farming of mud crab. Likewise, unsustainable farming practices across all sub-sectors have also been highlighted as a threat.
As a whole, despite these documented constraints, mariculture holds much promise in Madagascar. High quality seawater, larges areas suitable for development, as well as numerous potential candidate species, all highlight the strengths that are prevalent. Private-sector involvement, particularly in prawn farming, also magnifies the interest and potential surrounding the sector, which is further reinforced by the extensive bi-lateral support coming from donors and various European universities. The potential for sea cucumber ranching, as well as commitments from government and communities, also highlight the positives inherent in mariculture moving into the future. Thus, while priorities in sub-sector planning and common codes of practice need to be established, the opportunity for mariculture to become a significant substitute sector in the Malagasy economy is clearly evident.

The main activity in the marine sector is shrimp farming. Shrimp farming is a very recent activity. It began in 1992 with the establishment of the first industrial farm, AQUALMA, at Mahajamba, following the positive results of the feasibility study conducted at the pilot farm of Nosy Be and jointly funded by UNDP and FAO, Malagasy Government and Nosy Be Fisheries, a Malagasy industrial fishery company for shrimp (Avalle and Randriantomponiony 1994).

Madagascar has enormous potential to farm shrimp, 37 sites along the west coast have been identified, with a total area of 15,554 ha or net surface water of 11,138 ha, and 9 083 ha of disposable space in the form of pools. The west coastline of Madagascar, thanks to mangroves with their silty clay or sandy clay structures with high temperatures all the year, low rainfall and moderate and regular winds, offers ideal areas for shrimp aquaculture development. Moreover, the only species bred in Malagasy shrimp farms is *Penaeus monodon*, with growth-out and reproducive performance. Malagasy shrimp farming is semi-intensive with a density of 12 individuals per m^2 and a high water renewal of 20% on average, every day during the production cycle (about 4 months).

Five industrial shrimp companies currently exist and covered in 2007, 2,267 ha of catchment area and produced 8547 tonnes of shrimp (OEFC 2008). Much of the shrimps produced by these farms are exported after processing and packaging in recycling plants belonging to these companies. The export values contributed about 50% in 2003 and nearly two thirds of the revenue from Malagasy shrimp exports in 2007. They contribute with other fishery products to the sources of foreign currency and the constitution of GDP (between 2.3% and 2.9% in 2003 and estimated at 5.2% in 2007).

Besides these big industrial companies, there are a small number of artisanal farmers with small-scale surface farms smaller than 50 ha and only 0.50 ha to 12.2 ha converted land (International Conference on Responsible Shrimp Farming-GAPCM/SEPRH, 2003). These artisanal companies have only operated during their training period at the Centre for Development of Coastal shrimp because of a lack of financial support.

The other types of marine aquaculture are:

Seaweed culture

This is conducted by the company IBIS which cultivates brown algae (*Eucheuma spinosum* and *Eucheuma* *cottonii*) at Nosy Ankao and the Bay of Ampasimadera, north of Vohemar (SAVA Region) and in the Emerald Sea near DIANA Region. Overall this sector produced 892 and 1,232 tonnes of dried seaweed in 2006 and 2007 respectively, supplied by 120 farmers in 2006 and 254 farmers in 2007. The average monthly income of each individual farmer ranged from USD 37 to USD 46 between these two years (Randriambola and Rafalimanana 2006).

Spirulina culture in ponds

This is a well controlled practice and its production in fish farms is an effective weapon against malnutrition. Convinced of the vital role that spirulina can play in fight against hunger in the world and especially in Madagascar, several specialized entities such as "Antenna technologica France"; Institut Halieutique et des Sciences Marines (IHSM) and AMADA (Association Madagascar Aide au Développement par l'Algoculture) are funding and implementing research programs projects to create semi-industrial units of spirulina culture at Morondava and Toliara. These entities continue to announce that spirulina produced in existing basins (Toliara and Morondava) allows the complete treatment of 5000 children per 100 m^2 with an annual production of 2 kg per planted m^2. Besides its use in human nutrition, spirulina is tested in animal feed especially in artemi cultures (culture of zooplankton artemi) and shrimp farms.

Sea cucumber farming

This is being developed at a farm in Toliara and is now in the production stage. The farm breeds and grows out juveniles to the size required for their marketing (20 cm and 300g). The process takes 10-12 months and takes place in three phases, each requiring specific infrastructure such as indoor aquaria, outdoor pools and sea pens. From March 2008, tripartite partnership between Belgian universities, IHSM and COPEFRITO SA, led to the creation of Holothuria Madagascar SA (MHSA), a first commercial society based on the production and marketing of sea cucumber in Madagascar. With a maximum density of 3 individuals per m^2 in sea pens, the farm now produces thousands of sea cucumbers and plans to recruit coastal villagers, to reach 200,000 trepangs per year within 5 years. The company supervises members of various local organizations (groups of fishermen, coastal villages) in breeding method.

Freshwater aquaculture

The freshwater aquaculture in Madagascar includes fish pond culture, rice-fish culture and cage culture. Occupying valleys and lakes in Malagasy highlands, coastal populations are beginning to adopt freshwater aquaculture, especially along the eastern coast and also in the rice Great Plains such as Marovoay, Andapa, and the lower valley of Mangoky. Across the country, 150,000 to 160,000 ha of natural water bodies are favorable for cage culture and pens, 175,000 to 200,000 ha of rice fields suitable for rice-fish culture with the potential to produce 30,000 tonnes of market-size fish per year. On the contrary, the productivity of pond breeding has decreased from the 2,000 ha converted to ponds in 2007, to only 400 ha (MAEP/FAO 2007).

With an output of 2,630 tonnes of fish in 2007, aquaculture provides only 9% of national freshwater fish production. This includes 210 private producers of fingerlings and about 140,000 peasants and farmers. There are opportunities for freshwater fish fillet export to the USA or Indian Ocean country islands on one hand, and local fish market due to Malagasy consumer preference for freshwater fish on other hand. In this respect, the Ministry responsible for fisheries is focusing its efforts on (i) improved technologies for rearing carp and tilapia; (ii) promotion of professional organizations on carp and tilapia fields; (iii) promotion of industrial tilapia farming (*Oreochromis* sp.) and study on some endemic species (*Damba, Saroy, Marakely*) for commercial purposes and possibly for export.

Ports and maritime transport

Ports and rail have been documented as the two key modes of transport in the Malagasy coastal zone. Six ports have been identified, all of which are crucial to economic life due to the difficulty of inland movement. The most important ports, in terms of cargo and trade, are Mahajanga and Toamasina. Toamasina is highly significant as it is not only connected to Antananarivo by rail, but it is also an important point for both exports and imports. Mahajanga also provides transshipment services, however, a cyclone in 2006, as well as limited water depth, has constrained activity. Ports in Madagascar are largely state-controlled; however, some privatization has been seen with the ports in Toamasina and Ehoala, while further concessions are being made to the private sector due to capital constraints and a need for modernization. In regard to rail services, the private company Madarail is the most significant provider, carrying 94% of rail freight and 86% of passenger rail traffic in the country. In 2008, the transport of commercial and consumer goods by rail accounted for 45% of total tonnage in the country, a clear testament to the importance of rail services in the country.

Political instability and ethnic tension have been highlighted as weaknesses influencing the sector, as both have the potential to deter investment and private-sector activity. Cyclones and tsunamis have also been problematic, which pose serious threats to infrastructure and overall economic activity, while capital limitations have also been cited as a weakness, particularly prevalent in ports and in sea-based economic activities. Nevertheless, the country does posses a comparative advantage in its geographical position, evident in its strategic proximity to sea lanes linking the Far East with Africa and South America, as well as its easy access to a vast expanse of ocean.

Challenges are clearly apparent, however, there are numerous opportunities in the sector that could be capitalized on moving forward. For example, growth in the mining sector in Sakoa and Toamasina, as well as development in the oil and gas sector, could potentially facilitate development in the country's ports and adjacent coastal communities. Many mineral reserves in the country also remain unexploited, which again highlights the potential for future growth in sectors, such as ports and coastal transport that compliment mining activity. Similarly, the port in Ehoala has recently been upgraded with a joint venture between Rio Tinto, the World Bank and the Malagasy state government, again a testament to not only the significance of mining activity as a facilitator of growth in the sector, but also the potential for further private-sector participation in ports and coastal transport. Thus, while political instability does remain a challenge, the commitment to developing the country's ports and coastal transport, from both the private sector and the government, should accentuate the other strengths and opportunities identified in the sector.

