ASSESSING THE IMPACTS OF CLIMATE CHANGE ON MADAGASCAR'S BIODIVERSITY AND LIVELIHOODS

A WORKSHOP REPORT

MEEFT

CONSERVATION INTERNATIONAL

WWF

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List of Organizations and Acronyms

ANGAP	Association Nationale pour la Gestion des Aires Protégées (National Association for Protected Areas)
ARVAM	Agence pour la Recherche et la Valorisation Marine
CDM	Clean Development Mechanism (Kyoto Protocol)
Centre ValBio	Centre de Formation International pour la Valorisation de la Biodiversité
CEP	Commission for Environment and Fisheries
CI	Conservation International
CIREEF	Regional Forestry and Environmental Service
COP-13	Bali Conference of the Parties to the UN Convention on Climate Change
CORDIO	Coastal Oceans Research and Development in Indian Ocean
CSAG	Climate Systems Analysis Group
CSP	Centre de Contrôle et de Surveillance des Pêches (Center for Control and Surveillance of Fisheries)
DGDR	Direction Générale pour le Développement Rural
DPRH	Direction de la Pêche et des Ressources Halieutiques (Direction of Fisheries and Marine Resources)
DRDR	Direction Régionale pour le Développement Rural (Regional Direction for Rural Development)
ERE	Éducation Relative a l'Environnement
FID	Fonds d'Investissement et de Développement (Investment and Development Funds)
FFEM	Fonds Français pour l'Environnement Mondiale
GDRN	Gestion Durable des Ressources Naturelles
ICZ	Integrated Coastal Management
GCM	Global Climate Model
GOM	Government of Madagascar
GRT	Grand Recif de Tulear
GTZ	German Development Agency
ICDP	Integrated Development and Conservation Projects
IHSM	Institut Halieutique et des Sciences Marines (Marine Science and Resources Institute)
INSTAT	Institut National de la Statistique (National Institute for Statistic)
IPCC	Intergovernmental Panel on Climate Change
IRD	Institut de Recherche Développement
IRG	International Resources Group
IRRI	International Rice Research Institute
IUCN	International Union for Conservation of Nature
LODH	Lombard Odier Darier Hentsch and Cie
MAEP	Ministère de l'Agriculture, de l'Elevage et de la Pêche (Ministry of Agriculture, Livestock and Fisheries)
MAP	Madagascar Action Plan

MBG	Missouri Botanical Gardens
MEEFT	Ministry of Environment, Water, Forest, and Tourism
MPA	Marine Protected Area
PA	Protected Area
PACP	Fisheries Communities Support Project
PANA	Programmes d'Action Nationaux d'Adaptation (National Adaptation Program of Action of Madagascar)
PCD	Plan Communal de Développement
PES	Payments for Ecosystem Services
NEAP III	Third Phase of the Madagascar National Environmental Program
PNM-ANGAP	Madagascar Association for the Management of Protected Areas
PSDR	Projet de Soutien pour le Développement Rural (Rural Development Project Support)
ReBioMa	Réseau de la Biodiversité de Madagascar
REDD	Reduction in Emissions from Degradation and Deforestation
SAEON	South African Environmental Observation Network
SAGE	Service d'Appui pour la Gestion de l'Environnement (Support Service for Environment Management)
SAPM	Système d'Aires Protégées de Madagascar (System of Protected Areas of Madagascar)
SPRH	Service de la Pêche et des Ressources Halieutiques (Fisheries and Marine Resources Service)
UC-Berkeley	University of California at Berkeley
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USAID-EGAT	United States Agency for International Development - Climate Change team within the Office of Economic Growth, Agriculture and Trade
WB	World Bank
WCRP	World Climate Research Programme
WCS	Wildlife Conservation Society
WWF	World Wide Fund for Nature

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Executive Summary

The Government of Madagascar (GOM), Conservation International (CI), Worldwide Fund for Nature (WWF) and United States Agency for International Development (USAID), with support from the John D. and Catherine T. MacArthur Foundation and in collaboration with several partner institutions, jointly convened a three-day workshop**, Assessing the Impacts of Climate Change on Madagascar's Biodiversity and Livelihoods,** in Antananarivo, Madagascar, from January 28 – 31, 2008. The workshop brought together over 130 experts from more than 50 national, regional and international organizations across a wide spectrum of expertise. The Ministry of Environment, Water, Forests and Tourism (MEEFT) of Madagascar hosted the workshop. Opening remarks were given by the Minister of Environment, Water, Forests and Tourism, the US Ambassador to Madagascar, and the President of Conservation International. The aim of this meeting was to evaluate the risks that climate change poses to ecosystems, marine and terrestrial biodiversity, and human livelihoods in Madagascar. Its objective was also to recommend strategies to address these threats and build resiliency in natural and human systems to cope with climate change.

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, "there is unequivocal evidence that the climate is warming as evident from increases in global average air and ocean temperatures, melting snow and ice caps, and rising global average sea levels" (IPCC 2007a). To date, most of the discussion about climate change has focused on the need to stabilize the climate by reducing greenhouse gas emissions. Reducing emissions and preventing further climate change is essential; however, scientists also recognize that some temperature change is unavoidable. We must now develop strategies to cope with the impacts of climate change.

All countries will need to adapt to the impacts of changing climate in the short and medium term, but many countries in Africa, including Madagascar, are particularly vulnerable. Human well-being, functioning ecosystems and climate change are interlinked; conserving biodiversity can moderate the impacts of climate change on human communities by maintaining ecosystem functions and services. People depend upon nature for livelihoods, so biodiversity provides insurance under climate stress. As biodiversity declines, so does the resilience of ecosystems and the services they provide to humanity. Furthermore, climate change is causing a shift in human resource use patterns, and it is increasingly important to take this into account in conservation planning. Addressing human needs in sustainable ways may help mitigate climate change and reduce the vulnerability of ecosystems to its effects.

Thus, the workshop's objective was to provide a forum for policy-makers and experts from various disciplines - climate science, oceanography, marine and terrestrial ecology, conservation, and rural development - to examine the threats to livelihoods and marine and terrestrial biodiversity in Madagascar, one of the world's most biologically rich countries, and to generate recommendations for building resilience and adapting to the likely impacts of climate change.

Next steps include conducting studies to assess the feasibility of implementing workshop recommendations and filling key information gaps.

The outcomes of this workshop include:

- Provision of the best available future climate and oceanographic scenarios for Madagascar and implications for changes in species (terrestrial and marine) distribution and their population and habitat shifts.
- Development of recommendations for adapting to the impacts of climate change for the benefit of conservation, protected areas planning, and human livelihoods.
- Generation of information on climate change threats to human communities and identification of appropriate adaptation measures.

Summary Recommendations

A. Technical Recommendations

Participants identified ecological protection and restoration, integrated coastal zone management, and management of use at the watershed scales as important actions to build ecosystem resiliency in the face of climate change. Experts identified riverine forests as important areas to focus restoration and protection efforts because of the potential role of these forests as corridors to allow species to track their climate envelopes and for their potential role in acting as refugia. Sustainable forest management needs to be strongly promoted to maintain habitat for biodiversity and to provide refugia to ensure the availability of necessary habitat in the future. Workshop participants recommended focusing on the protection and sustainable management of forest corridors to maintain adequate habitat connectivity and migration corridors for vulnerable species within the protected areas network.

Participants recommended reinforcing the marine and terrestrial protected areas planning processes by integrating climate change impact considerations into these conservation instruments. Workshop participants recommended strengthening national policies and institutions for Marine Protected Area (MPA) selection, establishment, and management by including climate change criteria for prioritization of key sites. Participants recommended creating networks of marine protected areas along the length of Madagascar's coastline to include multiples of all marine and coastal habitats from coastal vegetation to the continental shelf and deep sea habitats, allowing species to shift to cooler waters as ocean warming progresses.

In order to inform conservation and development planning under climate change, there is an urgent need to have adequate climate monitoring data on key variables. Participants recommended that the GOM with partner institutions and non-governmental organizations prioritize the implementation of a long-term monitoring program with a network of marine, terrestrial and freshwater sites, distributed across latitudinal gradients cutting across the projected gradients of change. This will enable systematic and standardized collection of quantitative data on taxonomic groups, water quality, and habitat quality, socioeconomic, oceanographic and climatic variables, with data made available freely.

Participants recommended greater recognition of the links between human well-being, biodiversity and access to natural resources. They highlighted a critical need to promote land tenure regulation in regions around high biodiversity areas. In recognition of the clear synergies that exist between ecosystem functions, terrestrial and marine biodiversity, and human well-being, actions are needed to enhance resiliency and adaptation across all spatial scales and livelihood sectors. Ecologically sensitive agricultural intensification and diversification were suggested as options for safeguarding human livelihoods in the face of climate change, minimizing impacts on biodiversity. Participants recommended enhanced support for risk assessments, improving our understanding of ongoing community-based initiatives aimed at reducing vulnerability and adapting to climate change, and identifying potential triggers and pathways for human migration caused by climate stress. Promotion of environmentally-sound energy sources and more climate resilient infrastructure were amongst other measures suggested to facilitate rural adaptation to climate change.

B. Policy Recommendations

The workshop participants recommended four main policy actions related to governmental response to climate change. The first is the establishment of an inter-ministerial task force on climate change to facilitate environmentally sound adaptation measures across sectors. This body would be responsible for facilitating the integration of ecologically sensitive adaptation measures across diverse sectors such as mining, oil and gas, tourism, agriculture and fisheries within the Madagascar Action Plan (MAP) – a strategy document developed by the Government of Madagascar to guide development planning in the country and within regional action plans. Second, participants suggested the re-examination and review of Madagascar's Programmes d'Action Nationaux d'Adaptation (PANA) to allow for the integration of data and recommendations emerging from this workshop. Third, the gathered experts highlighted the need to develop a rural development policy around areas most vulnerable to climate change, for which one avenue is updating the Rural Development Policy Letter to integrate workshop recommendations. Finally, participants recommended the development and dissemination of methods of information–education–sensitization on climate change across all levels and sectors.

Workshop participants recommended policy and decision makers and practitioners to take advantage of various financing mechanisms such as the Clean Development Mechanism under the Kyoto Protocol and the United Nations' Adaptation Fund to finance ecologically sensitive adaptation activities on the island, which was established as one of the outcomes of the United Nations Framework Convention on Climate Change meeting held in December 2007 in Bali, Indonesia (COP-13). The Adaptation Fund is intended to finance concrete adaptation projects and programs in developing countries that are Parties to the Kyoto Protocol. In addition, payments for ecosystem services (PES) schemes present a potential source of funding to help better manage watersheds to secure hydrological services. PES schemes are in early stages in Madagascar, and their associated opportunities should be carefully explored.

A critical new source of funding arises from Reduction in Emissions from Deforestation and Degradation (REDD), also emerging from the recently concluded Bali COP-13 discussions. Under the Bali Roadmap (UNFCCC 2007), REDD is now a recognized strategy for dealing with carbon emissions, and Madagascar stands in a unique position to become a world leader in further development of methodologies and in securing major international investments through this approach. Many participants felt that Madagascar can benefit greatly from developing a national strategy for REDD in synergy with a national policy on adaptation to harness the multiple benefits offered by REDD – reducing carbon emissions, protecting forests for biodiversity, facilitating ecological adaptation on land and maintaining other critical ecosystem services. Participants recommended that a sound national strategy on REDD could bring benefits to local communities from REDD investments and build a strong foundation to undertake mitigation and adaptation activities in tandem.

Detailed recommendations emerging from technical discussions can be found at the end of the thematic sections in the report.

Introduction

According to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), "there is unequivocal evidence that the climate is warming as evident from increases in global average air and ocean temperatures, melting snow and ice caps, and rising global average sea levels" (IPCC 2007a). The consequences of this warming for terrestrial biological systems are manifested by changes such as earlier timing of spring events and the poleward and upward shifts in ranges of plant and animal species. For marine and freshwater systems the consequences of rising water temperatures coupled with changes in ice cover, salinity, oxygen levels and circulation patterns are evident in altered community compositions; range changes of algae, planktonic organisms and fish abundance in high-latitude oceans; increases in algal and zooplankton abundance in high-latitude and high-altitude lakes; and range changes and earlier fish migrations in rivers (IPCC 2007a). Coral reefs are clearly at great risk with reefs across the tropics already suffering from massive bleaching events. Agriculture is a key human livelihood sector projected to be greatly impacted. In Africa, climate projections indicate a greater vulnerability to changing climate with agricultural production and access to food severely compromised and millions of coastal people threatened by sea level rise. By 2020 yields from rain fed agriculture are likely to decline by 50% in some African countries (IPCC 2007a). Freshwater availability is likely to change in several regions impacting freshwater biodiversity, hydrological services and agricultural productivity putting at risk both ecosystems and people.

Madagascar with its high biodiversity and high level of human dependence on agriculture, fisheries and local ecological resources for survival, including sourcing energy from charcoal, presents immediate challenges for both human adaptations to climate change and for adapting biodiversity conservation to address climate induced threats. Approximately 80% of Madagascar's population lives in rural areas with subsistence agriculture a primary means of survival (Kistler and Spack 2003). Slash and burn, shifting agriculture *(tavy)* has been identified as the main cause of environmental degradation and forest loss. Lack of adequate infrastructure in many rural regions limits access to information, agricultural inputs and credit, and to markets – all of which are factors contributing to a perpetuation of *tavy* (Erdmann 2003). In addition, rain-fed rice production can be combined with other crops and the low-input nature of *tavy* makes it a risk-averse practice (Erdmann 2003). These factors also contribute to making human adaptation under climate change more challenging, for example, by limiting options for agricultural diversification and market access, and setting up farmers reliant on rain for irrigation as more vulnerable to changing seasonal and precipitation patterns. Combined with other land and resource use practices, *tavy* presents enormous conservation challenges in Madagascar primarily due to habitat destruction and degradation. Climate change is projected to exacerbate these threats, while creating an increased need for habitat restoration in order to facilitate species migration and survival. Similarly, Malagasy fishing communities highly reliant on coral reef fisheries are likely to be severely impacted by coral bleaching and degradation. Mangrove forests, threatened by potential sea level rise under climate change, are important breeding grounds for commercial fish species and shrimps (Cooke et al. 2003), providing coastal communities with timber, fuel wood and protection from storm surges.

Madagascar's biodiversity ranks among the most remarkable in the world. The island has been famously called "the naturalist's promised land" because of its large number of endemic species (Goodman and Patterson 1997). More than 92% of the island's mammals are endemic, as are nearly 60% of birds, 90% of plants and 97% of reptiles and amphibians (Goodman and Patterson 1997). Higher order endemism is exceptional as well. Madagascar ranks number one in percentage of endemic species among all biodiversity hotspots, and number two in absolute number of endemics (Myers et al. 2000). Madagascar's marine ecosystems are characterized by relatively greater connectivity, lower levels of endemicity, and more uniform biogeographic patterns. However, there is some evidence of a biodiversity high in the west-central Indian Ocean for scleractinian corals and reef fish on the northwest coast of Madagascar (Veron 2000, McKenna and Allen 2006). Madagascar has about 300,000 ha of mangroves, and about 3450 km of coral reefs including the Grand Reef around Toliara in the southwest (Cooke et al. 2003). Five species of sea turtles are found in Madagascar, four of which nest here (Ratsimbazafy, 2003) and several species of marine mammals have been seen in the waters around the island (Rosenbaum 2003). Madagascar's more than 5,000 km of coastline stretch from a tropical 12^{o}S to subtropical waters at 25^{o}S, giving it particular significance for regional biodiversity conservation that address the latitudinal shifts in species distributions expected to result from ocean warming and other ecological responses to climate change (e.g. Hughes et al, 2003; Precht and Aronson 2004).

To conserve this highly threatened biodiversity, the Government of Madagascar (GOM) is committed to a dramatic expansion of its marine and terrestrial protected areas network. Planning for this expansion is already underway and this is a critical phase to integrate the potential impacts of climate change on Madagascar's biodiversity and natural resources-dependent livelihood sectors. It is critical to understand the synergies between human adaptation needs and safeguarding long-term conservation in Madagascar.

In response to these challenges, the GOM, CI, WWF and USAID, with support from the John D. and Catherine T. MacArthur Foundation, and in collaboration with partners, organized an experts' workshop to assess the impacts of climate change on biodiversity, identify adaptation needs and options, and initiate the process of exploring the synergies and potentially competing needs for human adaptation and conservation efforts. The workshop, held in Antananarivo, Madagascar, from January 28-31, 2008, brought together over 130 experts from more than 50 national, regional and international organizations across a wide spectrum of expertise ranging from oceanography, climatology, ecology, biology, economics and social sciences as well as policy makers and conservation and development practitioners. The Ministry of Environment, Water, Forests and Tourism (MEEFT) of Madagascar hosted the workshop. The Minister of Environment, Water, Forests and Tourism, the United States' Ambassador to Madagascar and the President of Conservation International gave the opening remarks.

Participants focused on identifying the key impacts, vulnerabilities and threats climate change poses to Madagascar's marine and terrestrial ecosystems and the rural and coastal communities that depend on them. Discussions built on model predictions for species distributions and vulnerability to climate change, climate scenarios specially prepared for the workshop as well as experts' knowledge. Recommendations were made to enhance the resiliency of natural ecosystems and the ability of communities to adapt to the impacts of climate change. A central goal of the workshop was to develop and test processes for identifying areas for protection that may have natural resiliency or serve as important areas for corridors and restoration. The fate of biodiversity conservation and rural development in Madagascar is closely interlinked and climate stress is likely to impact both severely. However, there are opportunities within the current global framework through funding for avoided deforestation to promote both conservation and development, at least for terrestrial forest ecosystems. International mechanisms such as the Adaptation Fund are being established to facilitate adaptation to the impacts of climate change.

The following sections draw upon knowledge gathered prior to the workshop and from workshop presentations and discussions. Presentations elucidated the likely climate scenarios for Madagascar and implications for terrestrial and marine biodiversity, human livelihoods and ecosystems. The thematic sections highlight technical session discussions, main impacts and the recommendations emerging from each focus group to address these impacts and build resiliency for terrestrial and marine systems. Recommendations for integrating climate change considerations into the protected areas network, identifying synergies and potential conflict with human adaptation and needs, and the challenges and opportunities presented by tourism are addressed. A focus on regional cases explores the vulnerability, impacts and recommendations for adaptation for four regions of Madagascar: the Northeastern Tip (Cap d'Ambre to Ambodivahibe), the Central Highlands, the Northeast (Masoala, Makira, Antongil Bay) and the Southwest region around Toliara. The report is concluded with the text of the overall recommendations emerging from the workshop and discussions for next steps.

Section 1: Physical Change and Oceanography

Climate projections and oceanography around Madagascar were presented during plenary sessions to policy makers, government representatives and technical participants at the start of the workshop. Further presentations on different methods used for building climate projections and on understanding the nature of these projections were made during technical sessions on the second day.

Projected Future Climate Change

Projected changes in climate for Madagascar show warming across the island and areas of both increased and decreased precipitation[1]. Southern Madagascar is projected to have the greatest warming, with the coast and north showing lower projected temperature increases. Precipitation increase is centered in the northwest, while drying is projected in the east. These spatial characteristics are biologically significant because the south is already the driest region in the country, while the eastern forest is highly fragmented and vulnerable to drying.

[1] Tadross, M. Presentation at the Climate workshop.

Atmospheric temperature change projections are available from a suite of Global Climate Models (GCM), downscaled using a dynamic regional model or interpolated to 1km using splining. Figure 1 indicates the multi-model (13 GCMs taken from the World Climate Research Programme's (WCRP's) Coupled Model Intercomparison Project phase 3 (CMIP3) multi-model dataset[2]) minimum and maximum expected change in surface temperature for the period 2046-2065. These changes are produced using the change predicted by a regional climate model PRECIS - which better represents the local topography and therefore the spatial distribution of change according to Tadross et al. (2005), which is then scaled by the minimum and maximum change from the 13 GCMs. Downscaling using statistical methods and Regional Climate Models better accounts for local influences on climate and can aid convergence between multi-model estimates. However, downscaling is currently hampered in Madagascar because of the lack of a comprehensive network of weather stations. Most of the monitoring stations are located in airports and cities, with none in montane and forested areas, regions of conservation interest where long-term climate data are most needed.

Together the minimum and maximum temperature changes (Figure 1) represent the envelope of expected change given many model simulations. The lowest expected changes are in the north of the country and along the coastal regions (increases in excess of 1.1 °C). Expected warming increases away from the coast and especially towards the south where it is in excess of 1.5 °C. Around the coast the maximum expected change is in excess of 1.8 °C, which rises to more than 2.6 °C in the south of the country, indicating that the maximum expected change varies more depending on the spatial location than does the minimum expected change. It is also apparent that the range of projected temperature changes from the different GCMs is greatest and hence less constrained for southern Madagascar.

Projected changes in rainfall for Madagascar are available from the statistical downscaling of 6 GCMs, three of which were used in the IPCC 3rd assessment report (HadCM3, CSIRO MK II, ECHAM 4.5) and three used in the IPCC 4th assessment report (GFDL, MIROC, MRI CGCM). These downscaled projections of changes in rainfall are explained in (Hewitson and Crane 2006) and presented in Christensen et al. 2007.

The projected median changes in rainfall suggest that rainfall will increase throughout the summer months of January to April. Throughout the winter months of July, August and September the southern half of the east coast is projected to be drier by 2050, whilst the rest of the country is projected to be wetter. In October the dry region is only indicated for the most southerly station with the rest of the country becoming progressively wetter.

Models predict an increase in the intensity and thus the destructive power of cyclones over 2060 - 2100. However, efforts are underway at Meteorological Office to assess where, when and how these changes in cyclone intensity may occur. Changes need to be assessed in terms of probabilities of change rather than absolute predictions.

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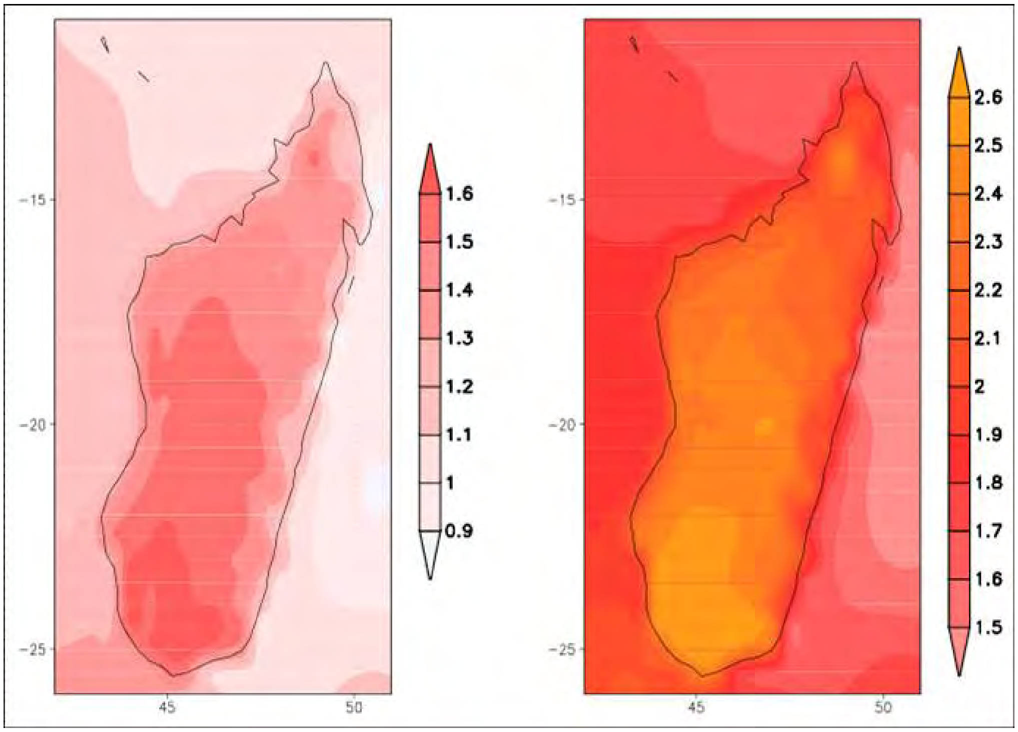
[2] http://www-pcmdi.llnl.gov/ipcc/about_ipcc.php



Lowest Change Highest Change

Lowest and highest changes in temperatures (2046-2065)

- *Lowest change around the coast and in the north (1.1+ °C)*
- *Highest change in the southern interior (2.6+ °C)*

Figure 1. Minimum and maximum temperature changes over 2046-2065

Oceanography and Climate Change

Oceanography around Madagascar is complex, and scientific understanding is incomplete (see e.g. Lutjeharms 2006; Reason et al. 2006). For instance, it is only within the last decade that oceanographers realized that there was no Mozambique current as such flowing between Madagascar and the mainland; instead, flow in the channel is characterized by a series of unpredictable eddies that vary in size, strength, direction, and temporal persistence (De Ruijter et al. 2002). Efforts are underway to model future oceanographic conditions and to establish a regional oceanographic observation system. The latter is essential to create a detailed and accurate view of current and future regional oceanography. Without better measurement and modeling of present oceanography around Madagascar, it is impossible to make specific predictions about possible changes.

Oceanic variables most used to inform analyses of the impacts of global warming on oceans are sea surface temperature (SST), sea level rise and, where available, pH or carbonate saturation state, as well as variables of particular concern relative to coral bleaching. Global models suggest an increase of SST from 0,5 to 0,6°C in the next 100 years, and an increase of the sea level from 20 to 50 cm (IPCC 2007b), but actual changes will vary significantly between regions. Rate of local sea level rise is influenced by tectonic factors, rates of sediment input, and local or regional atmospheric conditions, and SST by upwelling, currents, and other factors. Ocean acidification is occurring as a consequence of increasing concentrations of dissolved CO_2 in ocean water. This in turn results in stunted growth rates for corals and other carbonate based species. Under current predictions for atmospheric CO2 levels, by 2100 the growth rates of scleractinian corals will be significantly compromised (Kleypas et al. 2006).

In preparation for this workshop, a series of maps were created showing the sea surface climatology around Madagascar, including SST, PAR (photosynthetically active radiation), UV, chlorophyll a, surface winds, and currents. Analysis of these data suggest a more uniform oceanographic climate along the east coast (the influence of the South Equatorial Current), with greater latitudinal zonation along the west coast. There is a distinct zone of cool water along the south coast, and a relatively sharp demarcation between the cooler northeast coast and warmer northwest coast. Sea surface temperature is most variable in the southwest, and least variable in the northwest and southeast (see Fig. 2 b, c).

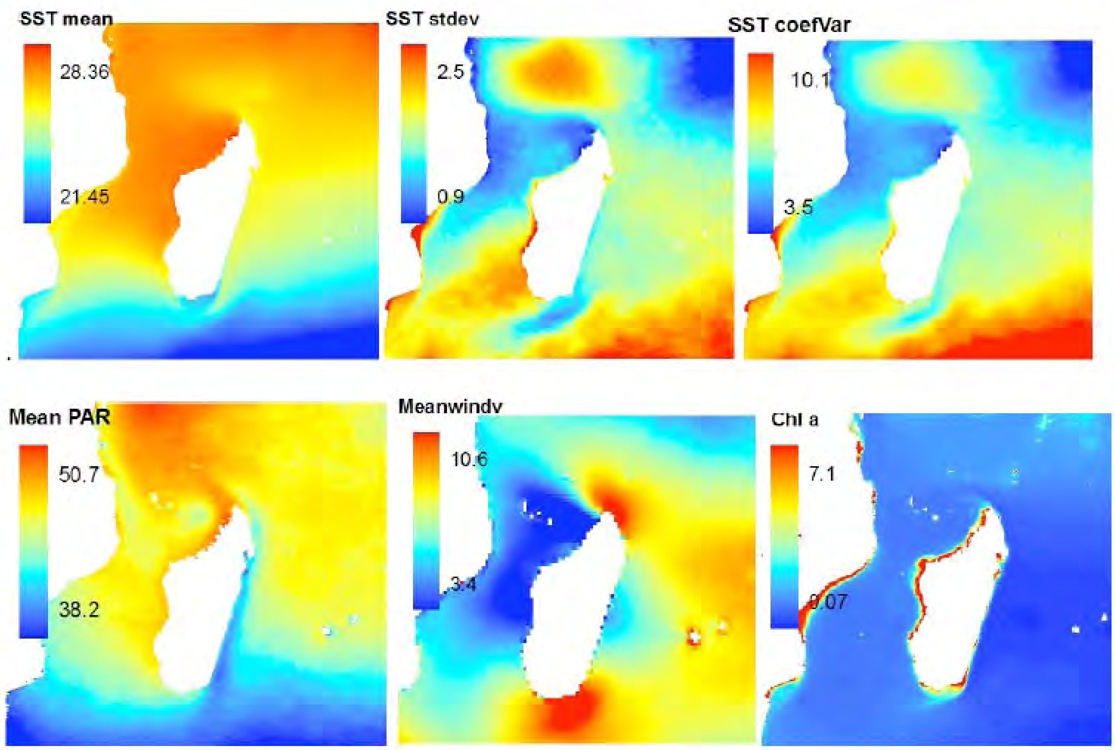


Figure2. Sea Surface Climatology, representative variables A) mean sea surface temperature, degrees Celsius; b) and c) standard deviation and coefficient of variation, respectively, for SST; d) mean photosynthetically active radiation, Einstein/m2/day; e) mean surface wind speed, m/s; f) mean chlorophyll a, mg/m3

Section 2: Terrestrial Biodiversity and Ecosystems' Impacts and Recommendations

Terrestrial biodiversity and potential impacts of climate change were highlighted during opening day plenary presentations and on the following day's the technical sessions in taxonomic working groups. The groups identified impacts and species' vulnerability within each of the following taxonomic groups: plants, small mammals and birds, primates, amphibians and reptiles, and invertebrates (butterflies). Representatives from each of these working groups then reassembled into regionally focused discussions to identify particularly threatened species and habitats. Following these discussions taxonomic specialists joined with practitioners and livelihood experts to identify areas in need of protection and regions important for human livelihoods and adaptation in sessions dedicated to evaluating protected areas and livelihood needs.

Terrestrial Biodiversity Vulnerability

Pre-workshop modeling of species distribution patterns under climate change, analyses of how changing temperature impacts tree phenology and their subsequent impacts on lemur populations in Ranomafana National Park, and a feasibility study to aid in the design of dispersal corridors for lemur species under two climate scenarios were used to inform discussions. Species distribution models that combine distribution ranges of plant and animal species with an analysis of environmental variables associated with the known distribution of a taxon can be coupled with climate scenarios to predict the total potential suitable habitat for species' in the future. As an example, the Milne Edwards Sifaka display lower reproductive success in warmer ENSO years – and this may be an indication of how this species will respond to warming temperature due to climate change. Species distribution modeling for over 190 endemic species of butterflies indicate that 62% may have declined and 38% expanded their ranges. A comparison of deforestation and climate change impacts shows that climate change is an emerging threat and the availability of suitable habitats to allow for dispersal of species as they track their climate envelopes will be a major determiner of extinction versus survival for species.

Taxonomic group discussions focused on identifying particularly vulnerable species, characteristics that could enhance vulnerability and regions at risks within Madagascar for plants, amphibians and reptiles, butterflies, small mammals and birds, and primates. The objective was to identify biological traits and distribution patterns that could render species and regions particularly sensitive or vulnerable to climate change, and areas that are important because of their potential for serving as biodiversity corridors and refuge habitats under predicted climate scenarios.

<u>Taxonomic Groups</u>

Plants

Presentations and pre-workshop species' modeling focused on over seventy endemic Malagasy plant species to shed light on their distributions under three future climate scenarios for 2020, 2050 and 2080. Some of the results of this modeling exercise and postmodeling analyses are highlighted here (Schatz and Cameron 2008). For example, in the south and southwest for sub-arid spiny forest species' projections for 2020 and 2050 show relative stability. However, by 2080, the core central part of their ranges is projected to become unsuitable with suitable habitat becoming restricted to the extreme southern coastal strip, as well as shifting eastwards toward Fort Dauphin. Beginning by 2020, and continuing through 2050 and 2080, distributions of western dry forest species are projected to shift eastwards and inland away from the coast. In contrast, the Menabe region north and south of Morondava is projected to be relatively stable throughout the modeled time intervals. Beginning immediately by 2020, the extreme northern areas around Antsiranana and to the north towards Cap d'Ambre become unsuitable for dry forest species. By 2050, and continuing through 2080, suitable habitat shifts dramatically to the south toward the Daraina region and lower slopes of the Northern High Mountains. In addition, suitable habitat is predicted on the mid slopes of the Montagne d'Ambre massif at 2050, but disappears by 2080. Many of these dry forest species endemic to the far North exhibit high substrate specificity to either limestone or sand, which are absent from the predicted climatically suitable areas to the south. Nearly all humid forest species show significant range contraction by 2080. Essentially no suitable habitat is predicted by 2080 for species currently restricted to the narrow littoral forest belt along the east coast. Distributions of mid-elevation escarpment species are predicted to shift to the areas of higher elevation in the Ankaratra, Ibity, Itremo and Andringitra massifs and alternately toward the Northern Mountains, whereas species already restricted to the Ibity and Itremo massifs are predicted to have essentially no suitable habitat by 2080. In contrast, the Masoala peninsula, with the exception of the extreme eastern coastal strip along the Indian Ocean, would appear to constitute a climate refugium, with nearly all species currently distributed in low elevation humid forest from Betampona to Sambava strongly predicted there through 2080.

Discussions during the technical sessions identified particularly vulnerable regions of Madagascar to include most of the Northern region where deforestation coupled with droughts and cyclones is already causing severe stress. In the north, plant species are projected to move southwards from the coast and to some extent migrate up the Montagne D'Ambre such that several localities in the region of Antsiranana are predicted to become unsuitable by 2080, and thus were identified by experts as highly vulnerable under climate change. Hence, although *Boswellia madagascariensis* exhibits overall range expansion according to model predictions, that expansion is mostly outside of its current distribution. Several humid to sub-humid forest species are projected to experience range size contraction by 2080 under the impacts of changing climate. Experts identified the littoral forests of eastern Madagascar as vulnerable because of projected reduction in their distribution area in addition to the vulnerability caused by their coastal habitats from potential sea level rise. Distributions of mid-elevation escarpment species are projected to shift to the areas of higher elevation in the Ankaratra, Ibity, Itremo and Andringitra massifs, whereas species already restricted to the Ibity and Itremo massifs are projected to have essentially no suitable habitat by 2080. The Masoala Peninsula, with the exception of the extreme eastern coastal strip along the Indian Ocean, is likely to constitute a climate refugium, with nearly all species currently distributed in low elevation humid forest from Betampona to Sambava strongly projected to maintain their presence there through 2080.

In addition to regional range restrictions, the plant group participants also identified species with irregular fruiting patterns as more likely to be susceptible under climate change. Many Malagasy plant species exhibit strong substrate preference (limestone, quartzite, marble, sandstone and unconsolidated sands, and basalt), which will further limit their ability to track climate change through migration. Tight co-evolutionary and mutualistic relationships involving pollination and dispersal will confer additional sensitivity to climate change for many plant species. For example, in Madagascar approximately 400 plant species, including, many orchids (Angraecoids), Rubiaceae (*Ixora*, *Hyperacanthus*, *Mantalania*, *Pseudomantalania*), *Lamiaceae (Clerodendrum), Apocynaceae (Pachypodium), Bignoniaceae (Stereospermum), Solanaceae* (*Tsoala tubiflora*), are pollinated by long-tongued sphingid moths; climate change impacts to pollinators will in turn effect plants, and vice versa. Participants identified dispersal modes as an important factor in increasing sensitivity to climate change given potential imperatives for migration. Thousands of plant species depend upon lemurs for dispersal, which in turn depend upon fruit as a major food source. Climate change impacts that disrupt fruiting cycles will adversely effect lemur populations, which in turn will reduce fruit dispersal. Species with low reproductive rates will be potentially more sensitive to climate change, and less able to adapt.

Primates

Data analyses and modeling exercises prior to the workshop included a preliminary study to design potential dispersal corridors for lemur populations to track their climate niche under two climate scenarios. Long-term data from Ranomafana on daily temperature, daily rainfall, monthly phenology and fruit production of over 200 individual trees, as well as lemur demography and feeding behavior was analyzed to detect the impacts of changing phenology on lemur feeding behavior and population demographics. Although these analyses show no discernible change in the mean annual rainfall total, the data do suggest an increase in number of dry season months. In response to these subtle climatic differences are changes in fruiting patterns in some species of trees. Other studies exist that suggest a decrease in successful reproduction in lemurs during years with extended dry seasons (King et al. 2005). The analysis of the daily temperature data over a 20 year period did not show high temperatures rises or annual temperatures increases in the rainforest. However minimum temperatures during the cold season were higher during the past ten years, compared to the previous decade. Future analysis will establish if this higher minimum temperature has an effect on tree reproduction, and consequently on lemur feeding behavior and demographics.

During the technical sessions, primate group discussion identified characteristics that can potentially increase the vulnerability of primate species under climate change to include traits such as hibernation, restricted habitat ranges, low dispersal abilities, low reproductive rates and small isolated populations. Disruption in the diet of lemurs through changes in fruit production can cause food stress, particularly in species that hibernate. Specialist species such as the *Prolemur*, *Varecia*, *Hapalemur aureus*, *Hapalemur alaotrensis*, are at risks from potentially destructive events such as increased intensity of storms, cyclones and flooding because of the impact on their diet fruits as well as direct impact on mortality and reproductive rates. *Hapalemur alaotrensis* is found only in the wetlands of Alaotra and can be impacted by changes in water level impacting the forests. Species with restricted ranges are more vulnerable to loss of habitat and fragmentation of forests, and many species found in the north and west are especially likely to be impacted by climate change. In the west, temperature rise and a longer dry season may increase the risk of fires causing further habitat destruction and degradation.

Within the humid forests of Madagascar, the species that are highly vulnerable include the *Varecia variegate and V. rubra, Propithecus candidus, Indri, Prolemur, Allocebus, H. aureus, Indri, Eulemur albocollaris,* while in the far north, species more likely to be vulnerable include the *Eulemur coronatus, Propithecus tattersalli, P. perrieri, and L. septentrionalis.* Around the southwest of Madagascar, the species that are particularly at risk include the *Propithecus verrauxi, Cheirogaleus/Microcebus,* Menabe species, *Lepilemur hubbardi, L. ruficaudatus* and in Northern Madagascar the *Eulemur coronatus, Propithecus tattersalli, P. perrieri, and L. septentrionalis*.

Small Mammals and Birds

During breakout group discussions, experts identified regions vulnerable for birds and small mammals excluding primates to include the west from north of Bemaraha to south of Mahafaly. This region has the largest number of taxonomic groups of the Afrosoricida with a strong micro-endemism and extremely isolated populations. Vulnerable regions in the east are from 1200 to 1600 m altitude. Species which are habitat specialists like the forest species are likely to be more threatened, and can only be conserved if the forest habitats remain connected. Riparian forests, particularly in the west, are important for maintaining Madagascar's avifauna and small mammals. Vulnerable species include *Mungotictis decemlineata* and *Galidictis grandidieri*, aquatic birds, *Nesomys audeberti, Nesomys rufus,* and *Nesomys lambertoni.*

Amphibians and Reptiles

The available distribution model forecasts for amphibians and reptiles under future climate scenarios suggest important range contractions. Few observations are available on changes in rainy season and effects on amphibian species; however, delay in the onset of rainy season in western Madagascar may imply a longer period of aestivation, phenological changes and may affect reproductive output. Similar observations made on freshwater fishes in two areas, Anjingo in the NW and Nosibolo – Marolambo in the east, where the fry period is longer and affects fishes. Species distribution models suggest that mid-elevation rainforests species where most of the diversity occurs are likely to be affected by warming, while low elevation areas seem to be less vulnerable to climate change.

During discussions experts identified mountaintop endemic species of amphibians and reptiles as highly susceptible to the impacts of climate change. The summits of the highest mountains (Andringitra, Tsaratanana, Marojejy) are a target priority for monitoring the impacts of climate change on Malagasy herpetofauna. In addition, all species found on mountain tops within humid forests may be affected by warming temperatures. Restricted ranges and aquatic habitat niches make Malagasy herpetofauna more vulnerable to the effects of climate change. These species are characterized by a high degree of narrow endemism, and for most species only a few locality data records are available, so actual ranges are unknown, limiting the ability to model species' distributions. Several restricted range species are found in areas other than mountain tops, and species showing fragmented distribution ranges due to deforestation may be particularly at risk.

Invertebrates (Butterflies)

Experts identified mountaintop endemics as the most vulnerable under climate change. Changes in precipitation, fire regimes, forest fragmentation and ecological dependence on other species (e.g. plants), and removal of suitable climate space all increase the vulnerability of butterfly species greatly. Distribution and biological traits that increase the vulnerability of butterfly species to climate change include dependence upon other animals, plants, elevational limits to distribution which could be a function of either temperature or host plant distribution and dietary restrictions to specific host plants.