Maritime Manufacturing

The industrial shipbuilding is situated at Antsiranana with the Société d'Etudes de Construction et de Réparation Navale (SECREN). This company has been provided with equipment and installation of a 200 m long and 24 m wide dry dock. The SECREN specializes in all types of construction, the repair of ships and boats of various types with wooden, fiberglass, plastic or metal shells. This project of strategic importance hosts mostly European tuna boats, especially from Spain, which represents 90% of its turnover (Agence Portuaire Maritime et Fluviale, Direction de la Régulation 2007). In addition, it hosts national shrimp trawlers for their carenage.

With regards to shipbuilding, the operations are custom-built and it can build a ship up to 100 m in length. The main types of ships are tugboats, catamarans, fishing boats, trawlers, coastal ships, skiffs, and barges. The shipyard has already built shrimp trawlers of 20 m length and artisanal fishery units such as "catcher" of 7-9 m length.

In 1989, 57 ships including 38 national and 19 tuna boats passed by SECREN for repair and refit (Secren 1991). However in 2008, only 30 ships passed through. The current situation cannot meet the challenge of its development because, besides the outdated state of its materials and equipment, the reduction of its active staff to 946, competition from other more modern and efficient shipyards in Durban, Port Louis and the Comoros, have significantly undermined its primacy in Western Indian Ocean.

There are also found other shipyards and naval workshops. These workshops although of modest size, have opportunities to build boats both in wood and in steel polyester polymer. These manufacturers are mostly based in Antananarivo. Artisanal shipyards are common in coastal villages close to extensive forest cover. Using simple tools, monoxyle dugout canoes and schooners (dhows) are built. Among target locations in this activity, there is the example of Belo/Sea where nearly all dhows sailing in the West Coast were built. Over 50% of fishermen in coastal villages, especially in East Coast, build their own dugout canoes.

Coastal mining

Madagascar has considerable mineral resources scattered across the country: it has several varieties both in the ancient bed rock which covers 75% of the territory and in sedimentary layers. Some 2,300 operators are currently active in the country, generating direct and stable employment for about 100,000 permanent workers and up to half a million seasonal jobs. Many deposits were identified a long time ago and reserves are still important. The Madagascar coastal zone has enormous potential for mineral wealth. The following are the types of minerals mined in Madagascar (Ministère de l'Énergie et des mines 2003):

- Industrial minerals such as graphite, chromite, quartz, mica, coal, iron, ilmenite and nickel.
- Ornamental stones in high demand such as labradorite, rock crystal, rhodonite, marble, cordierite, celestite, glassy beryl, quartz, opaque tourmaline, corundum, ammonite, aragonite and silicified wood.
- Gemstones such as ruby, sapphire, emerald, aquamarine and other beryl.
- Gold.

Despite considerable mineral wealth, mining production plays only minor role in the economy. Extractive industries contribute to only 3% of GDP and 1% of exports. Since 1996, the official value of mineral exports increased from USD 16 million to USD 37 million in 2000, mainly by trade in precious stones. Unfortunately, poor governance and corruption in the sector discouraged many formal investors and led to the trafficking of precious stones out of Madagascar, virtually without domestic value added. The value of illegal exports of precious stones and metals in Madagascar is estimated at USD 200 to 500 million per year, about 10% of GDP. It is therefore clear that a stabilization of this sector is a national priority; it must go through full integration to convert into a formal economic sector so that Madagascar can benefit from the exploitation of its mineral resources to ensure its sustainable development and help eradicate poverty. About 95% of the revenue generated by mining is from industrial mining of large companies and only 5% from precious stones since the majority of products are sold to traffickers. While minerals such as gold and precious and semi-precious stones offer interesting export opportunities, currently, large quantities of these minerals are illicitly sold out of the country. If these were sold officially, it could generate USD 100 million in revenue. Industrial minerals offer real prospects of exploitation that could improve mineral export revenues (Ministère de l'Énergie et des mines 2003).

Mining contributes to 3% to GDP in Madagascar, however, the USD 5 billion total investment in the Illeminite mine in Tolagnaro and the nickel-cobalt mine in Moramanga and Toamasina was documented as the largest investment in Madagascar's history. Expenditures on construction, for both mines, have been estimated to be the largest sources of hard currency in the country. Actual production has already begun at the Tolagnaro mine, while production will begin in Moramanga and Toamasina in 2011. Sapphire, ruby, gem and gold are also prevalent in the country, with over 500,000 artisanal miners identified to be mining gold on a part-time basis. The production of heavy minerals from sands, and limestone in Toliara, as well as iron in Soalala, are all currently in the study and permitting phase.

The two large mining projects financed by foreign capital (RTZ QIT: titaniferous sands and Sherrit: nickel and cobalt) could generate USD 400 million of export revenues per year, as long as the required investment (approximately USD 3 billion) is carried out over the next fifteen years. By the end of the next decade, the realization of these two projects could increase the export revenues from USD 25 million in 1997 to USD 500 or 600 million (Dahl 2005)

Direct and indirect employment is clearly one great benefit from coastal mining. In Tolagnaro, the construction phase provided over 6,000 jobs, while over 2,000 jobs are provided in the operation phase. Construction at the mines in Moramanga and Toamasina has provided over 11,000 direct and indirect jobs. The companies operating the mines, Qit Minerals Madagascar and Ambatovy, are also large contributors to community development. Qit Minerals Madagascar has not only developed an enterprise development program, but it has also developed initiatives around microfinance, education and health care. Likewise, Ambatovy has developed a project to assist local populations in developing job skills, as well as created a center for agricultural training. Both mines do, however, present environmental challenges, particularly around the destruction of flora and fauna, which could certainly become problematic in the future.

The formal mining industries are mainly concentrated in the Toamasina and Fianarantsoa regions. The most important components within the mining industry are the major substances such as quartz, graphite, chromite and mica which provide 95% of mining revenue.

Four major mining projects contributing to the improvement of domestic currency competitiveness are currently functional:

- Ilmenite mining project at Taolagnaro by the company QIT Madagascar Minerals (QMM), with an investment of USD 940 million.
- Nickel and cobalt mining project at Ambatovy by Dynatec -Implats-Sumitomo.
- Exploration and exploitation of bituminous sandstone at Bemolanga, on 6500 km^2 with an estimated bitumen reserve of 3 billion tonnes (10 billion barrels) of which 600 million will be open-cast workable by Madagascar Oil Ltd.
- Exploration and exploitation of heavy oil at Tsimiroro, with a capacity of 2.5 billion barrels.
- Mining policy in Madagascar is contained in the new Mining code No. 99-022 and governed by the texts cited in annex 20.

Madagascan mining resources are invaluable. However, there is little documentation on the resource. The single available document on mining indices and geological map is the results of research carried out by the French geologist, Besairie, a document dating from colonial period. The results of BRGM (Bureau of Geological and Mining Research) research are locked up in its headquarters in Orleans La Source (France) (Ralevazaha 2005).

Strong environmental and mining regulations, as well as a rich source of natural resources, both highlight the great strengths that will enable Malagasy mining move forward. Perhaps, however, the greatest obstacle in the sector is political instability. Due to the current lack of a legal government, international donors have ceased to provide assistance, coastal zone management plans have gone on standby, all development strategies have been postponed and mining investments have declined. Current political instability is, in this respect, a threat to not only coastal mining activity, but to coastal development as a whole.

Agriculture and forestry

Agriculture contributes 27% of GDP, employs 70% of working people and provides 20% of exports. Traditional agriculture makes up between 30% - 60% of total production, whereby, rice is cultivated by 86% of households, accounting for 37% of agriculture cash income. Small business accounts for less than 10% of household income along the coast, thus, over-dependence on natural resources is clearly a problem in the coastal zone. Thirty four percent of the population also lives within 100 km of the coast, which, in conjunction with extensive population growth, places even further strain on the country's coastal resources. Over 9 million hectares of fertile virgin land suitable for cultivation on large scale are unused. Only 3.3 million hectares are cultivated, including 1.1 million hectares of rice. The main agricultural products are paddy, cassava, maize and beans for food crops, coffee, giroffle, litchi, vanilla, cape peas, cocoa for export products, sugar cane, and cotton for industrial crops. The comparison between the census in 1984/1985 and the last census, in 2004/2005, published by the Department of Agricultural Statistics in July 2008, showed an increase of the cultivated areas with 0.9% annual average of growth rate.

Due to the aforementioned over-dependence, the over-exploitation and degradation of coastal resources has inevitably become problematic. Madagascar has lost much of its forests due to illicit logging and agriculture, which has had a serious impact on adjacent ecosystems. It has been estimated that if this trend continues, the country's natural heritage could disappear within the next century. Besides population pressure and lack of alternative income generating activities, weak capacity has also contributed to the degradation of the country's forests. For example, weak regulation has led to the over-exploitation of forests in commercial timber production, while the ability and capacity at the community level to implement sustainable practices remains limited. Similarly, limited information on government planning and management in the sector also suggests that domestic capacity is highly uncertain.

Despite these challenges, numerous strengths and opportunities are apparent in the sector. For example, the country's vast coastal resources and unique species offer great potential, particularly as a means to generate activity in the tourism sector. Similarly, a strong civil society and the presence of NGO's highlight the dedication on the ground to preserving the country's unique landscape, while the promotion of substitute sectors, particularly mariculture, also holds much promise in terms of its ability to generate employment away from more exploitative sectors. Expansion into more intensive agriculture could also be fruitful for both exports and livestock production. Overall, in most cases, there is an emphasis being placed on alternative income generating activities, which holds potential not only in terms of reducing the strain being placed coastal resources, but also in terms of having a broad impact on poverty in the Malagasy coastal zone.

Energy

Oil, gas and biofuel activity is currently minimal in Madagascar, with no data available on the contribution of the sector to GDP. Unconventional oil reserves have been discovered in Bemolanga, estimated at 9.8 billion barrels, and Tsimiroro, estimated at 2 billion barrels, while light oil has also been discovered inland, East of Tulear. There are also prospects for offshore oil fields on the Western and Northern coasts. The first oil exploration was initiated at the beginning of the 20th century, but activities started only in 1976, date of creation of the OMNIS (National Office for Strategic Industries) whose main function is valuing the Malagasy basement. Until 2005, most of the exploration efforts were concentrated in three sedimentary basins of Ambilobe, Majunga and Morondava, an area along and off the coast of the northwest side of the country. However, prospecting has recently been extended through bids in new areas - Tuléar, Fort Dauphin and the basins of the East Coast and the Cape Sainte Marie. Currently, 14 production sharing contracts exist in Madagascar. Contracts for 10 blocks «on-shore» of the Morondava and Tulear area are about to be approved. All the offshore exploration blocks in the Madagascar EEZ are summarized in Figure 23.

While state-owned companies have historically been dominant in the sector, most activities, particularly around oil, have been privatized since 2000. Downstream activity is concentrated in importation, processing, storage and sales, with all refined oil being delivered to Toamasina port. The Toamasina refinery was however, closed in 2004. In 2009, eighteen planned biofuels projects were identified throughout the country, all focusing on jatropha production. Many of these projects were however, cancelled due to the country's political crisis.

Numerous constraints have been identified throughout the energy sector. Political instability has been highly detrimental to activity. Government capacity is also relatively weak, which makes it difficult to enforce law and monitor the EIA process. Poor education and a lack of local employment in the sector have also been highlighted as a challenge, which is particularly relevant considering the high levels of poverty in coastal communities. In-migration of the workforce, a lack of land access for foreign companies in biofuels, as well as a weak private sector and recurrent natural disasters, have all also been identified as serious constraints in the sector.

There are, however, several strengths and opportunities that could be utilized to mitigate some

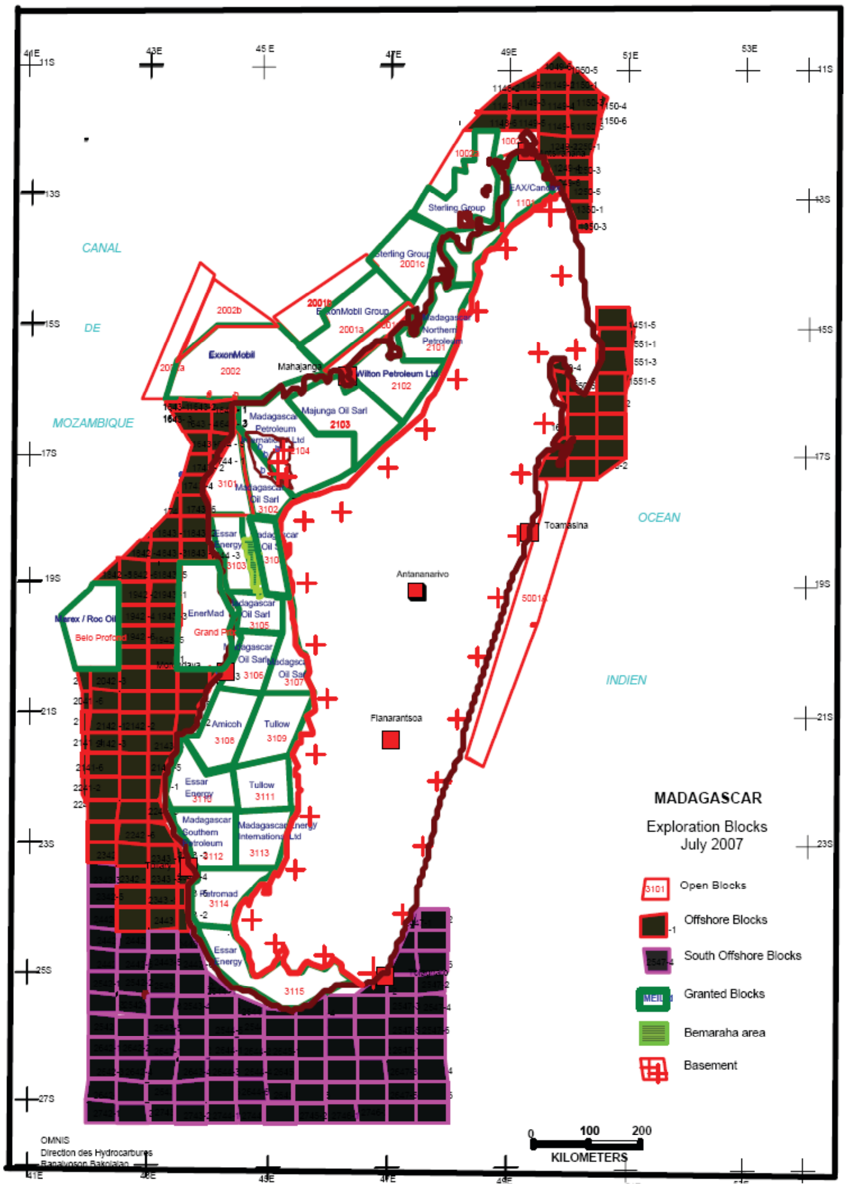


Figure 23: Madagascar oil and gas exploration blocks

of the aforementioned constraints. For example, sparsely inhabited oil fields, as well as strong environmental regulations, are both factors that could alleviate the exposure of coastal communities to spills. The government also continues to monitor attributes of the Dutch Disease which, in conjunction with the country's commitment to the EITI process, should ensure that policy and revenue is well managed in the energy sector. Similarly, despite the difficulties of land access for biofuels investors, the country's extensive land availability should be conducive to the resumption of biofuel activities in the future, while the experience of oil and gas companies in other regions should contribute to enhanced safety and efficiency in the sector. Nevertheless, political instability continues to present major challenges, thus, it is likely that many of these strengths and opportunities will not be realized until stability is re-established.

Conclusions

There are clearly numerous opportunities for sustainable economic development in the Malagasy coastal zone, many of which have the potential to create alternative forms of employment and mitigate the pressures being placed on coastal resources. At the same, there are also many challenges and constraints prevalent in the country, some of which, if left unchecked, could become deleterious to the development process. One clear challenge prevalent across all sectors is the over-exploitation of renewable natural resources and the degradation of the coastal environment. In the small-scale fisheries, for example overfishing of sea cucumber and shellfish and overexploitation in trawling zones have been identified as weaknesses in the sector. Similarly, unsustainable farming practices, juvenile harvesting and the destruction of mangroves have all been documented as threats in mariculture, while illicit logging and tavy agriculture have been highlighted as key practices in facilitating the massive degradation of Malagasy forests. Oil and gas exploration and exploitation as well as industrial coastal mining represent important threats to coastal and marine environment but offer great development opportunities. To mitigate the impacts of these industries, the involvement of local population in terms of jobs opportunities creation, livelihoods improvement is fundamental to contribute to human development in coastal zones. While all these cases appear unrelated, the common explanation for all has been the degree to which impoverished coastal communities are dependent on natural resources for subsistence and employment. Without alternative forms of employment, coastal residents have no other choice but to perpetuate the over-exploitation of their natural resources. This is also why substitute sectors, such as mariculture and eco-tourism, have been heavily emphasized in the report, as they not only have the potential to create alternative streams of income, as seen with prawn farming on the west coast, but they can also reduce the strain being placed on coastal resources.