Coastal rainforest endemics are likely to be more vulnerable, some have not been seen since 1950. Species with limited to narrow elevation ranges are much more vulnerable, as are species with narrow ecological amplitude.

Regional Focus Groups

Following the taxonomic breakout sessions, four groups each with representatives of each of the taxonomic groups were formed to identify specifically threatened or at risk species in each of those regions. These four regions were: the Humid forest of the east, the Dry forest in the west, the extreme North, and the Spiny forests of the south and southwest.

Humid Forest of the East

Within the humid forests of the east, mountaintop amphibians and reptiles show great vulnerability, while nearly all of the humid forest plant species are projected to show significant range contractions by models. According to the primate experts species identified as vulnerable in the humid forests include *Varecia variegate* and *V. rubra, Propithecus candidus, Indri, Prolemur, Allocebus, H. aureus, Indri,* and *Eulemur albocollaris.*

All of Madagascar's endemic reptiles and amphibians are at risks under global warming. Some species have been suggested to have moved upslope, for others there is no evidence. Several species have not been found anymore during the last decade, some may be extinct. Those include: *Boophis williamsi, Mantidactylus pauliani, Platypelis tsaratananensis, Anodontohyla montana, Mantella cowani, Calumma tsaratananensis, Calumma andringitrensis, and Lygodactylus mirabilis*.

Nearly all humid forest plant species show significant range contractions by 2080. Potential distribution models for plants suggest that mid elevation rainforest species, where most of the diversity occurs, are projected to be affected by global warming. Low elevation areas seem to be less vulnerable to climate change. Essentially no suitable habitat is predicted by 2080 for species currently restricted to the narrow littoral forest belt along the east coast. Distributions of mid-elevation escarpment species are predicted to shift to the areas of higher elevation in the Ankaratra, Ibity, Itremo and Andringitra massifs, and/or toward the Northern Mountains, whereas species already restricted to the Ibity and Itremo massifs are predicted to have essentially no suitable habitat by 2080. In contrast, the Masoala peninsula, with the exception of the extreme eastern coastal strip along the Indian Ocean, would appear to constitute a climate refugium, with nearly all species currently distributed in low elevation humid forest from Betampona to Sambava strongly predicted there through 2080.

Dry forest of the West

Plant species modelling indicates a shift of dry forest species eastwards, while for many amphibians and reptiles the length of the dry season can affect aestivation and phenology. For example, according to expert insights *Aglyptodactylus laticeps* is likely to be impacted. In addition, if the canyon habitats in Isaola National Park are impacted by the stochasticity of the rainfall pattern groups such as the *Scaphyophrine* and the *Brookesia* chameleons are likely to be affected. According to the species distribution modelling for endemic plants in the region, beginning by 2020, and continuing through 2050 and 2080, species' distributions generally shift eastwards and inland away from the coast, such that the Ambongo-Boina region including Ankarafantsika in the North, and the Mangoky river valley in the South, are strongly projected to be suitable for western dry forest species by 2080. In contrast, the Menabe region north and south of Morondava exhibits relative stability with strong projections throughout the future time intervals. Discussions in this group gave rise to a consensus amongst participants that riverine forests have an important role to play in maintaining connectivity and providing refuge habitats based on paleoecological records and insights from experts present.

Northern Forests

The north is seen by a region where plant species are highly vulnerable to climate change. Vulnerable species of primates in this region include: *Eulemur coronatus, Propithecus tattersalli, P. perrieri,* and *L. septentrionalis.* Reptile and amphibian fauna of Ankaranana is thought to be vulnerable, however there is minimal data. Some karst formations are projected to have less humidity than usual impacting groups such as the *Tsinguimantis*. According to plant distribution models, beginning immediately by 2020, the extreme northern areas around Antsiranana and to the north are projected to become unsuitable for the species modeled. By 2050, and continuing through 2080, suitable habitats are projected to shift dramatically to the south toward the Daraina region and northern lower slopes of the Northern High Mountains. In addition, suitable habitat is projected to occur on the mid slopes of the Montagne d'Ambre massif for 2050, but then disappears by 2080.

Spiny Forest of the South and Southwest

According to expert insights, spiny forest amphibian endemic species are unlikely to be affected and available models for reptiles do not suggest any certainty of impacts for reptiles. In the immediate future plant species in this area are likely to remain stable. Experts identified the following primate species as vulnerable in this region: *Propithecus verrauxi, Cheirogaleus/ Microcebus,* Menabe species, *Lepilemur hubbardi,* and *L. ruficaudatus*. It is likely that increasing duration of the dry season can potentially affect aestivation and phenology of many species of amphibians and reptiles. Plant distribution models for 2020 and 2050 show relative stability throughout the southwest with the exception of the extreme coastal strip north and south of Toliara. However, by 2080, the core central part of the southwest spiny forest is projected to become unsuitable, and suitable habitat is projected to be restricted to the extreme southern coastal strip, as well as to migrate eastwards toward Fort

Dauphin. Thus, the Mandrare basin is projected to remain a stable refugium for subarid spiny forest species through 2080.

Technical Recommendations for Management and Research

I. To reduce the vulnerability of biodiversity and enhance the resiliency of species and ecosystems to face climate change, the following management and conservation action recommendations are made:

- Protect all remaining forests to provide habitat for species and to facilitate species' movements.
- Maintain and/or restore connectivity between forest fragments, to create and maintain corridors and allow for species dispersal.
- Protect and restore riverine forests, recognizing their role in providing refuge habitat and migratory corridors to enable species to move, especially in the western region.
- Establish REDD projects, which can aid in both protecting forests for biodiversity and generate funds from carbon sequestration.

II. To better understand the impacts of climate change on Madagascar's biodiversity, further research is needed on:

- Fragmentation and edge effects, habitat types and specificity, dispersal abilities, distribution ecology of many newly described or identified species and reproductive patterns across sites for all taxon considered here.
- Restoration ecology studies especially for corridors to assess the feasibility of growing existing habitat.
- Identifying variables necessary for understanding species' responses to climate change and their capacity to adapt to it.
- Establishing long-term monitoring and data collection programs for a variety of taxonomic groups to gather data on indicators for a set of target species over long time periods, and obtain information such as a measure of population abundance changes between years. Monitoring of altitudinal transects for faunal and floral composition, and establishing genetic analyses programs to understand population movements better. Monitoring of invasive species' whose broader ecological tolerance may result in an expansion of distribution out-competing native species under climate change.
- Ground-truthing of climate model predictions, for example, how accurately can climate models predict the presence of species communities in contiguous versus fragmented survey sites.

Section 3: Marine Biodiversity and Ecosystem Impacts and Recommendations

Marine and coastal biodiversity and potential impacts of climate change were highlighted during the plenary presentations at the start of the workshop and during the following day's technical sessions in taxonomic working groups. The groups identified impacts and

species' vulnerability within each of the following taxonomic groups: coral reefs, mangroves, sea turtles, and marine mammals. Following taxon-based discussions, participants rearranged themselves into groups focusing on marine protected area (MPA) site selection and prioritization, MPA management, and interactions between climate change, livelihoods, and MPAs. The whole group then reconvened to discuss ways of moving forward given the relatively large gaps in biological and oceanographic data.

Marine Biodiversity Vulnerability

For coastal and marine biodiversity and ecosystems in Madagascar, there is insufficient biological and physical data available to facilitate detailed range mapping. One clear risk, however, is loss of coral reefs to bleaching as a result of warmer sea surface temperatures across the region. Coral reefs play a vital role for human livelihoods by supporting reef fisheries and tourism and provide protection for coastal communities. Reefs across the tropics have already suffered massive bleaching events. Ocean acidification – the decrease of the ocean's pH due to absorption of excess CO2 from the atmosphere – will slow the ability of corals to build their skeletons and consequently decrease their ability to keep up with erosion and sea level rise. Mangrove forests are also at risk from climate change, both from rising sea level (which may drown mangrove forests), a potential increase in extreme freshwater flooding during heavy rains, and increased soil salinity due to increased evaporation as temperature increase. Mangroves are an essential source of fuel, building supplies, and food (from mangrove-dependent fisheries), and also serve to slow coastal erosion. This last function will become even more important in the face of warming-induced sea level rise. Sea turtle nesting beaches are also at risk from rising seas and an increase in heavy rainfall events.

Coral Reefs

Significant information on coral reefs and their vulnerability to climate change and other stressors is included in a coral reef focused white paper produced prior to the workshop. Here we summarize major points discussed during the technical sessions.

Madagascar's corals are already suffering to varying degrees from both temperature- and non-temperature-related stresses, including mass bleaching events. Areas where reefs are overexploited seem particularly vulnerable to climate-related stressors. For instance, the relatively intact Motsadiniky reef near Belo Sur Mer recovered much more quickly from bleaching than the more degraded Antanambe reef near Mananara Nord (Maharave 2008). The Great Barrier Reef of Toliara is now highly degraded due to a combination of temperature-related bleaching, unsustainable use, and sedimentation. Green algae which used to grow only during the hot season now remain year-round in some parts of the reef (Maharave 2008). Working with local communities to limit unsustainable extractive uses, and at a larger scale to reduce terrestrial runoff, is fundamental to increasing the resilience of reefs to effects of climate change.

In broad terms coral species have relatively well known susceptibilities to changes in water temperature as a result of climate change. With respect to temperature, three broad groups of corals are known:

- Highly Susceptible – The fast growing branching genera such as Acropora, Pocillopora, Stylophora and Seriatopora, with the first two being important reef-building and pioneer species respectively.
- Resistant – The slow growing massive genus Porites and some genera such as Turbinaria and Pavona – Porites is a key reef-building coral and they all persist in many low-quality environments such as under high sedimentation regimes. These conditions are common around Madagascar, so resistant species may be common.
- Intermediate – Almost all other coral genera are highly intermediate and/or variable in their response to temperature.

Using a variety of variables known to affect bleaching risk (SST, PAR, UV, winds, and currents), a rough spatial model of coral vulnerability to bleaching was created (see Fig. 3). Modeled vulnerability does not clearly parallel observed patterns of bleaching, however. In particular, higher bleaching occurred in the southwest, and least in the northwest, the exact opposite of predicted vulnerability. There are several possible reasons for the disjunction between model results and actual bleaching patterns. Reefs in the southwest were already degraded from local anthropogenic stresses, and may have been rendered more susceptible to bleaching as a result (Obura 2005). While SSTs closer to the equator are higher than those in subtropical latitudes, corals acclimate locally (Coles and Brown 2003), thus the absolute temperature driving the model may inappropriately force the model for bleaching responses on current time scales. It may be more appropriate to ignore mean local temperature and model local variability and extremes.

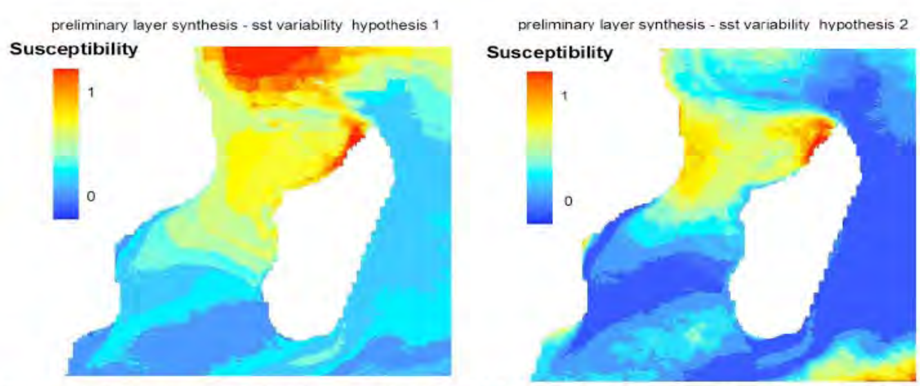


Figure 3. Preliminary modeled susceptibility of Madagascar's corals to bleaching. Hypothesis 1 assumes a linear relationship between temperature variability and bleaching susceptibility. Hypothesis 2 assumes a 'U'-shaped relationship, suggested by some field studies – i.e. that corals in low variability habitats have high susceptibility to warming as they are acclimated to stable unchanging conditions.

Other climate change threats to corals are less well understood. Ocean acidification is expected to slow coral growth rates, and in the extreme could make it difficult for stony corals to persist (Caldeira and Wicket 2005, Kleypas et al. 2006). Slower growth may

exacerbate the effects of sea level rise, since corals will be less able to keep pace with increasing sea level. Sea level rise may also increase sedimentation from coastal erosion.
Certain areas may be somewhat protected from water temperature increase because of a combination of topography and currents. For instance, there is an upwelling zone off the southeast coast of Madagascar, near Fort Dauphin, that keeps sea surface temperature in that region several degrees cooler on average that other regions (Fig. 2). As this upwelling is driven by topography and large-scale ocean currents, it is likely to persist even in the face of climate change, providing a cool refuge for marine species. This area is relatively poorly studied, however, but is unlikely to contain extensive reefs due to the presence of large, permanent rivers. Another area that may remain relatively cool due to upwelling linked to permanent currents and topography is Ambodivahibe in the North. Although the scale is much smaller than the region around Fort Dauphin, this bay and others like it in the North may serve as refuges for a variety of corals and other marine organisms.

The group discussed the relative vulnerabilities of different coral reefs around Madagascar. The southwest coast is an area of significant reef development in Madagascar, including the Grand Recif of Toliara, the third largest barrier reef in the world. These reefs were in good condition until recently but they are today fairly degraded, affected by coral bleaching phenomenon in 1998 (Maharave 2008). Turbid water from river outflow is now a constant phenomenon. According to the participants, offshore bank reefs north of Toliara appear to be in good condition, but fringing reefs and reef flats are highly degraded degradation condition.

The northwestern coast of Madagascar is sheltered from monsoon winds, providing a very calm environment. Two types of coral reefs are found here, coastal fringing reefs and isolated coral banks on sediment bottoms, some distance from the coast on the broad shallow platform. Overall, the open sea coral banks are in good condition whereas fringing corals are affected by human activities, particularly around Nosy Be. During the rainy season, turbidity in reef waters is very high.

The northeast coast is highly exposed to strong monsoon winds and swell, is subject to cyclones, and has a narrow continental shelf. Reefs fringe the coast from Diego bay to the Masoala peninsula and are generally in good condition due to poor accessibility and hazardous sea conditions. Ambodivahibe, a small bay southeast of Diego bay, has the highest coral cover of sites reported from the region which is attributed to its unique geophysical attributes (Maharave, 2008). Some reefs, close to highly populated areas in Antalaha district, are degraded. In the Masoala region, there is high pressure on reefs and consequently high levels of degradation.

The east coast of Madagascar is highly exposed to wind and waves, and has high rainfall, under the direct influence of monsoon winds. It is also strongly affected by cyclones on an annual basis, and consequent heavy rains, coastline erosion and sedimentation. Reef flats are highly exposed to intense human activities. The Mananara Nord region was affected by large scale coral bleaching in 1998 (Maharave 2008). The southeast coast has not been as well explored. It does not have much coral reef due to the presence of large permanent rivers, hence low salinity and sediments that are not conducive to coral development. Corals grow on rocky substrata, with less carbonate reef development.

Sea turtles

As highly migratory species, Madagascar's sea turtles are threatened not only by changes in Madagascar's seas and coasts, but also by changes in conditions affecting their migratory routes and other areas where they spend parts of their lives. Five species of sea turtles occur in Madagascar, four of which nest in the area (Ratsimbazafy 2003). Little is known about how climate change is likely to affect sea turtles in the open ocean, but potential effects are clearer for the four species of sea turtle that breed on Madagascar's coasts. Nesting beaches may be lost to rising sea levels and increased storm intensity and frequency. Increased influx of terrestrial sediments due to a predicted increase in extreme precipitation events and increased erosion caused by poor land use and deforestation upstream can change beach sand characteristics. This can discourage females from nesting or make it impossible for young turtles to dig their way out of the nest. The latter effect has been observed in the Masoala region (Bemahafaly pers. comm., January 29, 2008). Increasing temperatures will also change the sex ratio of hatchlings, increasing the number of females relative to males. A survey of nest beach locations was carried out in 1992, but anecdotal evidence suggests that some former nesting beaches are no longer in use (Harris, pers. comm., January 30, 2008).

The most significant non-climate stressor for sea turtles is human pressures. Both eggs and adults are commonly eaten, particularly in the southwest, and turtle carapaces are used to create items for use or sale. According to participants, there is virtually no data on turtle harvests.

Marine Mammals

Up to 31 cetacean species as well as the dugong and two pinnipeds are known to occur in Madagascar's waters (Wildlife Conservation Society 2006). A variety of characteristics affect the vulnerability of a given marine mammal species. Resident species such as the dugong may have less flexibility in location than the highly migratory species that pass through the area, such as large baleen whales, but national conservation efforts could have a bigger impact on resident species. Some species spend most of their time off-shore, while others live closer to shore. All pelagic animals, particularly long-distance migrants, will be affected by changes in large-scale current and temperature patterns.

The central problem with predicting the response of Madagascar's marine mammals to climate change is a lack of basic information about distribution, abundance, trophic interactions, and other key ecological/biological variables. Although many species of mammals, including offshore delphinids, pilot whales, and Risso dolphins, are known to feed extensively on squid, the actual diet of mammals around Madagascar is unknown (Cerchio 2008, workshop presentation). Studies elsewhere suggest that ocean warming will have a negative effect on squid populations, however. In the North Sea and the North Pacific, increased water temperatures were correlated with decreased fecundity in several species of marine mammals (e.g. Greene et al. 2003). Monitoring is needed to evaluate the impacts of increased water temperatures on Madagascar's mammal populations.

Although mammals end up as bycatch in some fisheries (primarily industrial off-shore pelagic fisheries that use seines), this is not nearly as important as direct hunting of marine mammals. Species living close to shore are most vulnerable to the combined effects of climate and non-climate stressors. In particular, many delphinids are a key food resource for certain coastal populations. Participants highlighted the potential of increasing hunting pressure on these populations as conditions in the south and southwest become less favorable for farming. Participants stated that in some Malagasy communities, delphinid hunting is important culturally as well as for subsistence, which poses a particular challenge. In contrast, for some cultures, such as the Sakalava people, it is a "fady" or taboo to kill dolphins.

Participants discussed the relative merits of ecotourism, particularly in the Southwest. On the one hand, demonstrating the monetary benefits of ecotourism based on protecting populations of whales, sharks, and turtles is a good way to encourage conservation. On the other hand, tourism can put a significant strain on local ecosystems. This may be particularly problematic in the southwest, where water and food resources are already under stress. Climate change has the potential to affect ecotourism, since there may be major distributional changes in mammals.

Mangroves

Because they occur along the coastline, mangroves are highly vulnerable to sea level rise. Their ability to keep pace with sea level depends to a large extent on sufficient sediment input and peat formation (McKee et al. 2007). The predicted increase in frequency of extreme rainfall events, particularly when combined with deforestation and poor land use practices, will likely increase the delivery of sediments to coastal ecosystems. However, the predicted increase in frequency and intensity of storms is likely to increase the rate of coastal erosion due to wind and waves. Too much sedimentation all at once can smother mangroves and associated flora and fauna, leading to massive die-off (e.g. NEMA 2007; Young and Harvey 1996; Smith et al. 1994). On the other hand, a sufficient rate of sediment input is essential if mangroves are to keep pace with sea level rise. If they are unable to accrete sediments rapidly enough to keep pace with sea level rise, it is also possible that mangrove forests can shift inland with the rising seas (Ellison 1993). If sediment input is too low, sea level rise is too fast, or topography or other factors prohibit mangrove forests from shifting their position inland, however, mangroves drown and mangrove forests disappear. Currently, there are no good estimates for rates of sea level rise or mangrove peat accumulation around Madagascar.

Effects of other elements of climate change – increased atmospheric CO_2, higher temperatures, changes in storm patterns - have received less attention. Both sea level rise and altered precipitation patterns will affect salinity, which structures mangrove zonation. Extreme flooding may also create deposits of debris in channels within mangrove forests, changing the flow of water within the forest and therefore the structure of the forest itself.

The group discussed the relative vulnerabilities of different mangrove locations around Madagascar. Riverine mangroves, such as those at Mahajanga or Bombetoka, are vulnerable to flooding and sedimentation; most are also vulnerable to the effects of land use practices upstream. Mangrove forests fringing small islands receive little or no sediment input, making it less likely that they will be able to keep pace with sea level rise. They also have little or no space for landward migration, and are thus strongly vulnerable to climate change. Mangroves in the southwest have few rivers draining them thus are limited by freshwater input, and this problem is likely to get more severe with climate change. Not only do models predict increasing drought for the region, but human demand for freshwater in the region is increasing. Mangroves in the northeast are most exposed to cyclones.