Weak capacity and infrastructure have also been identified as key constraints across sectors. For example, a lack of capacity to monitor and regulate the small-scale fisheries has, in some cases, facilitated the deleterious practices noted above, while massive post-harvest losses have largely been attributable to weak storage infrastructure. Similarly, extension capacity, as well as a need for improvements in research and development capabilities, has both been highlighted as weaknesses in mariculture activity, while the lack of capacity to effectively monitor the EIA process in the energy sector has been documented as a constraint. Weak capacity at the national and local level has also been identified as problematic in agriculture and forestry, particularly in relation to the regulation of timber production, while a need for modernization in the country's ports has been highlighted as a key factor motivating the government to privatize some of the country's ports.

Despite these constraints, numerous strengths and opportunities are prevalent across sectors, the most obvious being the country's extensive biodiversity and geographical placement. For example, lucrative resources of crab and rock lobster have been highlighted as a huge opportunity for the small-scale fishery moving forward, while numerous candidate species, as well as high quality seawater, highlight the potential for expansion and development in the mariculture sector. Similarly, the country's unique wildlife and vast coastal resources have been identified as key factors through which to develop a strong eco-tourism sector, while the country's strategic geographical position makes it a vital link between the Far East, Africa and Latin America. The country's easy access to a vast expanse of ocean has also been highlighted as a key strength in the ports and coastal transport sector. The country also has untapped oil reserves offshore and onshore, which could be economically fruitful in the future.

The development of the mining sector has also been highlighted as a key opportunity across sectors, particularly in the small-scale fishery and ports and coastal transport sectors. For example, the growth of new consumption centers from mining activity has the potential to increase demand for fishery products, which could allow greater value to be realized from the small-scale fishery. The development of the mining sector has also had a great effect on ports and coastal transport in the country, highlighted by the upgrades facilitated by Rio Tinto in the Ehoala port. Future mining development is also expected to open up similar opportunities for adjacent ports.

The potential for exports is also very promising in some sectors. In the small-scale fishery, international demand for fishery products has the potential to incentivize export development, while the potential for expansion in export crops has been highlighted as strength in the agriculture and forestry sector. Both prawn and seaweed are also currently being produced for export in the mariculture sector, while research and pilot projects are currently ongoing in mud crab, sea cucumber and eel, all of which are being developed for export.
Overall, there are clearly strengths and opportunities apparent that if capitalized on, could facilitate sustainable socioeconomic development in the coastal zone. Capital, particularly for the government does however, remain a constraint, which means a continuation of private-sector activity is required to effectively utilize these strengths and opportunities. Such activity is well underway in both the mariculture and ports and coastal transport sectors, and the development of the mining sector should facilitate similar activity. Political instability, weak capacity and the over-exploitation of natural resources all, however, remain constraints, which has consequences for all socio-economic activity considered in this report. Nevertheless, as this summary and report highlight, these constraints can be mitigated with proper planning, management and policies, which certainly magnifies the potential of the coastal zone in Madagascar.

5. POLICY AND GOVERNANCE

A comprehensive report was prepared on Policy and Governance, which is Annex V to this MEDA. A summary is presented below.

Administrative regions on land

The sustainable development of the coastal zone of Madagascar is guided by integrated coastal zone management (ICZM). The coastal zones of the island includes coastal municipalities and Antsiranana province on the land side whisle the water-side includes the territorial waters (12 nautical miles) and Exclusive Economic Zone (200 nautical miles) (National Action Plan for coastal and marine zones). The main administrative units are shown in Figure 24.

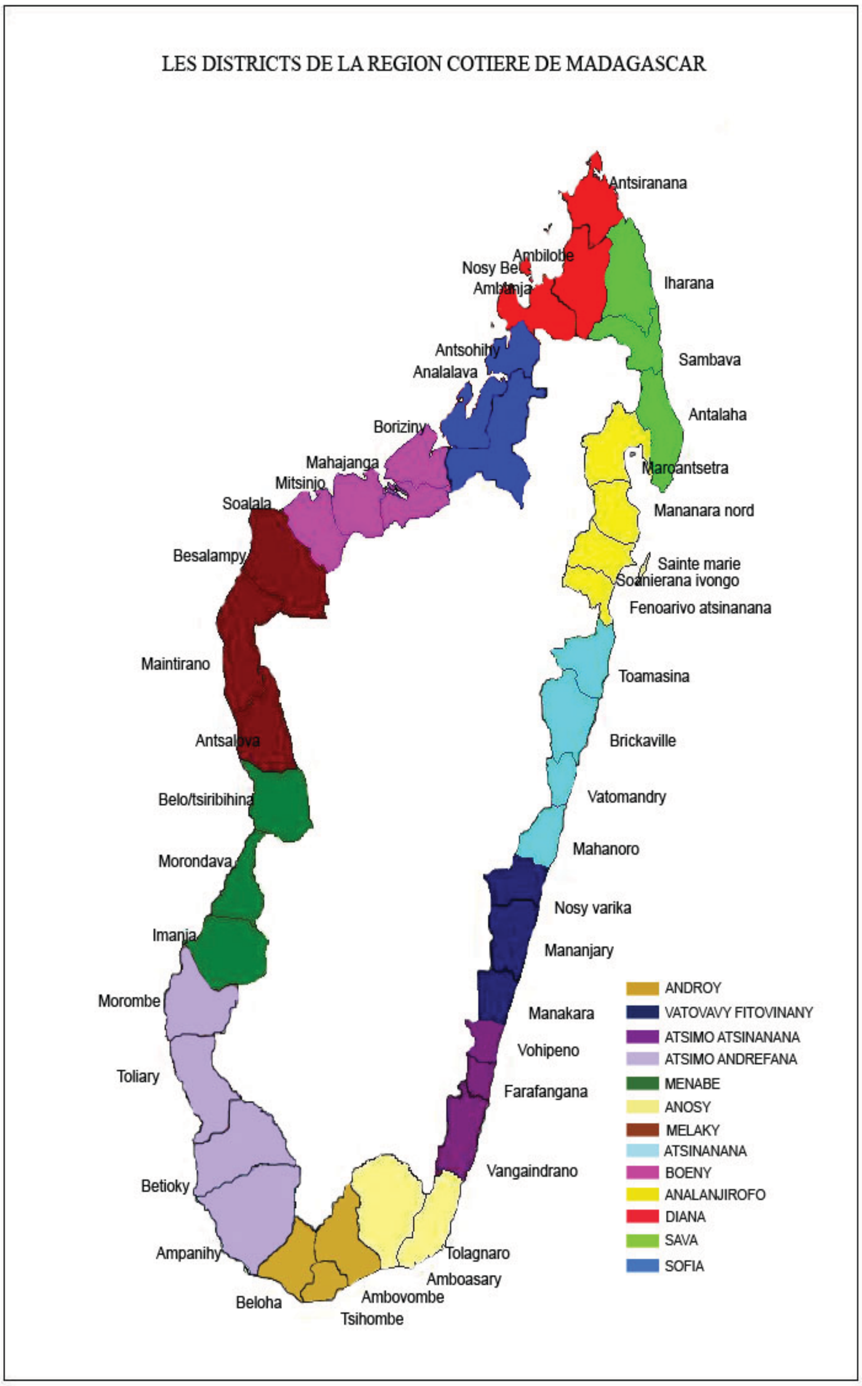


Figure 24: Districts of coastal regions of Madagascar

Administrative/legislative zones of the sea (territorial sea, EEZ)

At an international level, Madagascar is a full member of the International Maritime Organization. Two legal provisions - the code Vagnon and the law of the sea govern the coastal maritime areas. Figure 24 shows the extent of maritime zones in Madagascar.

i) Issues

The issues are administrative boundaries are political, based on land, not water; countries have not necessarily negotiated EEZs and baselines may be inadequate.

ii) Gaps

The main gaps are: data on improving the baseline of Madagascar and scattered islands are still under negotiation; regarding to fishing areas, the limits on scattered islands are not yet official. They only use basis for fishery monitoring and control until resolution of disputes that purpose.