A variety of physical and biological factors are likely to increase resilience of mangrove forests to climate change (group discussion and McLeod and Salm 2006). A gently sloping topography increases the likelihood that mangrove forests will be able to expand inland as sea level rises. This likelihood is further increased if the substrate is appropriate for mangrove growth in terms of porosity and chemical composition, and if sediment input is sufficient to support peat deposition but slow enough to allow time for seedlings to colonize new areas. Reliable freshwater input, such as from large rivers, may prevent excessive soil salinization. Because each species of mangrove has distinct environmental tolerances and preferences, mixed species stands are more likely to persist through time than single-species stands. Maintaining a large population size as well as genetic interchange among populations supports genetic diversity within species, which is also likely to increase resistance and resilience to climate change. The greater the genetic diversity, the greater the likelihood that some individuals will possess characteristics better suited to the changing climatic regime.

Many west coast mangrove sites meet most of the above criteria for resilience. Most have mixed stands with at least 3 or 4 species. Deltaic mangrove forests in bays from Bombetoka to Ambaro, such as Belo-sur-Tsiribihina, are backed by favorable topography (gentle slope) that would facilitate landward migration and receive significant freshwater input. A key question for these mangrove forests would be the likelihood of a major flood/sedimentation event that could decimate the trees. Although the topography of the northeast is much steeper, this is an extremely wet area with significant freshwater input. It may also be that mangroves here have developed somewhat of a tolerance for lower salinities due to frequent heavy rains.

Mangrove clearing for charcoal, timber, shrimp farming, tourist development, and urbanization will make mangroves more vulnerable to climate change effects. This is particularly true in the southwest, where regulations governing charcoal production have been temporarily suspended following instances of political upheaval (de Fontaubert, pers. comm., January 31 2008). Although regulations at the national level mandate that all development be set back from the shore by a certain distance, these regulations are poorly enforced (participant consensus). Shrimp farmers claim to preserve extensive mangrove forests around shrimp ponds, but this has not been independently verified. Shrimp farming and urbanization may further stress mangrove forests by releasing pollutants such as sewage or other waste products. Mangroves in the south are currently protected from the threat of shrimp farming because the climate is too cold for shrimp. This situation may change as global temperatures rise, however. Plans should be put in place now to ensure that if shrimp farming shifts further south, mangroves will be sufficiently protected.

Technical Recommendations for Management and Research

I. To reduce the vulnerability of biodiversity and enhance the resiliency of species and ecosystems in the face of climate change, the following management and conservation action recommendations are made:

- Create a marine reserves system based on factors likely to increase resistance and resilience to climate change, such as creating a network of reserves along latitudinal gradients, protecting source populations for larvae, protecting naturally resilient areas, establishing multiple reserves for each habitat type including deeper and offshore areas, and creating reserves to address a variety of needs (fisheries, biodiversity, etc.).
- Significantly increase the total area of MPAs; 1 million hectares will not be enough.
- Promote Integrated Coastal Zone Management, and consider the effects of upland watershed activities on coastal marine ecosystems such as mangroves, coral reefs, and sea turtle nesting beaches.
- Incorporate climate change into outreach efforts focused on marine resource use.
- Reduce non-climate stressors, including pollution, and unsustainable harvest, and excessive sedimentation, while providing alternative, sustainable, culturally appropriate sources of food and income.
- Use national legislation and enforcement to better govern the behavior of large companies and international interests.
- Support community engagement with reserve design, management, and enforcement.
- Support a coordinated, centralized database such as the one ReBioMa has created for terrestrial ecosystems that cover marine ecosystems as well.

II. To better understand the impacts of climate change on Madagascar's biodiversity, further research and/or action is needed on:

- Establishing long-term monitoring and data collection networks to document spatial and temporal changes in basic biological and oceanographic variables.
- Basic distribution, abundance, behavior and diet on marine vertebrates, particularly mammals and turtles, which should include migratory pathways.
- Identifying and mapping variables (e.g. natural variability, anthropogenic impacts, climatic variables) that contribute to species' responses to climate change and their capacity to adapt to it, and creating and refining vulnerability models such as the one created for coral bleaching.
- Oceanographic models for the region around Madagascar that accurately reflect current conditions and likely future changes.
- Finer-scale (sub-meter) topographic maps of the coastline.
- Probable changes human pressures on marine ecosystems as a result of climate change (e.g. migration from farmland to the coast).

Section 4: Livelihoods, Impacts of Climate Change and Recommendations for Adaptation

The impacts and vulnerability of food security and livelihoods to climate change in Madagascar were addressed during plenary presentations at the start of the workshop and during the following days' technical sessions with sector based breakout discussions. The sectors examined through presentations during the technical sessions include agriculture, fisheries, human health, forestry, food security and water accessibility. During breakout discussions, the groups identified key vulnerabilities, constraints to minimizing impacts and recommended adaptation measures for certain sectors. Climate change implications for human well-being were addressed again during discussions on Protected Areas (PAs) and Livelihoods, Tourism and in regional case studies to suggest adaptation mechanisms aimed at enhancing the potential for ecologically sensitive human adaptation.

The livelihood discussions were organized and facilitated by USAID and the International Resources Group (IRG), and partner organizations. Through their support, USAID Madagascar and the USAID Climate Change team within the Office of Economic Growth, Agriculture and Trade (USAID EGAT) enabled the integration of a more in-depth consideration of projected livelihood impacts thus further facilitating the preliminary identification of synergies and conflicts between human adaptation needs and conservation priorities.

Livelihoods

Prior to the workshop, surveys were conducted on community perceptions to climate change in three regions of Madagascar: the Northeast around Masoala and Makira, the Central Highlands and the Southwest around Toliara. In particular, the field level stakeholder meetings, consultation and focus group discussions with local communities were designed to gather information about the vulnerability of local livelihoods and rural production systems to increased climate variability and climate change (step 1), to identify adaptation options (step 2) and to conduct initial analysis (step 3) to summarize and report on community level perceptions, concerns and recommended interventions (Combest-Friedman 2008).

The impacts of climate change will increase the challenge of ongoing poverty alleviation efforts in Madagascar. Communities with close dependence on natural resources for their livelihoods will be the hardest hit. Survey findings point to particularly high vulnerability among the most climate sensitive livelihood systems, namely agriculture- and fishing-based communities. Within these subsistence systems, those groups already marginalized will be at a higher risk; for example, special attention should be given to reducing vulnerability amongst women, young children, elderly, and the ill or disabled.

The following sections are based on presentations and discussions during the technical sessions. Preparatory work include, in addition to the community surveys, preliminary modeling to project future rice production, yields and vulnerability in Madagascar. The Madagascar Action Plan (MAP) is committed to doubling rice production over the next five years. What are the measures needed to do so and how will climate change influence this goal were some of the issues presented and discussed during the technical group sessions.

Technical discussions focused on the key vulnerabilities resulting from the impacts of climate change on livelihoods for agricultural and fishing communities and on local use of forest resources, adaptation options to reduce these vulnerabilities and mechanisms that can be used to scale-up proposed adaptations.

Agriculture and Husbandry

Overall, there is predicted to be a continued increase in the intensity of cyclones (particularly in coastal Northeast zones), in the intensity and frequency of flooding, and in the variation of temperature and rainfall. In the South and highland areas, droughts are predicted to increase in intensity, frequency and duration. Locust and pest invasions are also expected to increase in the Southern regions of Madagascar.

These climatic changes will negatively impact soil fertility, particularly in highland areas where increased rainfall coupled with deforestation is decreasing soil cover through erosion. Variation in the rainfall and temperature (along with increased cyclone activity in some regions) has already led to shifts in the farming schedule/calendars of local farmers, and consequently an increase in crop failure. Water supply for agriculture on the whole is expected to decrease, with increasing concerns for the level of water management/control necessary to intensify agricultural production. These impacts coupled with the existing challenges of deforestation, inadequate agricultural intensification, predominance of rain-fed agriculture, inadequate management of hydro-agricultural resources, erosion within watershed areas, and poor management of pasture lands, will lead to increased vulnerability of agricultural-based livelihoods.

Current rice yields are extremely low. In the immediate future the need and opportunities for intensifying rice production are minimally affected by climate change, but it is necessary to understand and factor in change in water availability into plans for intensifying rice production. If yield is increased via through agricultural extensification rather than intensification, we need to identify non forest habitats to do so in. To maintain coherence with one of the main recommendations emerging from the workshop – maintaining and/or restoring forest corridors, increasing crop yield has to be done in non forest habitat areas. This can be done through a rehabilitation of irrigation schemes, amongst other approaches.

Scaling up natural fertilizer production would be very useful to cope with soil degradation, particularly compost centers that collect compost waste and produce enough to sell back to surrounding farmers at a low cost. Reforestation activities have also been started in many communities, but need to be scaled up for real impact. An increase in counter-season cropping and vegetable gardening is already observed, but should be scaled up. In addition, increased research into adaptive seed varieties and consequent access to these varieties is necessary. Overall increased infrastructure and capacity-building for use and maintenance of water management systems will be required.

Technical Recommendations for Agriculture and Husbandry

- Increase efforts in the implementation of the Second Green Revolution.
- Increase agro-meteorological stations; Establish and/or improve the research-action platform; Establish climate change observatories.

- Reinforce and improve the national microfinance strategy.
- Promote farmer-to-farmer learning.
- Strengthen the basis for fair trade.
- Professionalize the cattle herding livelihood and increase/reinforce cattle herder associations.
- Increased access to veterinarians.
- Promote (via production, multiplication, and dissemination) adapted/climate resilient seed varieties.
- Establish or enhance communication structures and mechanisms at all levels.

Forestry

Forest-based livelihoods will be increasingly vulnerable as forest cover decreases and the number of both natural and human-induced fires rises. In particular, forests around protected areas are projected to increase in vulnerability with the increasing pressures of climate change. A proliferation of invasive species, linked to natural disasters (e.g. cyclones in the Northeast) and human activities (e.g. slash and burn agriculture), as well as a reduction in the natural regeneration capacity of forests has already been observed. Landslides have increased in frequency with forest loss while current government services have been too weak to seriously counteract the continued degradation.

In order to adapt to the increased vulnerability posed by a reduction in forest cover and extractable timber products, an evaluation of agro-forestry options and use of non-timber products should be emphasized. To capitalize on the benefits of reforestation, there must be increased knowledge of, and consequent promotion of, native species. In addition, diversification of reforested species should be promoted, in part to better control invasive plant and animal species. These coping mechanisms should be integrated into continued efforts in management transfer around protected areas and support for co-management systems.

Technical Recommendations for Forestry

- Reduce the vulnerability around protected areas while assuring that the human demand is met.
- Treat protected areas that are near each other as a collective entity rather than isolated protected areas.
- Promotion of multi-species plantations and native species over monospecies.
- Improve zoning, land use planning, and forestry planning.
- Improve governance at all levels (national, regional, local).
- Ensure proper allocation and management of funds.
- Improve inter-ministerial communication and dissemination of key climate change reference documents.

Fishing

Offshore fish stocks have been greatly affected by sedimentation (impacting coral, acidity, temperature), which has been exacerbated by the increase in frequency and intensity of cyclones in the Southwest and Northeast. There has been increased migration to new fishing grounds, increased supplementary livelihoods, and, in the worst case scenario, conversion from the livelihood altogether. This latter coping mechanism is especially worrisome because conversion from a fishing-based livelihood to a livelihood based principally on agriculture (vulnerable itself) may not be a viable or sustainable alternative. Fishermen are on the whole required to travel longer distances out to sea to fish, creating an increased reliance on material and financial aid to obtain the necessary equipment (e.g. motors) to do so. Climate related stresses coupled with over-fishing increase the vulnerability of fishing-based livelihoods. Onshore fishing is most vulnerable to water supply and quality, sedimentation, and the migration of species.

In order to best obtain material, financial, and technical aid, as well as increase the rights of small-scale and line fishermen, more attention should be given to the creation and improvement of fishermen's associations/cooperatives. Further energy should also be put into the development and improvement of community management systems for marine resources. For onshore aquatic resources, there should be increased attention given to land use planning, including the intensification of fish-farming in rice fields and the protection of watersheds. Overall, a diversification of fishing activities will help mitigate vulnerability of fishing-based livelihoods. Achieving resilience to climate changes relative to fishing will require reinforcement of coastal management, including the planning and prioritization of the implementation of a national network of marine protected areas, improved regional communication strategies, and improved coastal surveillance; as well as intensification of onshore fishing activities.

Technical Recommendations for Fisheries

- Stop or reduce sedimentation, improve water quality for the protection of watersheds
- Communication frameworks to include all stakeholders.
- Reinforce an institutional framework for the implementation of the PANA and incorporate climate change in the MAP.

Section 5: Integrating Climate Change into Conservation Strategies

Protected Areas (PA) and Tourism were discussed during technical sessions as two conservation strategies that need to be made resilient to the impacts of climate change. The PA and Livelihood session formed a central piece of the workshop, with the goal of informing the decision making process of the Durban Vision on selection of new PA sites for both marine and terrestrial biomes. For the PA sessions, discussions were first split into two focal groups: identifying targets for conservation priorities and identifying regions important for livelihood adaptation and needs. Subsequent to these discussions, terrestrial participants reassembled into four groups categorized along the earlier habitat type discussions (humid forests, dry forest, spiny forest and extreme north), with each group including representatives from the biodiversity and human livelihoods' fields. The ultimate objective of these discussions was to improve our understanding of the synergies and potential conflicts between land use priorities for conservation and human adaptation.

Protected Areas and Livelihoods on Land

Madagascar is committed to expanding its protected area network from 1.7 million hectares to six million hectares, a threefold increase of area under protection, over a period of five years starting in 2003. The process of identifying sites for establishing protected areas is guided by the Durban Vision Group, formed after President Marc Ravolomanana of Madagascar made this commitment at the 5th IUCN World Parks Congress held in Durban, South Africa, in 2003. The process for expanding the network of PAs is well underway, however, without considering the potential impacts of climate change on vulnerable species and habitats. One of the primary objectives of holding this workshop was to generate the information needed to integrate potential impacts of climate change into the design of the protected areas network. An additional consideration was the potential of the indirect impacts of human adaptation strategies on areas identified as conservation priorities. The goal of the protected areas and livelihoods' session was, thus, to establish regions important for protection and regions important for livelihoods (herding livestock, rice agriculture, etc.). This would be a first step towards understanding the potential synergies and conflicts between adapting conservation strategies and human adaptation priorities.

The goal for the biodiversity and PA discussions was to synthesize the prioritization of important regions identified during the earlier taxonomic groups and regional discussions based on habitat types: humid forests, spiny forests, dry forests and the extreme north. The biodiversity discussion identified habitats for inclusion into the protected areas network based on resilient areas, critical corridors and vulnerable regions discussed in earlier sessions.

During the integrated biodiversity and livelihoods' discussions participants highlighted the regions prioritized for human adaptation based on importance for animal husbandry, agriculture, and cattle and regions prioritized for conservation. Experts were tasked with comparing between these regions to identify:

- Areas of conflict.
- Opportunities to minimize biodiversity and livelihood impacts simultaneously ("win-win").
- Most appropriate management interventions to minimize and moderate impacts on biodiversity and livelihoods.
- Identify critical knowledge gaps (site-based or cross-cutting).

Outcomes and Next Steps

Participants recommended that all further forest degradation and destruction be stopped immediately to re-build and maintain ecosystem resiliency. Continued deforestation and degradation will greatly exacerbate the impacts of climate change and will amplify its expected consequences. Pre-workshop modeling of vegetation and species' ranges together with experts' insights have helped to identify priority regions to build the resiliency of the network of protected areas, but more sophisticated analyses will also be needed to ascertain the value of including these areas and prioritizing the process of inclusion. Participants recommended that the government embrace ecological restoration as an important way to contribute to environmental resilience and biodiversity conservation in the face of climate change, and to provide a valuable source of wood and non-timber forest products to communities dependent upon natural resources. Plans for the protected area system also need to integrate environmental functions that are provided by protected areas. New protected areas should be established specifically to maintain environmental functions in areas where human livelihoods are the most vulnerable to climate change. Human benefits of mechanisms such as payments for ecosystem services (PES) need to be further evaluated and instituted around these protected areas. For example, an initial study conducted on bundling and mapping of ecosystem services (biodiversity benefits, water provision and carbon sequestration) yields priority areas that can be targeted for ecosystem services and provide both human and conservation benefits. Provision of water weighted for irrigation, direct human consumption and mangrove growth is shown in Figure 4a and areas suitable for targeted ecosystem services are demonstrated in Figure 4b. The preliminary results of this study indicate that 41% of the areas most suitable for PES are already protected areas, 21% are in areas proposed for new protected areas, 18% are in areas proposed for new forest reserves that would allow for sustainable timber management, and 20% did not overlap with any existing or proposed conservation intervention (Honzak 2008).

The discussions also built consensus around the importance of seeing the emerging carbon markets as a major development opportunity for Madagascar through REDD and the CDM mechanisms. However, in order to ensure the long-term viability of these adaptation and financing strategies, the Government of Madagascar should ensure that resources from carbon markets flow to local communities to provide human livelihood benefits.

As a preliminary step participants identified regions important for human livelihoods and for biodiversity. An initial discussion shows overlaps between zones that are important for agriculture, husbandry, rice production and biodiversity conservation. For example, the south which emerges as a critical region for protecting forests and ecological restoration of habitats is also important for various livelihood activities – livestock and agriculture. Similarly areas in the west around Menabe are important for both livelihoods and conservation, as well as in the north. However, this analysis needs to be done in greater detail and more methodically to produce verifiable results on overlaps between regions important for biodiversity and human adaptation. Such an analysis would be the first step in understanding the role of human adaptation in forcing land use changes with potential detrimental impacts on conservation. Alternatively, such an exercise is also necessary to evaluate opportunities for synergistic adaptation for communities and conservation efforts.

The critical next step is to hold discussions within regions on what the opportunities for simultaneous management for biodiversity conservation and livelihood benefits are while identifying potential conflicts well in advance in order to moderate such conflict causing impacts. One of the policy recommendations is to set up cross-sectoral task forces to address these overlaps and identify opportunities and management options to minimize impacts on biodiversity and livelihoods.

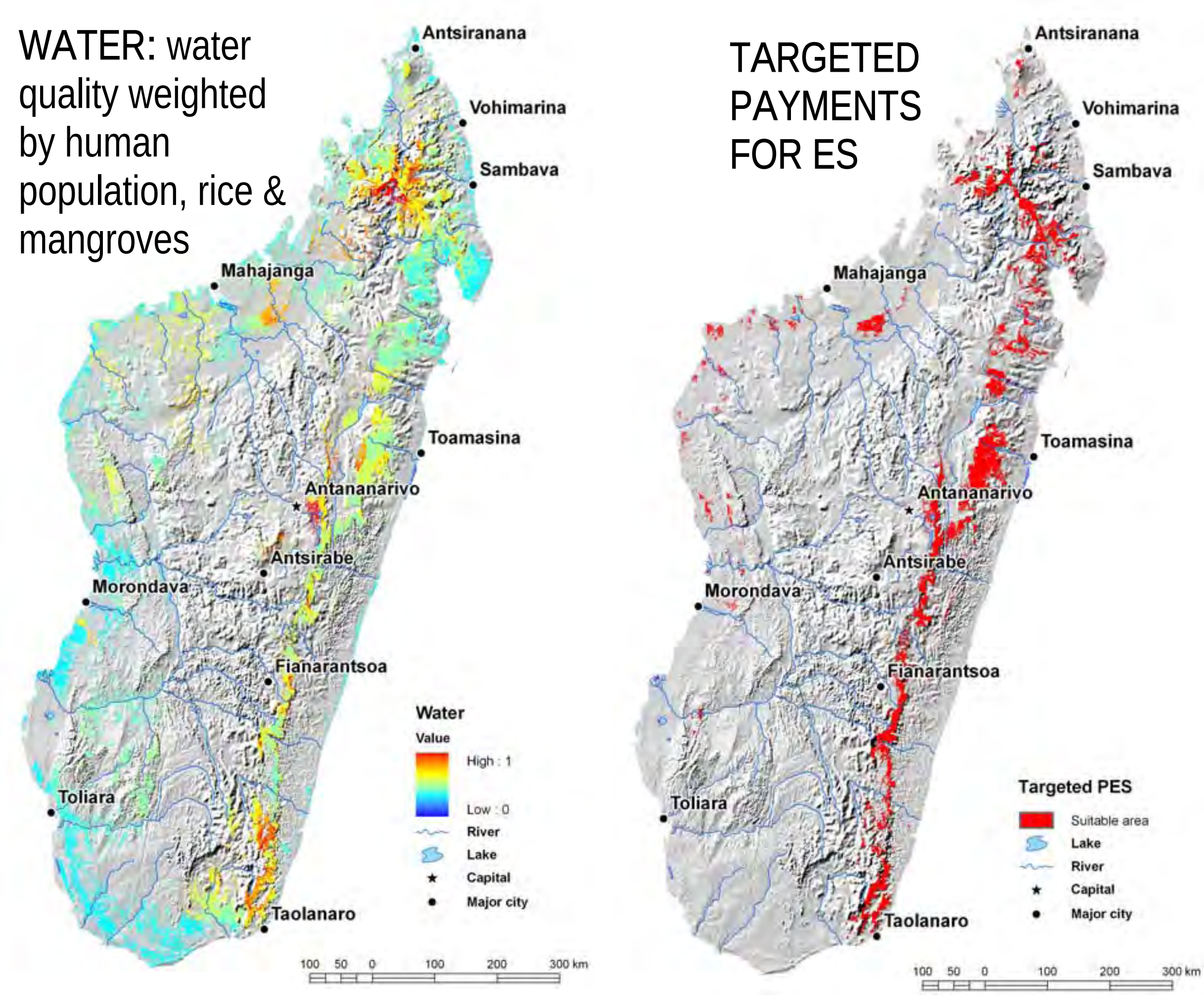


Fig 4a Provision of water quality weighted for benefits to communities, irrigation and mangrove forests. Fig 4b Suitable areas identified for targeted ecosystem services.