Legislation

i) Issues

The implementation/enforcement of legislation is weak and in some instances legislations are overlapping, creating confusion in their implementation.

ii) Gaps

In spite of the existence of the GIZC's decree, the implementation/enforcement of legislation is a major weakness. This needs to be improved by developing capacity at national level.

Continental shelf extent

The island covers an area of 590,750 km^2 and has a continental shelf of 117,000 km^2. Unevenly distributed in the west and east, the continental shelf of Madagascar has undeniable ecological and economic benefits. A project to establish the outer limits of the continental shelf is being finalized by the Ministry of Mines and Hydrocarbons. The project has been submitted to the United Nations. This extension has many economic advantages for the country. In addition, the recognition of the outer limits provides a legal basis to assert the sovereign rights of Madagascar on marine biological resources.

i) Issues and Gaps

The main issue is failure of Madagascar to submit its continental shelf claims in time. The project of extension was deposited in 2011. The data relating to this request of extension are available at OMNIS.

National, regional and local authorities in coastal/marine affairs

The institutions that play an important role in coastal and maritime affairs are: Ministries of National Defense (in particular navy and police force), Fisheries and fishery Resources, Environment and Forests, Transport and Public Works / Public infrastructure and Economy, Finance and Budget (Customs Directorate) Tourism, Health, "Aménagement du territoire", Mining, Hydrocarbures and Interior. Others include decentralized local authorities: Regions, coastal districts, municipalities and *Fokontany,* the Fisheries Monitoring Centre (FMC), as well as the affiliated institutions and projects.

i) Issues and gaps

The mandates of some institutions charged with responsibility for coastal management are overlapping and in some cases, the mandates are not very clearly defined leading to confusion and rivalry between institutions. There is therefore a need for review of mandates of key institutions and capacity building.

International relations, conventions and committees
Madagascar is party to a number of international conventions as shown in Table 23:

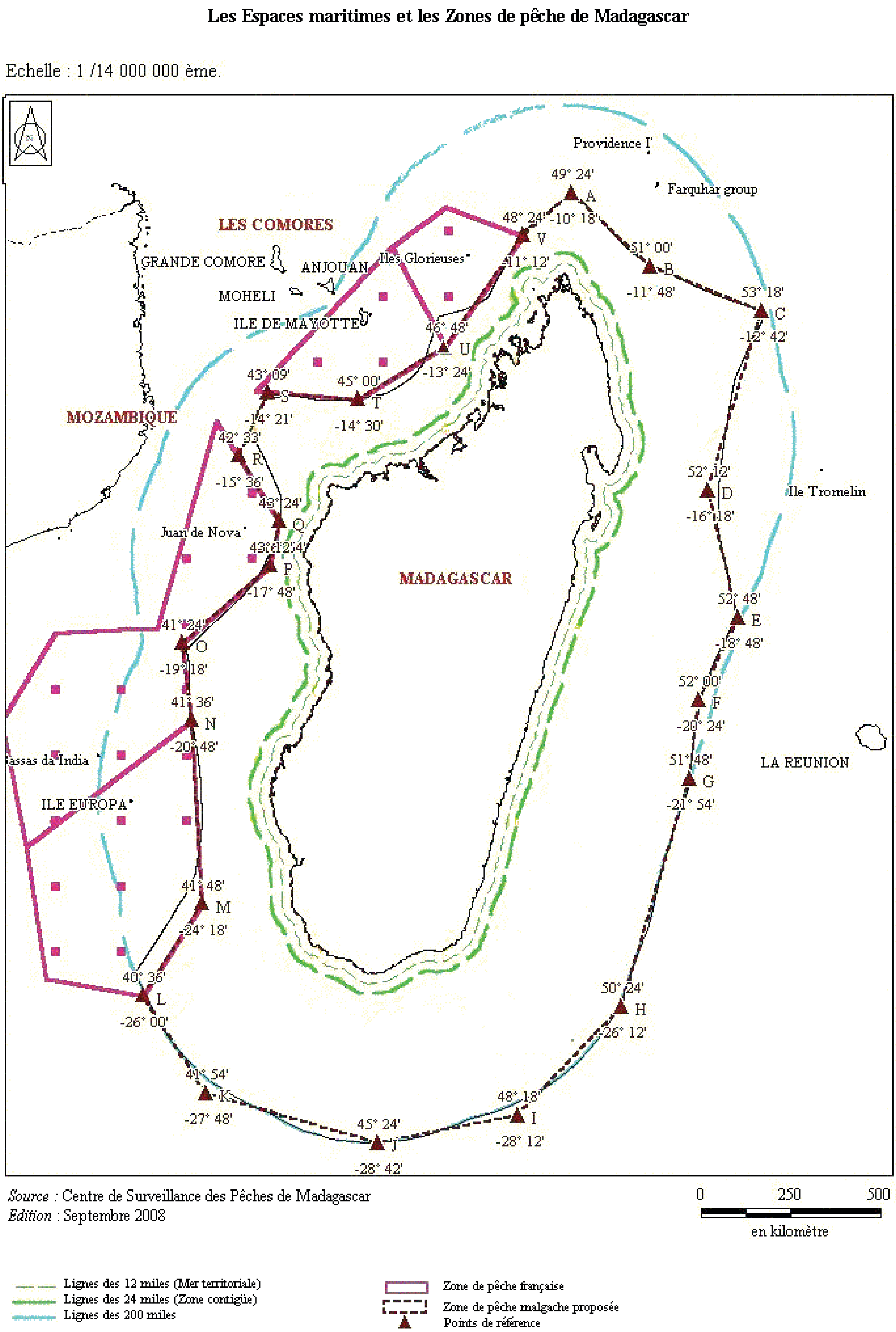


Figure 25: Maritime zones and fishing areas of Madagascar (Source: Centre de surveillance des pêches de Madagascar, 2008). The 59 basic points are in the step of négociation phase

Table 23: International conventions signed by Madagascar

Dates	Cities	DESIGNATIONS	DATE SIGNED	RATIFIED	DATE Implemented
1968	Algiers	African Convention on the Conservation of Nature and Natural Resources	16/09/68	23/06/70	23/10/70 (adoption)
1958	Geneva	Convention on Territorial Waters and Contiguous Zone, on Fishing and Conservation of Biological Resources of High Sea, Continental Shelf, and Agreement on Dispute Mandatory	31/07/62	18/02/63	-
1997	Kyoto	Kyoto Protocol under the United Nations Framework Convention on Climate Change	24/09/03		
1990	London	International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC)		11/09/01	10/08/04
1971	Ramsar	Convention on Wetlands of International Importance especially as Waterfowl Habitat	1978	1978	25/01/99
1985	Vienna	Convention for the Protection of the ozone layer		03/10/93	17/11/94 (adoption)
1989	Bâle	Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal	10/06/92	02/02/99	20/01/99
1979	Bonn	Convention on the Conservation of Migratory Species of Wild Animals	23/06/79		01/11/83
1994	Paris	United Nations Convention to Combat Desertification	1997	04/09/96 and 10/06/97	26/12/96
1992	New York	United Nations Convention on Climate Change	10/06/92	December 98	18/12/98
1987	Montréal	Montreal Protocol on Substances that Deplete the Ozone Layer	1996	02/05/96	-
1994	Abidjan	United Nations Convention to Combat Desertification		04/09/96 and 10/06/97	-
1985	Nairobi	Convention for the Protection, Management and Development of the Marine and Coastal Environment of the Eastern African Region	21/06/85	03/03/98	-
1998	Rotterdam	Convention on Prior Informed Consent (PIC) Procedure for Certain Hazardous Chemicals and Pesticides in International Trade in order to reduce risk of public health and environment on their rational use	08/10/98		-
2002	Rome	International Treaty on Plant Genetic Resources for Food and Agriculture (IT PGRFA)		13/03/06	-
1982	Montego Bay	United Nations Convention on the Law of the Sea (UNCLOS)	25/02/83		-
1992	Rio	Convention on Biological diversity (CBD)	05/06/92	09/08/95	29/12/93
1972	Paris	Convention for the Protection of the World Cultural and Natural Heritage	16/11/72	19/07/83	13/10/83
1993	Catargena	Cartagena Protocol on Biosafety to the Convention on Biological diversity	20/01/00	20/11/03	-
1973	Washington	Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES)	03/03/73	05/08/75	01/07/75

i) Issues and Gaps

The main issues include inadequate domestication of international conventions. In this regard, most of the international conventions and agreements are not effectively implemented in Madagascar. Capacity for domestication of conventions is also weak. In addition, there is lack of an efficient depository of international conventions.

6. PLANNING AND MANAGEMENT

National disaster management

Madagascar experiences various types of disasters such as oil spills, tsunamis, storm surges, floods, droughts, cyclones and coastal pollution. The capacity of addressing these disasters is limited in Madagascar. There are in particular challenges in the coordination of a multitude of agencies that are supposed to provide assistance during critical periods. The excessive centralization of decision making processes had led to a wait-and-see attitude among the local communities which are used to receiving foreign aid.

The law No. 2003-010 on the national policy of risk and disaster management (and its decree application) has established a national system of Risk and Disaster Management (RDM) consisting of some structures that correspond to institutions or coordinating entities at central and local levels. These include the Conseil National de GRC attended by the CPGU (Cellule de Prévention et de Gestion des Urgences), the Bureau National de GRC, Regional, Communal and Local Councils, NGOs and international cooperation agencies. The RDM in Madagascar is under the responsibility of the Bureau National de Gestion des Risques et Catastrophes (BNGRC).

The CPGU is a technical agency within the Prime Minister's Office that is responsible for assisting the Prime Minister and the CNGRC in the development of strategies for dealing with disasters. Moreover, the UN system in 2004 created a 'Thematic Group on Prevention and Disaster Management' which is currently chaired by UNICEF. This group regularly brings together emergencies focal points of different UN agencies. The Office for the Coordination of Humanitarian Affairs (OCHA) is providing support for coordination, preparedness and disaster management at the Resident Coordinator of the UN System and BNGRC offices.

There are also some specialized structures, with different status, acting directly or indirectly in GRC, among others. These include Corps de Protection Civile, attached to the Ministry of Defense, Centre National Anti-Acridien (CNA), Office National pour l'Environnement (ONE), Autorité Nationale De l'Eau et de l'Assainissement (ANDEA), mandatée pour l'exécution de plans d'urgence pour la prévention et la lutte contre les inondations et les sécheresses, Office National de Nutrition (ONN), Comité national de lutte contre la propagation de la grippe aviaire, Organe de Lutte contre les Evénements de Pollution marine (OLEP), attached to the Ministry of Environment.

There are also some units or offices within certain sectoral Ministries, particularly: Office des Travaux d'Urgence (OTU), newly established in the Ministry of Public Works; Direction des Urgences et des Catastrophes of the Ministry of Health; Direction de la Sécurité Alimentaire and Division des Opérations agricoles de secours of the Ministry of Agriculture.

Awareness and communication of plans in place

Recently, Madagascar has just obtained an atlas of disaster risks at the region level to fill the gap in centralized database on disasters. The key sectoral ministries of agriculture, health, transport and education do not have an up to date database on the impacts of disasters. The information available in these departments is generally incomplete and fragmented. Although efforts have been made to analyze risks and vulnerabilities, the country still lacks detailed risk maps that can be used for land development programme. Overall, it can be argued that the lack of basic information on risk analysis, mapping and identification of technical solutions to specific risks, harms the development of a risk prevention plan and the mainstreaming of disaster risk reduction into development processes.

When a disaster occurs, communication is usually made through radio, television and print media. Communication is coordinated by the Ministry of Interior and BNGRC. In affected zones, lack of means of communication (local radio, local television, transport) and the inadequate capacity of decision-making are among the major causes of poor dissemination of information. Nevertheless, the UNDP has supported Madagascar since 1997, in the establishment and implementation of an integrated information system on food security and disaster risk management.

Implementation of the disaster management plans

With limited resources, the BNGRC has promoted and established committees across the country. Unfortunately, lack of financial and organizational resources has inhibited monitoring and transfer of capacity to local collectivities, thus limiting the consolidation of operational network of committees throughout the country. Moreover, NGOs are involved at different levels in the establishment and strengthening of committees at the lowest territorial level.

During cyclones, the implementation plans are disrupted because the responsible people in the affected areas work as volunteers. They have their own activities and are not prepared in advance to deal with cyclone disasters. Also, during critical periods, their relatives and their assets are their top priority.

The CPGU, through integration of climate risk and disaster management in the economic development of Madagascar, is developing series of activities focusing on prevention and reconstruction in order to reduce the disaster risks. These measures aim at reducing the magnitudes of damages and losses caused by natural disasters. These activities include: 1) strengthening risk assessment, 2) risk mitigation through the adoption of anticyclone standards, 3) establishment of a contingency fund and a mechanism of risk financing and development of an early warning system and 4) national plan for risk management.

In addition, currently, the World Bank is carring out a study about the modélisation of the impacts of the Climate change integrating économic aspects. At administrative level, a decree about relating with standards of para cyclonic construction is adopted.

Contingency plans

In terms of reducing overall risk and vulnerability, progress is limited. Indeed, the actions developed by the CNS and its partners are focused almost exclusively in preparedness and disaster response. Although efforts have been made to take account of the GRC in the Strategy for Poverty Reduction and the Madagascar Action Plan (MAP), this does not happen in the form of mainstreaming and effective integration. No intervention has been developed to change the structural conditions of existing risks. Indeed, the institutional framework remains fragmented and lacks capacity for systemic and comprehensive management of risks.

Madagascar has a Contingency Plan for Natural Disasters. The first contingency plan was prepared in accordance with the commitments highlighted in the Madagascar Action Plan (MAP) 2007-2012 and based on lessons learnt from the 2006-2007 cyclone seasons. This plan, entitled "Contingency Plan of the Permanent Committee and the Government" is useful as a reference tool during cyclonic season. The preparedness, assessments and responses were coordinated by the BNGRC with the support of the CRIC (Committee of Reflection of Stakeholders in Disaster) and OCHA. The preparation was undertaken through several sectoral groups: Water and Sanitation, Nutrition and Food Safety, Health, Agriculture, Education, and Logistics and Habitat. This plan does not consider tsunamis and is annually prepared by the Malagasy State with the support of the United Nations Systems.

ALERT network for tsunami early warning

The Institut et observatoire géophysique d'Antananarivo (IOGA) noted that Madagascar is well within reach of waves from tectonic events occurring along the Sumatra fault, but the island is protected by a band of coral reefs. The threats to Madagascar were nevertheless considered since 2005 and in 2008. A project funded by the UNDP and UN-ISDR (United Nations-International Strategy for Disaster Reduction) aimed at establishing a tsunami warning system has been launched. This project led by BNGRC has regional scale covering the entire Indian Ocean zone.

ii) Gaps

The main gaps include lack of good hydrodynamic models for monitoring oil spill movement, tsunami run-up, storm surges, etc. Inundation maps are lacking.

Environmental sensitivity mapping

Madagascar faces many problems due to the degradation and loss of natural resources due to overexploitation. The main areas of concern are coastal erosion, loss of vegetation cover and high population growth. There is no specialized institution that is responsible for environmental sensitivity mapping. Different agencies develop their own tools using different data. There is also a lack of capacity for the interpretation and development of sensitivity maps. The use of sensitivity maps is also not considered a national priority. The capacity for the development of sensitivity maps is usually found in private institutions (offices, international organizations and NGOs in particular) working in the environmental field. A reef vulnerability-map is available at WWF and Mangrove's vulnerability map at WCS. Currently, blocs petrolier and mining exploitation maps which have an important interaction with the vulneabilty of the marine ecosystem are available.

Coastal management/ development plans
Mitigation of sea level change

Madagascar is vulnerable to sea level rise. The country is party to the United Nations Framework Convention on Climate Change that became effective on March 21st, 1994. The country is also a member of IOC of UNESCO and has participated in the IOC's regional project on adaptation to climate change (2008-2011). The project aimed at establishing regional cooperation on adaptation to climate change. Madagascar has also prepared its National Action Plan for Adaptation to Climate Change (NAPA). In the same way, Madagascar involves at ISLAND/COI project which aims the implementation of the Mauritius Strategy including "Assurance Risque aux aléas climatiques"

Spatial development plans
The Ministry in charge of the territory management is responsible for preparation of spatial plans in Madagascar. It has initiated the development of the National Policy on land settlement with the support of the UNDP. Currently, the elaboration of the national policy on land settlement includes learning phase and capacity building.