Marine Protected Areas

Madagascar has taken a strong stand on protecting its rich biodiversity by expanding its existing terrestrial protected area network to six million hectares and by establishing an initial goal of one million hectares of marine protected areas. Workshop participants emphasized that one million hectares will not be enough to ensure sustained marine biodiversity and livelihoods, and recommended that the government significantly expand its goal for total area of MPAs. Discussions were split into two focal groups: climate-smart selection criteria for MPAs, and strategies for MPA management that maximize resilience to climate change.

Within the past few years, the Commission for Environment and Fisheries (CEP) has undertaken a planning exercise using nine criteria to identify 29 potential MPA sites. Climate change effects were not included in the nine criteria, but as the MPA selection and designation process is still relatively new, there is an excellent opportunity now to incorporate climate change into marine protected area prioritization and management. Thus, this workshop was held at a critical time in the development of the MPA selection process.

Key questions that need to be considered as the siting process goes forward are:

- Do any new sites need to be added to the list? Sites that may be resistant and resilient to climate change may not have been included if they did not rank highly in the existing criteria.
- Do the existing sites need to be re-ranked amongst one other, as climate vulnerability may affect the urgency of establishing protection at one or more sites?
- Do the zoning, shape and size characteristics of any of the potential sites need to be revised with respect to climate change? In particular, bigger protected areas will include more habitat and more potential climate refuges, with greater options for buffering against future climate change threats.
- Does the distance or separation between protected areas need to be considered to ensure that MPAs function as a network? Connectivity between individual MPAs is a critical feature for network functionality, and needs to be incorporated.

Another emerging concern in Madagascar is the rapid expansion of oil and gas exploration and mining. It is essential that Madagascar take a pro-active approach to minimizing the potential harm caused by this expansion to marine ecosystems and the communities that depend on them. Terrestrial mining can have significant detrimental effects on marine ecosystems, so any new mining operations should be considered with an eye on implications for marine habitats. Offshore and deep water habitats should be included in the declaration and zoning of MPAs. These habitats are particularly vulnerable to oil and gas exploration and have often been ignored when it comes to protection, yet many ecological processes depend on deep-shallow linkages. With the extension of national boundaries over seabed areas likely to come into force in 2009, the government must consider how new habitats (especially pelagic and deep water) soon to be under its jurisdiction will be included in MPA networks and climate change considerations.

To protect both marine diversity and livelihoods, it is also essential to anticipate potential effects of climate change on livelihood activities, and the implications for pressure on marine resources. By thinking ahead in this way, and by engaging communities early in discussions of how to ensure their needs are met in the long-term, we can work to minimize conflict over protected areas.

Outcomes and Next Steps

Participants agreed on the need for a background document for guidance on incorporating climate change concerns into the MPA design and management process. Such a document could explain the benefits of building climate change into planning at the beginning, as well as illustrating how to apply principles of network resilience to planning and management. This workshop should serve as a springboard to a series of discussions between CEP and workshop participants to identify a way forward for incorporating climate change concerns into the CEP process. Specifically, participants recommended the following:

- Bring the findings of this conference to the attention of the CEP through a series of CEP meetings to identify a way forward for incorporating these into the CEP process.
- Identify a period of 6-12 months in which CEP members can consider the recommendations herein, identify priority areas for further clarification and/or study, and/or targeted information gathering.
- Identify a target date for finalizing transformation of the list of potential MPA sites into a coherent network of MPAs, for tabling and approval by the CEP, and follow-up action by members and responsible parties.

Understanding and mapping biological, physical, and socioeconomic factors that contribute to marine ecosystem and species resistance and resilience to climate change effects is critical. The coral vulnerability model created for this workshop highlights the benefits of vulnerability mapping for highlighting areas where further work is needed while simultaneously facilitating effective planning.

There is also a strong need to increase awareness of climate change in communities around Madagascar, and to build support for marine management approaches that protect both biodiversity and livelihood needs. This is true at all levels, from the government to individual villages.

Tourism Development

Tourism and its development potential were discussed by development experts and practitioners to identify vulnerabilities and adaptation options. Changes in the distribution of particular ‘charismatic’ species (such as particular species of lemurs or frogs or whales) as well as changes in popular recreational areas (such as the reduction of fine sand beaches, coral bleaching) have affected tourists’ choice of destination and the tour routes or packages themselves in the recent years. Present tourism infrastructure is vulnerable to cyclones, flooding, and erosion threats; and problems in water and power supply are predicted to worsen. In terms of handicraft production, climate changes are expected to reduce raw materials used in basket-weaving and the production of wood sculptures. One of the greatest risks to developing ecotourism is the threat of coral bleaching. While the Toliara region has seen significant reef degradation, Madagascar still boasts of tourism attracting beaches and reefs. In order to safeguard this growing revenue stream for the nation, threats from coral bleaching need to be assessed for the various coral reef sites.

Building resiliency to climate change in tourism will require the rapid identification of new tourism sites with charismatic species and coral reefs that demonstrate resiliency to date, to promote ecotourism as a development pathway. Coral bleaching threats need to be minimized by limiting non climate stressors such as land-based pollution and sedimentation on these high value coral reefs. Reefs identified as resilient to date to bleaching events should be protected and developed for ecotourism. Within each ecoregion, there is a need for research, implementation, and extension of ecotourism technology (including infrastructure and management of water and power) adapted to climate factors such as cyclones, flooding, and erosion. Development of tourism should be promoted in ways that reflect changes in resources availability under likely climate change scenarios. For instance, areas that have limited fresh water now and are likely to become drier should see only limited tourist development. In order to support communities in the management of raw materials used for handicraft production, it will be important to support initiatives to improve land tenure, increase technical capacity-building and craftsmen management, and implement a transfer of management process.

Outcomes and Next Steps

- Recognizing the importance of beach tourism in Madagascar, limiting non-climate stressors on coral reefs by addressing sedimentation, overfishing and runoff issues is critical.
- Conduct resiliency assessments for coral reefs that can identify sites such as Ambodivahibe where special oceanographic or geological features provide resilience to corals under warming sea surface temperatures.
- Implement a management transfer process for basket-weaving and sculpture craftsmanship.
- Inform and sensitize tour operators as to the effects of climate change and support tourism beneficiaries (hotel owners and protected area managers) in the implementation of new, climate appropriate technologies.
- Promote research in technologies for climate change adaptation/resilience (universities and academic institutions).
- Revise code of tourism.
- Establish a network of databases on climate change related trends.

Section 6: Regional Assessments

Four regions were explored in greater detail to assess risks to biodiversity and livelihoods and develop a more in-depth set of policy and conservation recommendations for these regions. The four regions were: the Northeastern tip of Madagascar, the Northeast (Masoala, Makira, Antongil Bay), Southwest (Toliara) and the Central Highlands. These regions were selected partly on the basis of discussions during the May 2007 planning meetings, early climate change projections and areas identified as biologically more

vulnerable. Sessions comprised of participants from all the representative biome types (marine, terrestrial) and livelihood specialists. Presentations on threats and implications for specific taxonomic groups, ecosystem types, livelihoods and subsistence sectors were followed by discussions aimed at evaluating particular needs and opportunities for each region. The goal of these focused regional discussions was to identify the particular vulnerability or vulnerability enhancing biological, physical and socio-economic attributes (where relevant) and recommend adaptation measures. For Makira, Masoala, Tulear and the Central Highlands surveys were conducted to assess community perceptions of climate change impacts and adaptation measures adopted. These surveys were used to inform much of the discussion for these three regions. For the Northeastern Tip region, existing socio-economic data were used. These regional cases are summarized below.

Northeastern Tip

The Northeastern tip (NET) of Madagascar considered for this session comprises marine and terrestrial ecosystems extending from a latitude 12°20'S to the uppermost tip of Madagascar (Fig. 5). It consists of the coastal regions from Ambodivahibe to Cap d'Ambre. For the purpose of this regional discussion session the NET region was divided into two different areas based on the difference in vulnerability to climate change and anthropogenic pressures. These two areas are the Bay of Diego Suarez (BDS) and the Bay of Ambodivahibe (BOA) and the marine sites outside the BDS.

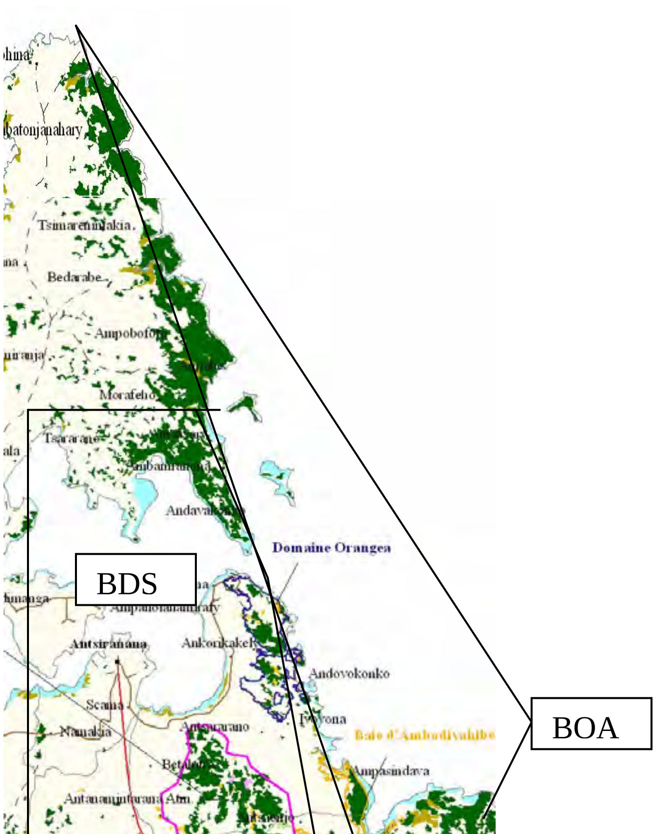


Figure 5. Area showing the extreme northern region under consideration for this case study

Group discussions during this session were split along marine and terrestrial foci, and considered both anthropogenic and bio-geophysical factors that could either promote resiliency or increase the vulnerability of the region.

The main pressures in this region include urban industries, shipping ports, and tourism. Rural communities depend upon fisheries for livelihoods; however, the Bay of Diego Suarez is heavily impacted by sedimentation. Agriculture and charcoal production are important livelihood and energy bases in the region and much of the forests are under pressure. Important forests remain in Montagne de Français and Orangea. While the marine environment of Diego is already impacted by land based activities and sedimentation, the Bay of Ambodivahibe is a high priority region for marine biodiversity protection. Ambodivahibe is home to coral reefs in good health that have managed to escape bleaching – a fact attributed to the bay's unique bathymetry, a deep marine canyon, moderated warming sea surface temperatures by being a conduit for cold water into the bay. Ambodivahibe is ringed with mangroves in good health, and fishing is the main occupation for the villages living in close proximity. Much of the fishing pressure reportedly comes from villages further north (towards Diego) or south, rather than from the small population that lives in its vicinity. Little agriculture is practiced in the region, with cattle raising one of the occupations.

This region sits in the path of cyclones and is witness to frequent high-intensity storms during the months of November to March. These climatic factors are already taking a high toll on the development capacity of the region. With a projected increase in high intensity storms and cyclones, agriculture, infrastructure, energy and other human development indicators are likely to be greatly impacted. This in turn increases the pressure on natural resources – both marine and terrestrial. Other factors that increase vulnerability of the region's marine and terrestrial biodiversity, and human communities include a high population density in and around the city of Antsiranana or Diego, lack of transportation and infrastructure, high rates of deforestation and overfishing, and physical attributes such as low-lying areas.

The coral reefs in Ambodivahibe have exhibited exceptional resilience to bleaching events to date, making the protection of the bay a top priority as a climate change marine protected area. Participants recommended that the planned boundaries of the MPA to be established in Ambodivahibe be extended to enhance the adaptation capacity of the surrounding areas to climate change. Pollution and sedimentation of the Bay of Diego Suarez from different sources should be limited and monitored in order to minimize the impacts of climate change in the bay. Restoration needs to be made on Orangea forest because of its role in the protection of the Bay of Diego Suarez. The current plan to establish a protected area in this site should incorporate the climate change impacts regarding its design and size. Coastal management should be put in place to avoid development in low-lying areas. Forest management should be improved to keep key forested areas to maintain the provision of important services for the adaptation of climate change.

Participants recommended the establishment of a monitoring system to detect the impacts of climate change on the region's biodiversity. Further studies are needed on marine biodiversity, including, biomass, connectivity, and species distribution to obtain a better understanding of the impacts of climate change and the relevant measures that need to be taken for adaptation in the region. Studies on terrestrial connectivity should be undertaken to learn about the dispersal of species in the face of climate change.

The apparent resiliency of the coral reefs in Ambodivahibe makes this a potential site to promote ecotourism to diversify the income base for surrounding communities and to provide further impetus for protecting this region.

NorthEast: Makira, Masoala, Bay of Antongil

The potential impacts and vulnerabilities in the regions of Masoala Peninsula, Makira and Bay of Antongil were evaluated during presentation and discussions, with recommendations made to cope with risks, minimize impacts and adapt to changes.

The main factors contributing to the vulnerability of biodiversity include: deforestation, unsustainable exploitation of natural resources, pollution of freshwater and near shore coastal waters, excessive sedimentation, and biological attributes such as slow regeneration capacity of littoral forests. These factors together with insufficient agricultural technology and information, under valuation of cultivable land, practices such as *tavy*, and a lack of long-term planning to incorporate potential risks and trends combine to undermine sustainable livelihood options. Together these factors exacerbate the vulnerability of both biodiversity and human livelihoods to the impacts of climate change. In addition, insufficient public services and a lack of funds to develop and maintain agricultural extension and socio-economic enhancement activities perpetuate the cycle of poverty in the region. The region is prone to cyclones, intense rains and regular flooding – conditions that significantly influence infrastructure, access to markets, agricultural practices and opportunities, and thus conservation.

During the discussions, participants recommended forest restoration using native species as one of the primary mechanisms for reducing vulnerability in the region. The river Mananara was recommended for protection as it is the second most important region for freshwater fish endemism in Madagascar. Participants stressed the need to accelerate the process of creating the protected areas around Makira and Bay of Antongil, implementing all the regulations aimed at patrolling and management of the protected areas. It is also necessary to conduct an analysis of the human dependence on natural resources around these PAs and the capacity of the zones of exploitation to meet these needs.

Participants recommended the need to have a comprehensive development plan for the northeast, which can harness the synergies between rural development needs and conservation priorities to reduce vulnerability amongst human communities and biodiversity. Reinforcing the capacity of small holder farmers and artisanal fishermen, developing pilot sites for alternative livelihood strategies and investing in region specific agricultural research were amongst the suggestions made to enhance human well-being. In addition, there is an urgent need to elaborate a plan of action to address and moderate the impacts of cyclones in the region.

Efforts need to be made to sensitize all levels of management and government to incorporate the potential impacts of climate change into their planning. Research to detail the impacts of climate change on various aspects of biodiversity and natural resources' based livelihoods is also a high priority. In order to fill key gaps in data on climate trends to facilitate planning for climate change, participants recommended the immediate establishment of climate monitoring stations in the Northeast.

Southwest

The southwest region, home of the Vezo people, is also home to the Toliara Reef System and extensive mangrove and spiny forest ecosystems. Although both marine and terrestrial ecosystems have been significantly degraded, the region is an increasingly popular tourist destination. Both government and non-governmental agencies are working to harmonize conservation and development by engaging local communities in the development of revenue-generating activities linked to protected areas.

The major non-climate threats in the region are depletion of fisheries stocks, sedimentation and dune displacement. All of these are likely to be exacerbated by the predicted climatic changes in the region.

Significant deforestation results from charcoal production, particularly following the recent de-regulation of charcoal production in the region. The de-regulation was in part a response to unreliable access to other energy sources in the region, suggesting that addressing energy concerns in a climate-friendly way, for instance through solar panels, might help to reduce deforestation. Agriculture, particularly of corn for export, is also an increasing cause of deforestation in this region.

Degradation of upland areas resulting in increased sedimentation has a strong effect on marine ecosystems around Toliara, as does pollution and runoff from the city of Toliara. Extractive mining is another major threat in the south because of the important mineral deposits there.

Human pressure on marine ecosystems has increased in response to decreased opportunities for land-based subsistence and declines in the productivity of these resource-dependent subsistence activities. These pressures may increase in the future as a result of the negative effects of decreased rainfall and increased temperature on agriculture. Severe droughts have occurred in this region in the past and down-scaled climate models suggest that this region will become even more hot and dry as climate change progresses.

Three populations of dolphins in the area have been found to be negatively affected by habitat degradation. Climate change impacts may make the situation even worse. Higher ocean temperatures may lead to reduced food availability, increased diseases, or other effects.

There are a number of actions that can reduce the vulnerability of this region to climate change. There must be capacity building at all levels, including widespread education on climate change and improved knowledge-sharing both through a centralized database such as

ReBioMa and through improved communication among individuals and organizations working in the region. There are many organizations working to protect biodiversity in this region; improved coordination among these organizations would greatly increase the likelihood of success. Key first steps in climate-smart conservation planning include identifying the most resistant and resilient areas and targeting them for protection, and taking immediate action to halt and reverse the rapid decline of the region's coral reefs.

Central Highlands

This evaluation took a stronger human livelihoods-focused approach to assessing the potential impacts of climate change. The discussions during this session focused on identifying the main factors influencing vulnerability of agriculture, forestry, public health and tourism around Fianarantsoa and Ranomafana National Park. Here, some of the last remaining tracts of the eastern rainforests with unparalleled biodiversity can be found in close quarters with high farming pressure. Strengthening the livelihoods of people living around the protected areas and other areas of conservation significance is of critical importance to safeguarding conservation actions and goals for the region. Participants recommended strategies for minimizing impacts and overcoming barriers to adaptation such as promoting ecological restoration and reforestation, reducing land tenure insecurity and strengthening local forestry governance.

Adaptation mechanisms identified during this session include reforestation of land from a watershed perspective – in order to minimize the destructive impacts of regular flooding in the rainy season, ecological restoration needs to be done at watershed scale. This is also needed to minimize the excessive loss of agriculturally suitable topsoil and prevent sedimentation of rivers, all of which flow into coastal waters. The participants recommended expediting the award of plantations and promoting long-term forest management schemes as a means of sustainably managing forest resources to prevent further loss of forests. There is a need for improved management of existing plantations to enhance income generation and maintain connectivity with corridors.

Participants recommended the restoration of degraded areas to improve ecological services, especially exploring opportunities for agroforestry to promote species that contribute to food security and income generation. Agriculture development should be clarified and planned along ecologically sensitive pathways – that is, adopting more of an eco-agriculture approach. Developing improved fallows, increasing farmer to farmer extension approaches, and dissemination the best farming practices are amongst recommendations aimed at enhancing the yields from agriculture to safeguard livelihoods and thus minimize the impacts of human adaptation on biodiversity. Participants recommended the diversification of agricultural practices to promote alternative livelihoods such as beekeeping, fish farming and promoting small scale animal husbandry. Ecotourism and agrotourism should be promoted to facilitate an income diversification strategy where possible. Amongst the most immediate recommendations for overcoming obstacles to adaptation is the need to strengthen local forestry governance and land tenure systems. Participants also recommended maximizing the rural benefits from economic valuation of ecosystem services, improved micro-finance schemes and reviewing the opportunities and challenges presented by climate change mitigation activities (e.g. growing biofuels).