Integrated development planning
Since 2001, the rate of Malagasy economic growth has been about 4% per annum. But this growth is being confronted by multiple challenges. The majority of the population lives on subsistence agriculture that is dependent on good climatic conditions and fertile soils. The government of Madagascar has established a National Development Plan that aims at developing the country's natural resources, increasing agricultural production, and promoting rural and urban development. The plan is expected to lead to considerable improvement of economic and social conditions in the country. At regional level, the country produces Regional Development Plans and at municipality level - Communal Development Plans are prepared for specific municipal areas. UNDP has supported the Ministry of Interior in preparing its Annual Action Plan that aims at integrating risk and vulnerability management in national economic planning and development.

Environmental management plans
Since 1990, three 5 year Environmental Programmes were implemented in Madagascar. Forty-six protected areas are managed by Within the Protected Area Network managed by the Madagascar National Parks, through the Code des Aires Protégées (COAP): a new law COAP is on standby for adoption (2011). The marine and coastal component of the National Program of Environmental Action was implemented by the ONE and SAGE (Service d'appui à la gestion de l'environnement), with financial and technical assistance from many donors and NGOs. At the end of the third and final phase of the Environmental Programme, the country intends to develop a Sector Programme of Environmental Management. In addition, there is the Malagasy Maritime Code that aims at protecting and preserving the marine environment against marine pollution.

Coastal management plans
The Integrated Coastal Zone Management (ICZM) is a requiredment under the Malagasy Environment Charter (Law No. 90-033 of December 21, 1990 with its amendments). Madagascar has also ratified international conventions that are relevant to ICZM such as the Framework Convention on Climate Change, UN Convention on the Law of the Sea, the Nairobi Convention on the management and development of marine and coastal environment, among others. In addition, the Malagasy Maritime Code also provides protection and littoral management measures.

In 2001, a guidance document for the formulation of sustainable development of coastal areas policy in

Madagascar was published. The policy of sustainable development of coastal and marine zones in Madagascar aims at promoting integrated management of coastal zones. Eventually, this process should lead to national, regional and local plans on integrated management of coastal and marine zones of Madagascar. The National Action Plan of coastal areas is the basis for the implementation of the policy on sustainable development of coastal and marine areas of Madagascar. Since 2009, the ICZM National Committee was institutionalized by law 2173. Currently, the national Strategy is focused on the preparation for the implementation of the ICZM policy.

In 2009 and 2010, the ICZM national Committee (CNGIZC) updated the basic documents for a sustainable development of the coastal and marines zone envisaged by the "livre blanc". Therefore, Madagascar has got a National Policy, a National Strategy, and a National Action Plan. In addition, the ICZM is regulated by the decree n°2010-137 and the first National Programme of ICZM based on the ICZM National Action Plan (PANGIZC) was started for 2011 -2015.

Wastewater management plan

Currently, only 5% of wastewater from domestic and industrial sources is treated or recycled in Madagascar. Law No. 98-029 of January 20, 1999 on Water Code (J.O. n° 2557 E.S. of 27.01.99) governs the water sanitation problem. The texts relating to sanitation and waste treatment are numerous and are in fact included in many other sectoral laws (health, land use, environment, and industry) coordinated by various ministries. The Ministry of Water has been assigned the role of bringing together the various supervisory authorities and ministries in order to optimize the development of the sector. The Ministry of Water has also developed the National Sanitation Policy and Strategy. Furthermore, Madagascar anticipates, in its Maritime Code, marine environment protection measures against pollution from different sources. In the Maritime Code, it is stipulated that urban planners must respect the opinions of municipalities and Ministry of the Environment services must assess the environmental impacts of development.

At regional level, Madagascar participated in the implementation of UNEP-GEF Project "Addressing land-based activities and sources of pollution in the Western Indian Ocean". The project was implemented in the period 2004-2010. Its major outputs include the Transboundary Diagnostic Analysis (TDA) and the Strategic Action Plan (SAP) for addressing land based sources of pollution of marine environment.

i) Issues

A Régional ICZM Comittee was implemented to avoid the lack of coordination between agencies. The various Malagasy institutions are involved in coastal management and most have certainly taken actions that are more or less appropriate for addressing the degradation of the coastal zones. However, these interventions are generally occasional, isolated and mainly sectoral.

Rapid coastal population growth: The low level of economic growth compared to the relatively high population growth inhibits the success in consolidating the process of economic growth and this has resulted in an increase in poverty levels in the country. The current high rates of population growth impose a huge burden on the islands resources and its social and environmental services. Although the major cities of Madagascar have Town Planning Guidelines, these do not sufficiently consider the population growth and expansion due to rural-urban migration.

ii) Gaps

There is no operational and formal specific tool in Madagascar for integrated management of the littoral zones. The country lacks capacity (limited human, financial and material resources) for championing sustainable development. The ICZM National committee is still ineffective and its actions are very limited.

Areas under special management

The management of protected areas in Madagascar is governed by Malagasy Code of Protected Areas Management and its implementing regulations. Three formal MPAs exist in Madagascar under the management of Madagascar National Park. Current initiatives are integrated into the System of Protected Areas of Madagascar (SPAM) through the interministerial "arrêté" n° 52005/2010 about temporary protection statut. Ten sites for creation of additional MPAs have been identified according to criteria established by the

Committee on Environment and Fishery.

Madagascar has a system involving local communities in coastal natural resources management through its GELOSE governed by law 96-025. Fifty two (52) transfers of management were officially carried out for marine and coastal resources and four (4) contracts of Community Management of Forests focused on the mangroves have been established. In addition, several projects related to conservation and protection of coastal and marine resources are also implemented with the support of the World Wildlife Fund, Madagascar National Parks, PACP program funded by the African Development Bank, Fanamby and Wildlife Conservation Society (WCS).

i) Issues

Conflict between users
Conventional methods of marine and coastal ecosystems management have failed in Madagascar. The authorities have extended the reserves into areas where local people have been evicted. This has forced Malagasy people to perpetuate destructive resource exploitation practices. The model of "protected areas" has also caused many conflicts between parks and local population. In most cases, these methods do not provide a compromise between the needs of conservation and those of the people. Also, the use of land reserves for tourism are in conflict with oil exploration and mining.

Lack of participation in planning process
During the second phase of the Environmental Program the regions of Toliara and Nosy Be were chosen by the Belgian Marine and Coastal Environment (EMC) project as pilot areas. The design and implementation of development plans followed a participatory approach but the mechanism was not followed by appropriate measures in its application throughout the country. Conservation efforts are thus being undertaken without proper consultation of local communities and stakeholders.

Lack of tangible benefits of managed areas
The lack of tangible benefits for local communities from conservation activities ultimately affects the long-term success of these activities. Without appropriate models for community integration into conservation initiatives and sharing of benefits, local support for conservation projects is unlikely.

Conflicts over increasing area under protection
The problems related to lack of awareness and poverty make the setting up of marine protected areas difficult in Madagascar. The low level of knowledge and lack of livelihood alternatives accentuate the dependence on the fishing areas. Indeed, to address the problem of high levels of poverty, the strategy adopted by the population is either to extend the fishing areas, or intensify fishing effort, or violate any laws with consequences on ecosystem integrity and performance. This matter is made worse by rapidly expanding population in coastal areas.

ii) Gaps
The MPA network is still low and insufficiently representative of the most important marine habitats (coral reefs, mangroves, seagrass beds - particularly in the west coast). The current MPA network does not cover all the "hotspots" of marine biodiversity. Many MPAs are managed in a participatory way with local communities, particularly in the context of GELOSE. Half of entrance fees in protected areas are used to finance local micro-projects. However, the level of tourism remains low and this limits the development of the benefit sharing mechanisms.