Section 7: Monitoring and Measuring Changes

Presentations and discussions on the morning of the third and last day of the workshop focused on ecological monitoring needs and measuring change methodologies needed to collect relevant data over a length of time to shed light on the impacts of climate change on the floral and faunal community of Madagascar. While this session was specifically dedicated to more in depth presentation and discussion of knowledge gaps and monitoring needs, these long-term data and information constraints were recognized and highlighted in most sessions from the onset of the technical discussions.

Terrestrial

Presentations focused on monitoring the loss of forests, forest fires, and linkages between increases in forest loss and El Nino years which could shed light on future trends under climate change. Potential linkages between lemur feeding behavior and changes in tree phenology under changing precipitation patterns were considered based on the analysis of a twenty year dataset from Ranomafana. Participants recommended restoration ecology studies to fill existing knowledge gaps and assess the feasibility of growing forests and restoring degraded lands.

Experts stressed the need for monitoring to increase our understanding of how species could respond in the future to climate change. Participants discussed the role played by riverine forests in providing refuge and migratory corridors under past climate change events, and recommended further research and feasibility studies on existing riverine forests. These studies would help assess options for riverine forests' restoration and their use as migration pathways by biodiversity. One of the avenues for disseminating all available ecological and biological data collected in Madagascar is the ReBioMa program.

Recommendations for Measuring and Monitoring of Terrestrial Ecological and Climate Variables:

- Establish appropriate climate monitoring stations at representative sites, to capture seasonal and long-term trends in changing precipitation and other climate variables within regions of conservation interest as well as rural areas.
- Maintain and restore riverine corridors, spanning elevational gradients.
- Collect empirical data to understand how different taxa could use riverine corridors for dispersal (e.g., how far; and over which elevations).
- Collect long-term quantitative data on several taxa, land cover change and climate in a coordinated fashion, and spanning a range of elevations, at representative sites in each of the major centers of endemism.
- Ecological and climate data should be made broadly available to government, NGOs and scientists to improve both climate forecasts and projections of species range shifts.
- Many changes currently observed in Madagascar are being driven by human activities at a global scale. The government of Madagascar should take advantage of REDD, as a new and unprecedented financing mechanism for increasing the resiliency of ecosystems in Madagascar to global change.

Marine

Presentations focused on remote sensing techniques for coastal management, monitoring protocols for coral reefs, current work on building resilient MPAs in the region, and approaches to network design and site selection. While satellite images provide a wealth of critical information, there is a need for information with finer spatial resolution for coastal MPA planning. Participants debated the need for a uniform monitoring protocol. While data inter-compatibility is important, it is not essential that everyone use exactly the same method. The first focus should be on what we want to measure, and the second on choosing site-appropriate methods that best measure the desired variables. Another MacArthur-funded project is developing a rapid bleaching assessment protocol, and it would be useful to develop something similar for other ecosystems. A key need in the development of such protocols in other ecosystems will be improved understanding of metrics that best measure resilience to climate change. All participants felt that the opportunity for knowledge-sharing and coordination provided by this session was important, and recommended exploring ways to maintain coordination in the future.

Recommendations for Measuring and Monitoring of Coastal and Marine Ecological and Climate Variables:

- Coordinated regional coastal and oceanographic monitoring networks to improve our understanding of basic oceanographic and coastal processes and capture seasonal and long-term trends in variables such as sea level, ocean temperature at a variety of depths, pH, etc.
- Updated mapping of sea turtle nesting beaches, and programs to engage local communities in monitoring and protecting turtle nests.
- Complete assessment and mapping of coral reef and other critical habitat distributions around the country, particularly in areas currently not well-documented.
- Detailed mapping of mangrove species distribution for several key areas, along with long-term monitoring of changes in species composition, mangrove health, and rate of peat build-up relative to sea level rise.
- Fine-scale (sub-meter) topographic mapping for key mangrove and sea turtle nesting areas, either through LIDAR (Light Detection and Ranging; an airplane-based remote-sensing technology) or on-the-ground work; without this, it is impossible to systematically and accurately assess the vulnerability of these ecosystems to sea level rise.
- Long-term monitoring programs for key taxa (e.g. marine mammals, sea turtles, seagrasses, important fish and invertebrate species), coupled with funds and capacity for data analysis. This should include increased tracking of migratory species to allow coordinated conservation efforts throughout a species' migratory range.
- Increased modeling and measuring of terrestrial runoff into marine ecosystems, both for current conditions and for projected future conditions. Models and measurements should address effects of upstream habitat degradation on marine ecosystems, and terrestrial and marine monitoring efforts should be more closely coordinated.
- Increased remote sensing capacity in the region.

Section 8: Conclusion and Workshop Recommendations

The final plenary presentations on technical recommendations emerging from the terrestrial, marine, livelihoods and integrated biodiversity-livelihood discussions were made on the afternoon of the third and last day of the workshop. Plenary presentations highlighted the findings of the technical sessions on projected climate change, threats to and implications for various taxonomic groups and socio-economic sectors examined, their vulnerability and recommendations to build resiliency and enhance adaptation. These presentations were followed by a plenary discussion to draft the main conclusions and overall recommendations of the workshop. The text of the recommendations follows at the end of this section.

Discussion

The three days of discussion between climate, ecology and livelihood experts, conservation practitioners and policy makers provided a forum for understanding the vulnerability of marine and terrestrial biodiversity and the livelihood sectors to changing climate. These discussions laid the groundwork for integrating an understanding of climate change impacts into conservation planning in Madagascar, and specifically into the ongoing process for expanding terrestrial and marine protected areas, by identifying strategies to facilitate enhanced conservation and enable human adaptation while maintaining natural resources.

For adaptation to climate change, the technical steps necessary in follow-up to the workshop are feasibility studies of riverine corridor protection and restoration, income from REDD, CDM and energy production, restoration of fragmented forests, provision of alternatives to community use of natural forests that are needed for biodiversity adaptation, study of human adaptation to climate change and how it may impact biodiversity, and improved monitoring systems and how to maintain them in remote locations.

Biological considerations suggest that conservation of riverine forest corridors, restoration of native forest for connectivity and management of all native forest for species' responses to climate change are essential elements of an adaptation strategy. On the research and implementation side, immediate priority should be given to protecting all remaining forest habitats, restoring corridors linking fragmented and highly vulnerable forests. Mechanisms linking benefits from carbon mitigation to human well-being need to be elucidated. Just as important, synergies between areas of mitigation and ecological adaptation need to be assessed. A first step in reinforcing ecological resiliency through the restoration and maintenance of corridors should be a study to assess the options and feasibility of protecting and, where necessary, restoring riverine corridors. Riverine corridors are important to maintain migration pathways that have facilitated species range migrations in the past and that may be expected to do so in the future. The status of riverine corridors is poorly-known, and is a major research priority. Restoration of these connective habitats will facilitate future biological responses to climate change through mechanisms indicated to have been important in past changes.

Between the riverine corridors, areas of endemism have developed that are vulnerable to fragmentation. Decreasing fragmentation in these forests restores capacity for them to endure climate change with little excess species loss. The high endemism in these areas exists precisely because they lack broader connectivity. These forests are very vulnerable to climate change in their current, fragmented state. Because Madagascar has already lost most of its natural forest, the forest that remains will play a critical role in allowing species movements in response to climate change. Madagascar has already committed to tripling the size of its protected area system. The roughly 30% of natural forest remaining outside of protected areas is needed to provide wood, forest products and income to some of the poorest communities in the world. Resolving the conflict between biological need for natural forest and human needs for subsistence and income is best met by restoration of native forest and creation of forest plantations on degraded land. Restoration of forests and minimizing forest loss will also address excessive sedimentation and flooding during rains, thereby improving water quality and preventing damage from crops. Managing land use at a watershed scale is extremely important to safeguard water, limit sedimentation and runoff into rivers and coastal waters, and ultimately limit the non-climate stresses on both terrestrial and marine ecosystems to build resiliency.

A critical next step is the establishment of a comprehensive climate monitoring network. This is necessary given the lack of adequate climate monitoring stations, especially in areas of conservation interest such as forested and montane areas, and marine habitats. This is needed to not only inform climate scenario modeling to generate more accurate projections but also to monitor species' response to climate variables. Such a network of terrestrial, freshwater and marine monitoring sites will involve systematic and standardized collection of quantitative data on taxonomic groups, water quality, and habitat quality, socioeconomic and climatic variables.

The next steps for integrating climate change into marine conservation in Madagascar include improved vulnerability modeling for key species and habitat types, increased climate change expertise for marine conservation practitioners and policy makers in Madagascar, coordinated monitoring and data sharing programs for variables linked to climate vulnerability, and improved maps of species distribution in priority areas identified by workshop participants. The relative dearth of basic information on coastal and marine species and habitat types must be addressed. Rapid assessments of mangrove and reef ecosystems in areas identified by experts as having the potential to be particularly resistant or resilient to climate change effects will verify initial impressions, provide baseline data from which to measure future changes, and support effective management planning. For instance, Ambodivahibe in the northeast has a unique topography that keeps water cooler than much of the surrounded ocean, providing a refuge during regional coral bleaching events. From bathymetric maps, it appears possible that similar "cool spots" may occur further south along this stretch of coastline, but on-site measurements are needed to confirm this.

Fine-tuning the coral reef vulnerability assessment model presented at the workshop will highlight what information is needed to further improve country-wide vulnerability mapping for this critical ecosystem, as well as helping to pinpoint key sources of climate change vulnerability which could be the target of focused action to increase resilience (e.g. land-based pollution, unsustainable harvest, etc.). Workshop participants expressed a strong desire to expand spatial vulnerability mapping to other habitat types and species, with mangroves and sea turtle nesting beaches identified as the top priorities. Mangrove vulnerability mapping would synergize with other efforts in the region (e.g. a GEF-funded project on mangroves and climate change in Cameroon, Tanzania, and Fiji), and work with sea turtle nesting beaches could closely parallel the MacArthur-funded project in the Caribbean.

An overarching theme is the importance of integrating assessment and management of terrestrial and marine health. We need to incorporate the conservation and overall health of upland terrestrial areas into vulnerability assessments for coastal marine ecosystems, and work to link marine and terrestrial protection and management.

Protected areas expansion on land and water under the Durban Vision needs to integrate climate considerations. Information generated at the workshop is the first step in enabling this process to become “climate conscious.” Immediate priorities include in depth analyses to confirm the resiliency and/or vulnerability of regions identified for priority action during the discussions on PAs. Additionally, further analysis of potentially conflicting and complementary resource use patterns for regions identified during these discussions by livelihood and biodiversity experts needs to be initiated. This would enhance our ability to predict zones of synergies and conflicts well in advance, to implement actions necessary and plan with a long-term, climate change- integrated vision.

Much of what is needed to facilitate the integration of climate change considerations into conservation planning needs to be done in tandem with safeguarding human livelihoods. There is an urgent need to diversify the income base for many communities, to strengthen agricultural systems via ecologically sensitive intensification, enhancing access to markets and technology transfers to improve yields. An insurance scheme to provide a safety net to farmers should be considered with future climate risks from increased storm and cyclone intensity in mind.

To plan effectively for climate change scenarios biodiversity conservation strategies need to take into account community based adaptation actions already being adopted. We need to understand how future resource use changes may impact priority areas for conservation and minimize these impacts to the extent possible. Madagascar presents opportunities for both climate mitigation and adaptation. Given the close linkages between biodiversity and human well-being, conservation planning has to be in coordination with human adaptation under climate change and vice versa.

Key Recommendations
The overall recommendations generated by participants at the end of the three days of discussions and presentations are highlighted below.

Technical Recommendations

- *Strengthen national policies and institutions for Marine Protected Area (MPAs) selection and establishment, including climate change criteria for prioritization of key sites. Focus the planning and establishment of MPAs on a robust and resilient network covering all marine and coastal habitats, protecting key species and extending from the shore down the continental shelf and to deep sea habitats.*

- *The Government of Madagascar, in collaboration with the conservation and scientific community, should develop an action plan to maintain, restore and advance understanding of riverine corridors, including those that span elevation gradients.*

- *Maintain or restore forest corridors to reconnect forest fragments.*

- *Ensure sustainable forest management to maintain habitat for biodiversity and to provide refugia to ensure availability of future necessary habitat.*

- *Implement a long-term monitoring program with a network of marine, terrestrial and freshwater sites, distributed across latitudinal gradients and that cuts across the hypothesized gradients of change. This will involve systematic and standardized collection of quantitative data on taxonomic groups, water and habitat quality, and socioeconomic and climatic variables. The climate-monitoring network should be implemented immediately. Data generated by the network should be immediately and freely available (in both raw and synthesized forms).*

- *Clear synergies exist between human well-being and ecosystem functions and between terrestrial and marine ecosystems. Actions are needed to enhance resiliency and adaptation across all spatial scales with ecological restoration and watershed management being a crucial part of this response.*

- *In high biodiversity regions, promote land tenure, environmentally respectful and ecologically sustainable intensification and diversification of agriculture, environmentally sound energy sources, infrastructure more likely to withstand predicted climate changes, following the specific strategy for rural development (see above).*

- *Support risk assessments and improve our understanding of ongoing community-based initiatives to reduce vulnerability and adapt rural livelihoods to climate change, to better understand how human migration will be affected under stress from climate change.*

- *Reinforce SAPM and CEP planning and the effective management of protected areas by integrating climate change impacts, and ensure sustainable management in order to maintain all of Madagascar's natural forest, marine and freshwater ecosystems.*

Policy Recommendations

- *Establish an Inter-Ministerial Task Force on Climate Change under the supervision of the EPP/PADR that will integrate environmentally sound adaptation measures across sectors (Oil, Tourism, Mines, Agriculture, Fisheries, Regional Planning), in the Madagascar Action Plan (MAP), in regional MAPs, and in national strategies, with the support of the institutions attending the workshop.*

- *Re-examine and adapt the PANA by integrating data and recommendations from this workshop.*

- *Develop and disseminate methods of information-education-sensitization on climate change and adaptation across all levels and sectors.*

- *Develop a rural development policy around areas most vulnerable to climate change, in particular through updating the Rural Development Policy Letter (LPDR) to include the recommendations of this workshop.*

- *Take advantage of the opportunities presented by a variety of different financing mechanisms like the MDP (under the Kyoto Protocol), Adaptation Fund, etc. The government should develop a national vision to utilize these mechanisms and tools to finance and promote rural development and conservation.*

- *Explore different methods and mechanisms that are in place for ecosystem service payments (water, disaster prevention, etc.).*

- *Madagascar should pay very special attention to developing a national strategy for Reduction in Emissions from Deforestation and Degradation (REDD) interlinked with national policy on adaptation. REDD provides multiple benefits, including maintenance of carbon stocks and other critical ecosystem services, as well as providing added resources for biodiversity conservation and direct benefits to local communities. Madagascar has already led with some of the world's first pilot projects on REDD, and REDD post-Bali now presents a unique historic opportunity to continue protecting forests and to secure investments in forest conservation far beyond anything else realized thus far. Madagascar is for the moment uniquely positioned to become a world leader in further development of methodologies and in securing major international investments through this new approach.*

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Appendix I. Workshop Agenda

Workshop Agenda

<u>Monday, January 28th (Salle de Réunion, Ministère de l'Economie, du Commerce et de l'Industrie, Anosy)</u>

14:00 – 15:30

Opening Remarks:

- **Dr. Russell Mittermeier, President of Conservation International**
- **His Excellency Niels Marquardt, United States Ambassador to Madagascar**
- **His Excellency Harison Randriarimanana, Minister of Environment, Water, Forests and Tourism**

Presentations (Government of Madagascar)

- Objectives of the workshop within the context of Madagascar's current environmental and rural development goals and guidelines
- Climate Change context for Madagascar based on existing international and national frameworks and strategies for adaptation.

15:45 – 18:00 **Plenary Presentations: Modeling Climate Change Predictions and Implications of Climate Change**

15:45 – 16:00 – Climate change trends and adaptation in Madagascar
Presented by: Zo Rabefitia, Direction Générale de la Météorologie

16:00- 16:15 – Future climate scenarios for Madagascar based upon modeled layers by University of Cape Town, using precipitation and temperature data
Presented by: Mark Tadross, University of Cape Town

16:15 – 16:30 – Scenarios for terrestrial species' distribution changes under climate predictions based upon ReBioMa and MBG species' modeling
Presented by: Alison Cameron, University of California, Berkeley

16:30-16:45 – Oceanography and Climate Change for Madagascar
Presented by: Juliet Hermes, South African Environmental Observation Network

16:45 – 17:00 - Scenarios for marine species
Presented by: David Obura, CORDIO

17:00 – 17:15 – Projected and observed impacts on livelihood sectors (agricultural productivity) from modeling and stakeholder consultations
Presented by: Harifidy Ramilison (Consultant), Patrick Rasolofo (CNIS); Andoniaina Ratsimamanga (WB)

Appendix I. Workshop Agenda

17:15 – 18:00 – Questions and Answers

Tuesday, January 29th (Palais National de la Culture et des Sports, Mahamasina)

8:30 – 8:45 **– Presentation of the agenda for the technical sessions**

8:45 – 9:15 – Plenary: Climate scenarios for Madagascar
Presented by: Mark Tadross (UCT) and Robert Hijmans (IRRI)

9:30 – 13:00 ***Technical Sessions: Parallel interactive working group sessions***

Objective: *Provide a platform for focused presentations and discussions in order to assess the level of climate change induced risk, adaptation needs, and regional priorities for each of the following key area types:*

- Terrestrial Ecosystems
- Marine and Coastal Ecosystems
- Rural Livelihoods

1. **Terrestrial Ecosystems –**
   Coordinating Agency: Missouri Botanical Gardens – Madagascar and MEEFT
   Facilitators: Pete Lowry and Omer Laivao

2. **Marine and Coastal Ecosystems**
   Coordinating Agency: WWF, SAGE, MEEFT
   Facilitator: David Obura, CORDIO East Africa, Hajanirina Razafindrainibe, Laurette Rasoavahiny

3. **Impacts of Climate Change on Livelihoods**
   Coordinating Agency: USAID-Madagascar and IRG, MAEP, MEEFT
   Facilitator: Harifidy Ramilison (Consultant), Patrick Rasolofo (CNIS)

13:00 – 14:00 – Lunch

14:00 – 16:15 **– Technical Sessions Continue**

16:15-16:30 Coffee Break

16:30-18:00 **– Plenary: Report back on Technical Sessions**

Objective: *(1) Report back on key results, recommendations and regional priorities by each session group and (2) Discuss overall regional priorities for Madagascar based on the priorities identified by individual sessions*

Appendix I. Workshop Agenda

16:30 – 17:00 – **Terrestrial Ecosystems' Group**

17:00 – 17:30 – **Marine and Coastal Ecosystems' Group**

17:30 – 18:00 – **Livelihoods' Group**

Wednesday, January 30th (Palais National de la Culture et des Sports)

8:30 – 9:00 - Plenary: Brief presentation on previous day's concluding discussions

9:00 – 13:00: **Sessions in parallel: Protected Areas and Livelihoods (Marine and Terrestrial)**

9:00 - 13:00 - ***Protected Areas and Livelihoods***

Objective: *Propose mechanisms to address regional problem areas or vulnerabilities for protected areas located in each region*

1. **Protected Areas and Livelihoods (Terrestrial)**
Coordinating Agency: CI, ReBioMa, ANGAP, DGEF
Facilitators: Claire Kremen (ReBioMA), James MacKinnon (CI Madagascar), ANGAP, Laurette Rasoavahiny, Harifidy Ramilison

2. **Protected Areas and Livelihoods (Marine)**
Coordinating Agency: WWF, ANGAP, SAGE, CORDIO,
Facilitators: Jennifer Hoffman, David Obura

13:00 - 14:00 – Lunch

14:00 – 14:30**: Report back on Protected Areas discussions**

14:30 – 18:00 **Regional Case Study Sessions**

Objective: Identify problems, vulnerability and potential adaptation measures to address the impact on both biodiversity and livelihoods within regions
Coordinating Agencies: CI, WWF, WCS, ANGAP, DGEF, USAID/IRG

- Multiple breakout groups with representation from the livelihood, terrestrial, and marine sessions for each of the four regions:
    - Southwest (Toliara) – WWF
    - Central (CAZ & COFFAV) – USAID/IRG
    - North-East (Maronstetra & Baie D'Antogil) – WCS
    - North (Diego & Ambodivahibe) – CI

Appendix I. Workshop Agenda

Thursday, January 31st (Palais National de la Culture et des Sports)

8:30 – 9:30 – Plenary: Report back on regional group discussions

9:30 - 12:00 **– Sessions in Parallel: Measuring and Monitoring Changes**

1. Measuring and Monitoring Changes: Research priorities and filling knowledge gaps (Terrestrial)
Coordinating Agency: CI (TEAM) and ONE
Facilitator: Sandy Andelman

2. Measuring and Monitoring Changes: Research priorities and filling knowledge gaps (Marine)
Coordinating Agency: WWF

12:00 – 13:00 **–**
Coordinating Agency: CI & WWF
Discussion on recommendations and validation of presentations to be given in the afternoon

13:00 – 15:00 **-** Lunch

15:00 – 16:30 – **Plenary**
Concluding presentation by the Government of Madagascar and partners on workshop results, priorities, and future action needed.

16:30 **Closing Remarks, Poster Session and Reception**

Appendix II. English Literature Review

Potential impacts of anthropogenic climate change on the terrestrial and marine biodiversity of Madagascar

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Appendix II. English Literature Review

Introduction – *Madagascar's present day climate*

Madagascar is home to the world's richest concentration of endemic flora and fauna (Wilme et al. 2006). It has been designated a biodiversity hotspot, an attribute that is in part a consequence of geographic variation in climatic regimes. Madagascar is located off of the southeast coast of Africa at 12-25°S, 43-51°E, extends 1,650 km long and 580 km wide and has both tropical and subtropical climatic conditions. The topography and terrestrial ecosystems are diverse, ranging from spiny desert forests at sea level in the southwest to montane rainforests at altitudes of >3,000 m along the eastern ridgeline (Kull 2002, Jury 2003). Southwestern Madagascar is dry and cool (precipitation: 350 mm year^{-1}, temperature range: 20-27°C) relative to the humid north (precipitation: 3,500 mm year^{-1}, temperature range: 26-29°C; Ingram and Dawson 2005). Grassland and savanna are common throughout low-elevation, inland portions of Madagascar, and tropical dry forest habitats are located along the west coast (see Figure 1, Kull 2002). In upland, mountainous areas, temperatures below freezing are common and rarely exceed 20°C during the austral winter (Jury 2003). Madagascar's climate is characterized by two seasons. Dry trade-wind conditions are common in the austral winter (May-September), whereas monsoon-driven wet conditions occur during the austral summer (December-March; Jury 2003). During the wet season, rainfall on the east coast is often two- to three-fold greater than on the west coast (Jury et al. 1995).

Abiotic changes to Madagascar's terrestrial environment

Geographic and seasonal variation in Madagascar's abiotic environment will likely be altered by anthropogenic climate change (Williams et al. 2007). The accumulation of greenhouse gases in the atmosphere is predicted to lead to an increase in average global air temperature and altered patterns of precipitation in the terrestrial environment. Globally, the average air temperature has risen by 0.74°C over the last 100 years, and 0.2°C warming per decade is expected during the coming century (IPCC 2007a). Similar changes are expected in Madagascar (IPCC 2007b). Total annual rainfall has also increased steadily in Madagascar between the 1960s and the 1990s, the most recent years for which we found data (Jury et al. 1995), and precipitation during the wet season is expected to increase by 5-20% throughout the country over the next century (IPCC 2007a). In contrast, the dry season in Madagascar is expected to become drier: precipitation is predicted to drop by 10-30% in the next 100 years (IPCC 2007a). Since the 1950s, average wind speeds in Madagascar have increased by >1 m s^{-1}, and the probability of extreme events—specifically, tropical cyclones—has increased and will continue to do so (Jury 2003).

Anthropogenic climate change will also affect larger-scale, oceanographically-driven phenomena, such as the El Niño Southern Oscillation (ENSO) and the Indian Ocean Dipole (IOD). In the southwest Indian Ocean, ENSO events, which occur in ~4 year cycles (Timmermann et al. 1999), are characterized by higher sea surface temperatures (SSTs), increased precipitation, and increased monsoon winds (Jury et al. 1995, Jury 2003). In southern Africa (Thomson et al. 2003) and in Madagascar in particular (Ingram and Dawson 2005), the year following an ENSO event is often characterized by drought and wildfires. ENSO events are expected to become more frequent with increasing greenhouse gas concentrations (Timmermann et. al.1999). The IOD, recently identified by Saji et al. (1999), occurs with a 4 – 6 year periodicity (Behera et al. 2006) and is thought to have occurred for >6,500 years (Saji et al. 1999). The positive phase of the IOD, like ENSO, is characterized by increased SSTs and greater precipitation in the southwest Indian Ocean. During its negative phase, drier, cooler conditions occur in this region (Saji et al. 1999). Though there is little consensus on whether IOD events require ENSO forcing (Baquero-Bernal et al. 2002, Black et al. 2003, Saji and Yamagata 2003, Yu and Lau 2004, Behera et al. 2006) or how the IOD may interact with climate change, climate models suggest that in the absence of ENSO events the IOD would occur every 2 years (Behera et al. 2006). In years in which ENSO and the positive phase of the IOD co-occur in the southwest Indian Ocean, SST, rainfall, and wind anomalies tend to be greater than average (Behera et al. 2006). Together, these observations imply that the increasing frequency of ENSO events resulting from anthropogenic climate change (Timmermann et al. 1999) may cause the IOD to occur less often, but to have more pronounced effects when it co-occurs with ENSO events.

Anthropogenic climate change is expected to increase precipitation in Madagascar during the wet season, as a result of more frequent ENSO events, and via stronger positive phase IOD events. This increase in rainfall will have important hydrological effects on Madagascar's freshwater ecosystems. Madagascar is characterized by a variety of rivers, streams, and other freshwater habitats (Benstead et al. 2003a) that drain primarily along the west coast (Cooke et al. 2003). These freshwater habitats include at least 143 native fish species (e.g. cichlids, rainbow fishes), of which 65% are endemic (Sparks and Stiassny 2003, Benstead et al. 2000). Though invasive, tilapiine cichlids are also a critical resource for the aquaculture industry and occur throughout Madagascar (Benstead et. al. 2000). Aquatic ecosystems are highly threatened by human land-use practices such as deforestation (Benstead et al. 2003b, Benstead and Pringle 2004) because ecosystem protection and reserve design have not been implemented from a watershed perspective (Benstead et al. 2000). Because of deforestation, freshwater temperatures have increased and natural erosion processes have accelerated, increasing the sediment load in rivers and altering the natural habitat (Green and Sussman 1990, Benstead et al. 2003a). Increased rainfall expected as a result of climate change will aggravate these already seriously degraded aquatic ecosystems by further hastening erosion and sedimentation rates. The lack of vegetation on deforested lands will reduce the ability of soils to retain moisture, and increases in river runoff are expected to be on the order of 10-40% (Gable et al. 1991, IPCC 2007b). Loss of vegetation will increase soil dryness in the wet season, and worsen flooding in the wet season. For instance, many drainages in deforested regions have already shown, and may continue to show, a shift from continual to intermittent or even nonexistent flow during the dry season as the storage capacity of the land declines with decreases in vegetation (Benstead et al. 2003a). In contrast, deforestation combined with enhanced precipitation will increase the potential for loss of flood control during the wet season (Wells and Andriamihaja 1997, Kremen and Ostfeld 2005). The Irodo River, the rivers draining the Tsaratanana Massif, rivers of the Masoala Peninsula, all of the rivers draining parcels of relatively intact eastern rain forest, and rivers draining the region of Andohahela are particularly vulnerable to climate change impacts because these regions correspond to areas of high human pressure (Benstead et al. 2000). Whether deforestation will in turn affect patterns of precipitation, in addition to climate change, is unclear. Long-term data on rainfall patterns in forested, deforested and savannah regions of the Amazon basin suggest that deforestation increases rainfall (Chagnon and Bras 2005). In contrast, simulation models of the Amazon region have traditionally shown that deforestation will decrease rainfall (Nobre et al. 1991, Walker et al. 1995).

Ecological responses to climate change in the terrestrial environment

Changes in Madagascar's abiotic environment will influence the physiology, morphology, and behavior of individual organisms (Harley et al. 2006). In addition, some impacts of anthropogenic climate change will materialize through population- and community-level interactions (e.g. dispersal, consumer-resource dynamics). Together, these effects will produce emergent ecological responses such as species extinctions and/or changes in species distributions, increasing temporal variability in the abundance of species, and alterations in phenology (reviewed by Parmesan and Yohe 2003, Root et al. 2003). In this section, we review the published, peer-reviewed English literature documenting and/or predicting ecological responses to climate change in Madagascar's terrestrial environment (see Appendix for details about literature review).

Appendix II. English Literature Review

Over geological time, variation in the geographic location of microclimates on Madagascar is thought to have been critical to its unparalleled rates of endemism (Wilmé et al. 2006). Microendemism is the hypothesis Wilmé and colleagues put forth to explain the small spatial scale patterns of endemism in Madagascar. According to this hypothesis, glacial cycles caused variation in climatic conditions and thus repeated species' expansions and retreats along riverine corridors. Vicariance events separated populations, eventually leading to allopatric speciation among Madagascar's watersheds (Wilmé et al. 2006). Today, terrestrial biodiversity on Madagascar faces new pressures as the possibility of disappearing and novel climates, especially in central and northern regions, becomes a reality (Williams et al. 2007). That is, microclimates that existed on Madagascar in the 20th century will be eliminated in the 21st century, while at the same time never before seen microclimates are expected to develop. Tropical montane regions of Madagascar will see especially rapid changes (Williams et al. 2007). These climatic shifts increase the likelihood of species extinctions and/or changes in species distributions. Changes in species distributions in turn can cause community disruption and the formation of novel species assemblages (Williams et al. 2007).

Together, the microendemism hypothesis and the potential for disappearing and novel climatic conditions raise particular concern about the effects of anthropogenic climate change on Madagascar's flora and fauna. First, many of the potential dispersal corridors along Madagascar's montane riverine passes are degraded or lost due to deforestation (Green and Sussman 1990, Benstead et al. 2003a). This observation suggests that range changes may not be viable options for terrestrial flora and fauna in Madagascar's present day landscape. Second, many Malagasy taxa have narrow climate envelopes, or ranges of climatic conditions in which they occur, including plants (Dumetz 1999), lemurs (Goodman and Ganzhorn 2004, Lehman et al. 2006), reptiles and amphibians (Raxworthy and Nussbaum 1994, Lehtinen et al. 2003, Raxworthy et al. 2003), butterflies (Lees et al. 1999, Lees 2002), snails (Emberton 1996, 1997), and ants (Fisher 1999, 2003). It remains an open question as to (1) how the distributions of these species will shift in response to anthropogenic climate change, and (2) how quickly Malagasy species can adapt to accelerating anthropogenic climate change, if at all. However, there exists a substantial body of research that may help identify which anthropogenically-induced changes in the abiotic environment will produce the greatest stresses on specific taxa.

Vegetation

The published literature on climate-change induced effects on the flora of Madagascar suggests that it will be stressed via increased climatic variability through the disappearance or shifting of climatic conditions (Ingram and Dawson 2005, Dumetez 1999). From 1982-2000, the strength of ENSO events in one year was negatively correlated with the green leaf biomass on Madagascar (i.e., NDVI) in the following dry season (Ingram and Dawson 2005). Increases in the frequency or strength of ENSO and/or IOD events (Timmermann et al. 1999), and the corresponding variability in patterns of precipitation, suggest that Madagascar's vegetation may show increasing temporal variability in abundance in response to anthropogenic climate change. In addition, anthropogenic climate change may exacerbate threats to plant species that are restricted to narrow ranges and/or are threatened by deforestation. For example, plant species that occur in coastal lowland forests are currently severely threatened by deforestation (Dumetz 1999), and are at risk from predicted increases in sea level and from increases in tropical cyclone frequency due to their geographic location.

Lemurs

Explicit links between anthropogenic climate change and the distribution and abundance of lemurs have not been drawn in the published literature. However, we can make educated inferences about the likely effects of climate change on lemurs given what we know about their ecology. The most serious effects of climate change on lemurs may occur indirectly, as a result of impacts on the abundance and phenology of their food resources. Fruits and young leaves are the principal items in lemur diets. Tree mortality that may result from an increase in the intensity and frequency of cyclones (e.g. Jury 2003) will reduce fruit set and the abundance of young leaves. Such declines in these food resources will in turn have negative impacts on lemur populations (Sauther 1998, Ganzhorn et al. 1997, Wright 2006). For instance, in 1997 the worst cyclone in Madagascar's history resulted in an 80% canopy loss and a 50% decrease in the size of lemur populations at Manombo reserve (Wright 1999). In addition, if climate change causes longer, more intense dry seasons and/or more drought years (e.g. IPCC 2007a), lemur populations could become food-stressed and intra- and inter-specific competition for food resources could increase (Gould et al. 1999, Schulke 2003, Wright 2006, White et al. 2007, Lahann 2007). For example, a prolonged drought in 1991-1992 caused ring-tailed lemur (*Lemur catta*) survival to decline precipitously (up to 30% mortality for adults and 80% mortality for infants) in the Beza-Mahafaly Reserve of southwestern Madagascar (Gould et al. 1999). The authors attributed this increased death rate to the reduced abundance of high-quality food resources during and following the drought period (Gould et al. 1999).

Anthropogenic climate change may also cause changes in plant phenology (Root et al. 2003, Parmesan and Yohe 2003) that have indirect negative effects on lemur survival and reproduction. Lemur species have adapted to the seasonality of food resources by relying on a variety of tree species that produce fruit at different times throughout the year (Sauther 1998, Ganzhorn et al. 1997, Overdorff 1993, Wright 2006) and moving more frequently and farther distances during the dry season to acquire food (Tarnaud 2006). Thus, variation in rainfall in Madagascar, brought on by anthropogenic climate change (e.g. IPCC 2007a), may alter tree phenology, in turn reducing lemur survival (Wright 2006). Additionally, the coexistence of many lemur species on Madagascar is made possible in part by strict temporal differentiation of breeding periods that last for short time periods (i.e., 1-2 weeks; Wright 1999, 2006). Changes in plant phenology may constrain or eliminate breeding opportunities for certain lemur species, or cause the breeding periods of different species to overlap. Both possibilities could potentially lead to declines in species abundance. Lastly, the adaptation of lemurs to plant phenology allows females to successfully lactate and wean their young (Wright 2006). If anthropogenic climate change causes longer, more intense dry seasons and/or more drought years (e.g. IPCC 2007a), the survival of infants produced by older female lemurs may be reduced, potentially threatening species persistence (King et al. 2005, Wright 2006).

Amphibians and reptiles

Amphibians, and to a lesser extent reptiles, are perhaps the poster children of anthropogenic climate change (e.g. Daszak et al. 2005, Reading 2007, Whitfield et al. 2007, and references therein). Recent evidence from Costa Rica suggests that the well-documented, negative effect of anthropogenic climate change on amphibian and reptile populations does not result from the recent emergence or climate-driven outbreaks of chytridiomycosis (a fungal pathogen). Instead, warming-induced reductions in standing leaf litter the preferred microhabitat of amphibian and reptiles, causes declines in their populations (Whitfield et al. 2007). Warming effects on amphibian populations have also been documented in temperate regions (Daszak et al. 2005, Reading 2007).

The available data suggest that habitat loss due to deforestation (Raxworthy 1988, Raxworthy and Nussbaum 1994, Andreone et al. 2005) rather than anthropogenic climate change poses the greatest threat to Malagasy amphibian and reptile populations (Andreone et al. 2005). However, many of Madagascar's herpetofauna are restricted to particular climate envelopes (Raxworthy and Nussbaum 1994, Raxworthy et al. 2003) as well as specific habitat types (e.g. primary forest, Raxworthy and Nussbaum 1994). As a consequence these taxa may be particularly vulnerable to the direct impacts of anthropogenically-induced changes in climatic conditions. For example, while low altitude specialists may find refuge at higher elevations as temperatures increase, high altitude specialists may suffer if the climatic conditions currently present at high elevations disappear (Raxworthy and Nussbaum 1994, Williams et al. 2007). Of course, biotic interactions (e.g.

interspecific competition, predation) may also limit the extent to which retreat of low altitude specialists is possible. Nonetheless, the disjunct present-day distribution of reptiles in Madagascar indicates that these types of adjustments to changing climatic conditions are likely to have occurred in the geological past (Raxworthy and Nussbaum 1997). Ecological niche models that predict species distributions based on a suite of climatic variables may serve well to generate expectations for future distributions of amphibians and reptiles in Madagascar under different anthropogenic climate change scenarios. Just such an ecological niche model was developed for Malagasy chameleons by Raxworthy et al. (2003).

Butterflies

The butterflies of Madagascar have been used frequently as an indicator taxon for biodiversity patterns in its humid forests (Lees et al. 1999). In the face of anthropogenic climate change, Malagasy butterflies will likely prove sensitive to changes in environmental conditions (e.g. temperature; Lees 2002). Though butterflies perform poorly as surrogates of plant diversity, they perform well as indicators of anthropogenic disturbance (Kremen 1992). Furthermore, species richness of butterflies peaks at mid-latitudes and at mid-elevations on Madagascar, as does species richness of beetles, moths, chameleons, frogs, birds, lemurs, tenrecs, and rodents (Lees et al. 1999). In fact, Kremen (1994) proposed that the endemic species of Malagasy butterflies in the genus *Henotesia,* alone, are as good as the entire butterfly fauna for delineating topographic, elevational, and other environmental gradients. Similar to the situation with the amphibians and reptiles of Madagascar (e.g. the occurrence of altitudinal specialists), the consensus view regarding Malagasy butterflies is that each species occupies a relatively narrow niche and species distributions can be defined well by specific climate envelopes (Lees 2002). Biotic interactions (e.g. interspecific competition, predation) may contribute to the limits of species ranges (e.g. upper altitudinal limits) in Madagascar, but the extent to which these factors will interact with human-induced changes in climatic conditions has not been treated in the peer-reviewed literature. Together, these observations suggest that the butterfly community will be sensitive to anthropogenic climate change and its ecological responses may provide insights into the severity of changes in climatic conditions occurring on Madagascar. The climatic envelope models of Lees (2002) should prove useful in predicting future distributions of Malagasy butterflies under different anthropogenic climate change scenarios.

Invasions

Anthropogenic climate change may shift environmental conditions in directions that facilitate the success of invasive or exotic species. Though many possibilities exist, we present two examples of how inferences can be made about the effects of increasing greenhouse gas concentrations on invasive species. One approach involves choosing to focus on an invasive species that has been particularly successful in establishing itself in non-native ranges, but has yet to establish in the focal area. By characterizing the invasive species' climate envelope, one can then ask which uninvaded regions are most vulnerable to future establishment. Roura-Pascual et al. (2004) and Hartley et al. (2006) use this tactic with Argentine ants (*Linepithema humile*), one of the most successful invasive species on the planet, to demonstrate that Madagascar is particularly susceptible to invasion under current climatic conditions. However, Roura-Pascual et al. (2004) also simulated the predicted climate in Madagascar in 2050, and found that the island will become less hospitable or inhospitable to Argentine ants under typical global warming scenarios.

An alternative approach to predicting how anthropogenic climate change will affect invasiveness is to focus on an invasive species that has already established itself in a focal non-native region. One can then ask if the focal region's future climatic conditions are likely to include the invasive species' climate envelope. For instance, the Asian snakehead *(Channa maculata)* thrives in Malagasy freshwater systems with low oxygen content, where it can prey easily on native fish species (Benstead et al. 2003a). Warmer waters often are characterized by lower oxygen concentrations. One can infer that if anthropogenic climate change leads to warmer waters surrounded by less vegetation (e.g. due to an interaction with deforestation), the oxygen content of rivers will be lower. These future conditions would facilitate the invasive spread of Asian snakeheads in Madagascar.