Monitoring, Control, Surveillance
Madagascar has nearly 5,603 km of coastline and more than one million km^2 of areas under its jurisdiction includes strategic shipping lanes. The country undoubtedly has a huge potential for development opportunities focused on the sea. In 2008, the government gave priority to the development of State Action at Sea concept. The ratification of the United Nations Convention on the Law of the Sea in 2000, clearly shows the country's commitment in ensuring it has jurisdiction on its EEZ. Besides the Naval Forces, Madagascar now has six other agencies that operate in the framework of the State Action at Sea, depending on their specific capabilities: the Gendarmerie Nationale, the Centre for Fishery Monitoring of (CSP), the Autorité Portuaire

Maritime et Fluviale (APMF), the Organe de Lutte contre l'Evénement de Pollution marine par hydrocarbures (OLEP), the Administration des Douanes et Sécurité civile. The FN and CSP have capacity to operate in high seas The Centre also has trained and specialized staff to carry out surveillance and control activities. It currently has two offshore surveillance ships named Atsantsa and Tendromaso; one support ship for fast units (*Telonify*), seven rapid response units, satellite monitoring equipment (Vessels Monitoring System in conjunction with IMARSAT and ARGOS). While communications were recently established between these different agencies, their actions are still not yet coordinated by a single authority. This brings in the issue of lack of coordination in monitoring, control and surveillance.

The Fishery Monitoring Centre of Madagascar was created in April 1999 by Decree No. 4113/99 of 23 April 1999. For rational and sustainable exploitation purposes, this centre has to protect and preserve fishery and aquaculture resources through its monitoring, control and surveillance activities. Monitoring of fishing effort concerns the traditional, artisanal and industrial sectors. Control of fishing activities is carried out throughout the country. Monitoring ensures compliance with laws and regulations by all ships operating in Malagasy waters and by all economic sectors, particularly those of fishery and aquaculture.
ii) Gaps
Madagascar with 1.14 million km^2 of maritime territory has considerable assets that can make it a maritime power. These include oceanographic research organizations, ship-owners, shipbuilders, and the national navy. The sea affairs governance must however be enhanced. In order to achieve this, a mechanism for coordinating all matters related to sea must be established, in order to improve efficiency and consistency of the State power.

7. COST-BENEFIT ANALYSIS

Madagascar is the poorest island state within the ASCLME region: the life expectancy for Malagasy is 59, the GNI per capita is 410 US$, and the HDI for Madagascar is 0.543. The half (55%) of the 19 million inhabitants are in coastal zones. (Earth Trends, 2003)

Economic valuation of provisioning services

a) Food production

Fisheries in Madagascar have three components: inshore fisheries, mariculture, and offshore fisheries. Inshore fisheries are undertaken within the territorial sea by local fisherman, in a traditional or artisanal way. Mariculture is undertaken by industrial units, aiming a high quality added value. Offshore fisheries are undertaken by international seiners or longliners within the economical exclusive zone.

The total production of artisanal and traditional fisheries is 72,422 tons/yr and the mariculture production is 6,994.2 tons/yr. For offshore fisheries, the total intake is about 22,885.4 tons (Andrianaivojaona, 2010).

The fisheries contribution to GDP is 7% and the Malagasy GDP is 5,410Mus$. The annual gross income from fisheries is 378.7Mus$. It is estimated that direct employment for the sector is 62,000, and indirect employment is 194,000. Then a total of 256,000 people depend on fisheries sector. Annual salary for employees is 500 us$ per person, and the annual cost of salaries for all the people depending to the sector is 128Mus$. It is assumed that operating costs are at 10% of gross income (Andrianaivojaona, 2010).

Given these parameters, the annual net value for the fisheries sector is 212.83Mus$ and the net present value for a thirty-year period, with a 3% discount rate is 4,171.56Mus$.

b) Raw materials

As for Comoros, we will use benefit transfer for the valuation of raw material extraction from mangroves, with reference to the Costanza value (162 us$/ha/yr). The transfer rate is 0.04 and the Malagasy mangrove area is 3,097 km2.So, the annual benefit from raw material extraction is 2.08Mus$ and the net present value for a thirty year period with a 3% discount rate is 40.83Mus$.

c) Ornamental resources

Benefit transfer will be used for this valuation, referring to Sukhdev (2009). The standard value is 264 us$/ha/yr, and the benefit transfer rate is 0.04. Madagascar has a 2,230 km2 area of coral reefs. Based on these data, the annual benefit from ornamental resources harvesting is 2.44Mus$, and the net present value for a thirty year period, with a 3% discount rate is 47.91Mus$.

d) Total economic value of provisioning services

The sum of economic value for ornamental resources, raw materials, and food production is the total economic value for provisioning services. Its value is about 4,260.30 Mus$.

Economic valuation of regulation services

a) Shoreline protection

For shoreline protection valuation, we will use the Cesar's values as reference for benefit transfer. The benefit transfer rate is 0.04 and is assumed that agricultural use of coast is from10% to 30%, and the human settlement use is from 20% to 30%. The length of Malagasy coral reefs is 2,700 km. Based on these data, the benefit value for agriculture protection is from 0.045 to 0.135Mus$, and the benefit value for settlement protection is from 5.51 to 8.26Mus$. Then the total value for shoreline protection is from 5.55 to 8.40Mus$.

b) Disturbance regulation

For disturbance regulation, we will refer to Costanza's value for benefit reference (1,839 us$/yr/ha) and the transfer rate is 0.04. The mangrove area for Madagascar is 3,097 km2. Based on these data, the value of annual benefit for disturbance regulation is about 23.65Mus$ and the net present value for thirty years at 3% discount rate is about 463.48Mus$.

c) Climate regulation
Two ecosystems produce climate regulation services: coral reefs and mangroves. As for Comoros, benefits from coral reefs regulation will be estimated based on benefit transfer method and benefits from mangroves regulation by market prices.

Climate regulation by coral reefs have a 648 us$/ha/yr value (Sukhdev, 2009). This value may be transferred without adjustment, given the nature of benefit. Madagascar has a 2,230 km2 area of coral reefs. So the total amount of annual benefits for climate regulation is 144.5Mus$, and the net present value for a thirty year period at 3% of discount rate is about 2,772.81Mus$.

For carbon sequestration by avoided mangrove deforestation, it is assumed that the loss of 309.7 km2 of mangroves is avoided, and the biomass rate is 292.8 t/ha. The total volume of not emitted CO2 is 16.625 MteCO2. The market price is 10us$/teCO2, and the cost for avoided deforestation is 2.51 us$/teCO2. Based on these data, the net value for climate regulation by mangroves (carbon sequestration) is 124.52Mus$.

d) Total economic value of regulation services
The total economic value of regulation services is the sum of the three previous services: shoreline protection, disturbance regulation, and climate regulation. The total amount of this service is from 3,366.36 to 3,369.21 Mus$

Economic valuation of cultural services

The economic value of cultural services is estimated through the tourism sector. The mean arrivals for last five years is 282,100 and the contribution of tourism sector for GDP is 3.7%. The Malagasy GDP is 5,410 Mus$, so this sector contribution is 200,17Mus$. In the other hand, the total number of employees in the sector is 27,300, and the annual salary is 500 us$ per person. It is assumed that other operating costs are at 30% of gross income (Rajeriarison & Picard, 2010).

Based on these parameters, the net annual value is 126.47 Mus$, and the net present value for a thirty years period and at 3% discount rate is 2,478.85 Mus$

Economic valuation of supporting services

a) Maintenance of genetic diversity
This is a global service produced by coral reefs, so we can use benefit transfer without adjustment (13,541us$/ha/yr, Sukhdev). Madagascar has a 2,230 km2 coral reefs area, so the annual benefit value is about 3,019.64Mus$. The net present value for thirty years at 3% discount rate is 57,942.22Mus$.

b) Nutrient cycling
Nutrient cycling by oceans is another global service. The reference value is Costanza's (118 us$/ha/yr). Madagascar has 124,900 km2 of territorial sea. Consequently, the annual value for nutrient cycling service is about 1,473.82 Mus$, and the net present value for a thirty year period at 3% discount rate is 28,887.52 Mus$.

c) Total economic value for supporting services
The sum of the economic value of the two former services is the supporting services value. This value is about 86,829.81 Mus$.

Total economic value

The table below gives an overview of all ecosystem services value for Madagascar. The total economic value of these services is estimated from 96,935.36 to 96,938 Mus$.

Table 24: An overview of all ecosystem services value for Madagascar

	Direct use value (Mus$)	Indirect use value (Mus$)	Total (Mus$)
Provisioning services	Food production: 4,172 Raw material production: 41 Ornamental resources: 48		4,260
Regulating services		Climate regulation: 2,897 Disturbance regulation: 463 Shoreline protection: 6-8	3,366-3,369
Cultural services	Tourism & recreation: 2,479		2,479
Supporting services		Nutrient cycling: 28,888 Maintenance of genetic diversity: 57,942	86,830
Total	6,739	90,196-90,199	96,935-96,938

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