Implications of climate change impacts on terrestrial ecosystems for human communities

Though the potential impacts of climate change on the Malagasy people are many (e.g. species extinctions may reduce ecotourism revenues), here we mention two ecological responses that have been addressed in the peer-reviewed literature. First, vector-borne diseases like malaria are likely to be influenced strongly by changes in climatic conditions associated with greenhouse warming. Malarial risk increases with temperature (Bouma 2003), a change that is virtually guaranteed under current anthropogenic climate change projections (e.g. IPCC 2007a). In fact, if anthropogenic climate change brings even small increases in temperature in normally cool highland areas like Antananarivo province, malaria transmission intensity, duration of the transmission season, and areas susceptible to transmission are likely to increase greatly. As a consequence, it is expected that malaria incidence among its inhabitants will also increase. In addition, a nearly 20-year long time series of malaria incidence in Antananarivo province suggests that there tends to be an increased risk of epidemics in the year following ENSO events (Bouma 2003). Should ENSO events increase in frequency as predicted (Timmermann et al. 1999), so too will the incidence of malaria in at least some areas of Madagascar. The expected increase in frequency of ENSO events may also lead to crop failure in Madagascar. For example, following the 1982-83 ENSO event maize crops in Madagascar failed altogether due to prolonged dry conditions (Tadross et al. 2005). Others have suggested that commercially important exports such as coffee, cotton, and vanilla may also decline due to anthropogenic climate change (e.g. Jury 2003). Reductions in agricultural products could have devastating impacts on an already impoverished nation (Kremen et al. 2000).

Geography and physical properties of Madagascar’s marine and coastal environment

Madagascar is best known for its terrestrial biodiversity and endemism. However, the approximately 6,000 km of Malagasy coastline (Gabrié et al. 2000) are also home to an impressive diversity of marine habitats and species. Extending from tropical waters in the north (mean annual sea surface temperature, SST = 28°C) to the interface between temperate and tropical systems in the south (mean annual SST = 22°C), the island’s waters include coral reefs, mangroves, seagrass beds, estuaries, sandy beaches, rocky inter-tidal reefs, and pelagic habitats (see Fig. 14. in Gabrie et al. 2000; Cooke et al. 2003). These near-shore marine ecosystems are influenced by two exogenous sources: offshore patterns of oceanographic circulation and terrestrial inputs from Madagascar’s rivers and streams.

A complex system of ocean currents influences the SST around Madagascar and transports nutrients to its nearshore ecosystems. The south equatorial current moves west bringing warm water from across the Indian Ocean. Encountering the east coast of the island, it deflects north into the North Madagascar Current and south into the East Madagascar Current (Pollock 1993, Cooke et al. 2003, Palastanga et al. 2006). The North Madagascar Current wraps around the northern tip of the island and runs through the Mozambique Channel, becoming the Mozambique Current (de Ruijter et al. 2002, Cooke et al. 2003, Palastanga et al. 2006). A series of cyclonic eddies form regularly in the Mozambique Channel, and are potentially important retention centers of marine larvae which then settle in the coral reefs and mangroves along the western coast of Madagascar. In contrast, the East Madagascar Current moves extremely fast (in some places up to 100 cm/s) along the east coast and toward the south of the island in an area of major upwelling and productivity between Tolagnaro and Tulear (Cooke et al. 2003). Typical patterns of ocean circulation can be altered by the IOD. For instance, during the positive phase, waters of the eastern Indian Ocean cool; however, these cooler waters do not reach Madagascar because of a simultaneous weakening of the south equatorial current.

Nearshore marine ecosystems are also influenced by patterns of land use on Madagascar. In particular, deforestation and burning of grasslands increase sedimentation rates in rivers and streams (Gabrie et al. 2000, Webster and McMahon 2002, Cooke et al. 2003). In Madagascar, the largest rivers drain on the west coast of the island where most of the coral reefs and mangroves occur. The rivers dump sediments, alter salinity levels, and increase levels of turbidity, nutrients and suspended organic matters in these sensitive habitats (Cooke et al. 2003). Large scale soil erosion affects 80% of the land in Madagascar and is most severe in the east coast and northwest of the island (Gabrie et al. 2000, Webster and McMahon 2002).

Predicted changes to the marine and coastal environment

Anthropogenic climate change will likely alter the marine and coastal environments of Madagascar. However, because information in the peer-reviewed literature specific to Madagascar is sparse, we briefly list the global predictions, indicating which information is local. First, global air and SST have risen by 0.5-0.9°C over the last century (IPCC 2007a) and are predicted to rise 1-6°C by the end of the 21st century. Second, sea levels are projected to rise ~ 2mm/yr, to a total of 0.2-0.6 m above pre-industrial levels by the end of the 21st century (IPCC 2007a). Third, the world's oceans are expected to acidify (Kleypas et al. 1999, 2006, Feely et al. 2004, Sabine et al. 2004, Orr et al. 2005). Average ocean pH has already declined by 0.1 units since pre-industrial times and is expected to drop by another 0.14-0.35 units over the next century (IPCC 2007a). However, this trend is slower in the tropical oceans than in the polar regions (Kleypas et al. 2006; Feely et al. 2004). Fourth, global storm intensity and frequency is predicted to increase, including ENSO events (Timmerman et al. 1999) and intensified wind fields along coastlines (IPCC 2007a, Harley et al. 2006). On a regional scale, more frequent tropical cyclones are expected to hit East Africa, leading to increased erosion and shoreline recession (Gable et al. 1991). Fifth, anthropogenic climate change may alter natural patterns of ocean circulation in the Indian Ocean and Madagascar region. For example, warm waters of the southwest Indian Ocean typically feed the Alguhas Current, transferring warm salty water into the Atlantic Ocean. However, IOD and ENSO events interact with this process, creating greater variability in the transfer of water masses into the South Atlantic (de Ruijter et al. 2005). Because of potential impacts of anthropogenic climate change on the intensity and frequency of IOD and ENSO events, this process, which is key to thermohaline overturning in the global ocean (Lutjeharms et al. 2000), could be disrupted. Changes in ocean circulation and sea level rise may also disrupt marine speciation processes. For example, the genetic structure of Malagasy lobster populations was affected by climate-induced sea level rise in the geological past (Pollock 1993). Finally, the warming of surface waters from climate change will likely increase stratification of the water column, which can decrease dissolved organic matter and increase UV penetration deep into the water column (Vodacek et al. 1997).

Madagascar's marine and coastal habitats: geographic distribution and vulnerability to climate change

Anthropogenic climate change may cause a variety of ecological responses in marine systems, such as changes in species distributions (for non-Madagascar examples of fishes see Holbrook et al. 1997 and Roessing et al. 2004; invertebrates see Sagarin et al. 1999; for a general review see Harley et al. 2006), increased heat stress and oxygen consumption (Roessing et al. 2004, Harley et al. 2006), and increased incidence of disease (Roessing et al. 2004). Here we indicate potential vulnerabilities of each marine ecosystem in Madagascar to climate change. Very few papers were available in the peer-reviewed literature that explicitly tested for effects of climate change on marine ecosystems and/or species in Madagascar. Therefore, much of the information about vulnerability presented here comes from studies of similar ecosystems occurring elsewhere around the world. We indicate which information is specific to Madagascar in the text. We also describe basic geographic information for coral reefs, mangroves, seagrasses, and other Malagasy coastal and marine ecosystems to provide additional information on some of these lesser known habitats.

Coral reefs

Coral reef ecosystems in Madagascar cover an area of 2,000 km^2 (Gabrie et al. 2000) and extend along >3,450 km of coastline (Cooke et al. 2003), including the entire west coast and parts of the north and central east coast**.** Much of the information about Malagasy coral reefs in the peer-reviewed literature comes from two French research centers, the National Center for Oceanographic Research (CNRO) started in 1954 in Nosy Be and the Institute of Saltwater Resources and Marine Sciences (IHSM) in Tulear (Gabrie et al. 2000). The most recent information comes from a program created in 1999 to assess the health of Indian Ocean Coral reefs in 11 countries: Coral Reef Degradation in the Indian Ocean, or CORDIO (www.cordio.org). The consensus view from the CORDIO research is that Madagascar's coral communities are healthy relative to other coral reefs in the western Indian Ocean. Recent surveys suggest that average live coral cover is 38% in Madagascar (Webster and McMahon 2002). For instance, near Nosy Be in the northwest live coral cover is 27-53% (Webster and McMahon 2002) and near Tulear coral cover is ~40% (Quod and Bigot 2000). The most pristine reefs in Madagascar are located between Morombe and Morondava (Belo-sur-mer), which is a submerged barrier reef (Cooke et al. 2003). To put these figures in a regional context, the average live coral cover in Kenya, Tanzania, and Mozambique is 11%, 26%, and 35%, respectively (Obura 2002), whereas the global average is 33% (Hodgson 1999).

Although coral cover in Madagascar might be comparable to, if not higher than, other areas in the Indian Ocean, the most dramatic impact of anthropogenic climate change on Madagascar's coastal ecosystems nevertheless may be the bleaching of coral reefs. The reefs in Madagascar are extremely diverse. More than 300 species of reef-building corals occur in the waters around the island (Gabrie et al. 2000, Webster and McMahon 2002) with more than 112 species and 57 genera of corals identified in the Tulear region alone (Pichon 1978, cited in Sheppard 1998). Corals are dependent on symbiotic algae called zooxanthellae. Coral bleaching occurs when coral polyps expel zooxanthellae, disrupting the mutualism (Hoegh-Goldberg 1999, West and Salm 2003). Factors influencing the occurrence of bleaching include elevated or decreased SST, freshwater flooding (reduced salinity), pollution, sedimentation, disease and changes in light availability (Hoegh-Goldberg 1999, West and Salm 2003). Because many of these threats will likely increase with anthropogenic climate change, scientists predict a higher frequency and severity of coral bleaching, especially in the Indian Ocean, in the future (Sheppard 2003). For example, Sheppard and Rayner (2002) demonstrated that the 1998 ENSO-associated bleaching event was the largest of its kind in the Western Indian Ocean for more than 130 years. Coral mortality in the Indian Ocean averaged 50-80%, and in some locations was as high as 100% (Obura 2001, Sheppard 2003). In some areas of Madagascar, 80-90% of the corals died (McClanahan and Obura 1998). Other reefs in Madagascar that were affected include Tulear, where bleaching caused 23% mortality at one site and 70% at another (Quod and Bigot 2000), and the pristine reefs between Morombe and Morondave where 40-60% of the surface was bleached (though bleaching-induced mortality in this location was not reported; Cooke et al. 2003). Obura (2005) reported 10% and 30% bleaching mortality in southwest and northeast Madagascar, respectively. Though these different bleaching mortality reports conflict to some degree, the overall impression is that bleaching-induced mortality in Madagascar was not as pervasive as in other areas in the western Indian Ocean (McClanahan et al. 2007).

Evidence from the 1998 event also demonstrated that certain species of corals suffered greater mortality due to thermal-stress induced bleaching than other species. *Acropora* and

Montipora corals tended to be extremely sensitive to bleaching (McClanahan et al. 2007). For instance, fast-growing *Acropora* colonies around the Masaola Peninsula likely experienced total mortality in 1998 (Obura 2001, 2005), as did *Acropora* colonies in the nearby Maldives (McClanahan 2000). Though *Acropora* and *Montipora* corals are currently the dominant genera on Madagascar's reefs (McClanahan et al. 2007), the expected increase in the frequency of warming events in the Indian Ocean do not bode well for their survival (Sheppard 2003).

In addition, Madagascar's corals may be particularly vulnerable to bleaching because they likely have exclusively type C zooxanthellae (Burnett 2002), which Rowan and colleagues (1997) showed are not very tolerant towards heat stress. Increases in global temperatures of as little as 1-3°C are likely to lead to a heightened frequency of bleaching and extent of coral mortality (IPCC 2007b). Between 2010 and 2050, most sites in the Indian Ocean between 1° and 15°S latitude have a 20% chance, annually, of experiencing a month as warm as the temperature during 1998 when the large bleaching event occurred (Sheppard 2003). Taxa that are particularly vulnerable to future extinction based on their response to warm water, population density, and commonness include largely low-diversity genera with narrow environmental ranges, such as *Gyrosmilia interrupta*, *Plesiastreaversipora*, *Plerogyra sinuosa*, and *Physogyra lichtensteini* (McClanahan et al. 2007).

In addition to temperature stress from climate change, coral reefs are threatened by ocean acidification. Global predictions indicate that calcification rates will decrease up to 60% within the 21st century, with a decrease of 30% likely for most coral reef ecosystems (Kleypas et al. 2006). Decreased carbonate ion concentration significantly reduces the ability of reef-building corals to produce their calcium carbonate skeletons, affecting growth of individual corals and the ability of the reef as a whole to maintain a positive balance between reef building and reef erosion. For instance, in a recent paper from the Red Sea, scientists showed that corals exposed to low pH in a laboratory experiment lost their calcium carbonate skeletons and took on the appearance of soft-bodied anemones (Fine and Tchernov 2007). Other shell-forming organisms that live in and around corals, such as coralline algae, foraminifera, molluscs, and echinoderms may also be negatively affected by ocean acidification. In the long term, the negative effect of decreasing pH could cause a shift in dominance to shell-free invertebrates and algae or other organisms with siliceous shells and skeletons.

The Fine and Tchernov (2007) study indicates some ability of corals to adapt to lower pH levels by transforming into soft-bodied organisms. However, loss of the hard, complex structure that these animals provide could have severe consequences for fishes using coral reef habitats. Thus, while Malagasy fish species might suffer from direct effects of climate change, such as altered metabolic rates and oxygen deprivation (Roessing et al. 2004), indirect effects, via the negative impact of climate change on corals, are likely to be important as well. The loss of structural complexity due to coral bleaching has led to declines in fisheries yields (Hoegh-Goldberg 1999) and changes in fish communities (Wilson et al. 2006 meta analysis of studies in Australia, Hawaii, Japan, Dubai, Seychelles, Polynesia, Tanzania, and Papua New Guinea). For example, a meta-analysis of 17 studies by Wilson and colleagues (2006) showed that disturbances causing greater than 10% decline in coral cover leads to a decline in fish species richness within 3 years. While the Hoegh-Goldberg (1999) study is not specific to Madagascar, coral bleaching has occurred and will continue to occur around the island, potentially jeopardizing fish communities. On a longer time scale of decades to centuries, coral mortality could lead to loss of energy capture by zooxanthellae and coral polyps, and result in a reduction in trophic transfer of these energy sources to fishes on coral reefs (Hoegh-Goldberg 1999).

The combination of coral mortality and altered fish communities may have cascading effects on Malagasy coral reefs that will likely become difficult to reverse. The main space competitors with corals are seaweeds (i.e., macro algae). When corals bleach and die, space opens and macroalgae increase in abundance (Hughes et al. 2003, Obura 2005). If loss of coral structure leads to a reduction in the abundance of herbivorous fishes, then macro algal populations will replace corals as the dominant members of the benthic community (Hughes et al. 2003). This problem is compounded on reefs, such as those in Madagascar, that are exposed to sedimentation, pollution and increased nutrient inputs from deforestation and erosion.

Mangroves

The role of mangrove ecosystems in protecting coastlines from the impact of waves and from erosion, capturing nutrients, fixing carbon, providing a source of wood for fuel, harboring commercially-important fisheries species, and maintaining water quality in nearshore waters is long established (Gable et al. 1991, Gabrie et al. 2000, see Alongi 2002 for a recent review). In Madagascar tidal marshes cover 425,000 ha of this area, 327,000 are mangrove forests (Cooke et al. 2003, Roger and Andrianasolo 2003). Almost all mangroves (98%) occur on the west coast of Madagascar (Roger and Andrianasolo 2003). Some mangroves line the east coast north of the Masaola peninsula and a few occur just north of Tolagnaro in the southeast. More than 70% of the western mangroves are large stands, >500 ha (Cooke et al. 2003). Eight species of mangrove trees have been identified in Madagascar and of those, one (*Ceriops boiviniana*) is endemic (Roger and Andrianasolo 2003).

The peer-reviewed research on mangroves in Madagascar indicates these ecosystems could also be affected by anthropogenic climate change. Of all the possible effects of anthropogenic climate change, sea-level rise likely presents the greatest threat to mangrove ecosystems worldwide (Field 1995). Evidence from Caribbean mangrove ecosystems during the Holocene suggests that mangroves may be able to adapt to sea level rise by shifting towards land (Parkinson et al. 1994), and if sea level rise is slow enough accretion may allow mangrove forests to persist in situ (Ellison, 1989). However, the extent to which such shifts inland are possible depends on nearshore topography and coastal development (Alongi 2002). In addition to the threat of sea level rise, increased greenhouse-warming induced heat stress may influence Malagasy mangroves. Like many intertidal organisms (Helmuth et al. 2002), mangrove tree species must cope with heat stress during low tide cycles. In Tulear, mangroves drain completely at low tide (Laroche et al. 1997), so that the entire root systems of the mangrove plants are exposed to air for some portion of the day. Thus, Tulear mangroves cannot use water as a refuge from the increase in air temperatures predicted to occur with anthropogenic climate change. Such shallow habitats are also at risk of becoming increasingly saline as evaporation rates increase with temperature.

Like coral reefs, mangrove forests provide habitat and structure for ecologically and economically important fishes and invertebrates. In Madagascar, mangroves are habitat for >60 fish species (Laroche et al. 1997) and serve as nurseries for juvenile fishes. Commercially valuable shrimp, in particular *Penaeus indicus* and *P. monodon,* also rely on mangroves for habitat. The cyclical presence of freshwater in mangrove ecosystems is vital to the breeding cycle of these shrimp (Cooke et al. 2003). The effect of anthropogenic climate change on salinity levels via increased run-off may directly reduce shrimp abundance in some mangroves. Likewise, indirect negative effects of anthropogenic climate change on shrimp populations, acting through the loss of mangrove habitat, are also possible.

Other marine and coastal habitats in Madagascar

In this section we briefly describe the geographic distribution and vulnerability to climate change of other marine and coastal ecosystems that occur in Madagascar. Seagrass beds and salt marshes (or estuaries) generally develop in lagoons adjacent to coral reefs and are found mostly on the west coast of Madagascar. Sandy beaches are most common on the eastern side of Madagascar and around some of the small islands off of the northeast and northwest coasts. Rocky inter-tidal reefs are located predominantly on the east coast. Pelagic ecosystems occur on many oceanic banks off the coast of the island (Cooke et al. 2003). In our peer-reviewed literature survey, we found virtually no information about the potential impacts of anthropogenic climate change on these ecosystems in Madagascar. Below, we borrow from research in other regions of the world to speculate on some of the potential impacts to Madagascar's coastal habitats.

Seagrass beds are indirectly vulnerable to anthropogenic climate change, via the negative effects on coral reefs. Seagrass habitat in Madagascar occurs in lagoons (Cooke et al. 2003). These bodies of water are formed by coral reefs separating nearshore waters from the open ocean and wave action. If anthropogenic climate change degrades coral reefs as expected, lagoons may disappear and seagrass habitat will be lost. Rising sea levels could also dramatically alter seagrass communities and their composition, as seagrass distribution and abundance are determined by salinity, light, depth and currents (Short and Neckles 1999). Seagrass beds may also be negatively influenced by indirect effects of anthropogenic climate change on rates of sedimentation and eutrophication. If climate change results in periodic spells of abnormally high rainfall on Madagascar (e.g. during the wet season, IPCC 2007b), sedimentation could smother seagrass beds and high nutrient loads could encourage growth of epiphytes which would in turn decrease seagrass growth. Enhanced UV light penetrance is also expected to affect seagrass photosynthetic ability (Larkum and Wood 1993), although seagrasses may have some ability to protect themselves from slow changes through increased production of UV-blocking pigments (Dawson and Dennison 1996).

Salt marshes, and the associated fish and invertebrate communities, may be affected by the impact of sea level rise on habitat availability (Roessing et al. 2004). In Madagascar, loss of salt marshes would have consequences for many other species, such as the fish eagle, which rely on salt marshes for habitat and are already threatened by overfishing and deforestation (Watson and Rabarisoa 2000). In addition to providing habitat for fish and invertebrates, salt marshes are also used by people for salt production (Roger and Andrianasolo 2003).

Sandy beach ecosystems may also be affected by sea level rise. The degree to which these ecosystems move landward will depend on coastal development (Harley et al. 2006). The loss of coral reefs via climate change will also negatively affect sandy beaches in Madagascar. The highest diversity beaches occur near the Masoala Peninsula and they are currently protected by coral reefs (Soares 1997). Loss of sandy beaches and/or increased thermal stress due to anthropogenic climate change may lead to loss of the species that use these habitats, such as sea turtles that use sandy beaches in Madagascar for their nesting grounds (Cooke et al. 2003, Ratsimbazafy 2003). Sea turtles have temperature-dependent sex determination, so changes in the temperature of the sand will change the sex ratio of sea turtle populations. If the sex ratio becomes too strongly skewed towards one sex or the other, this would further threaten sea turtle populations.

Organisms living in the pelagic ecosystems around Madagascar, such as marine mammals and planktonic taxa, may also experience effects of anthropogenic climate change. The potential impacts of climate change on marine mammals include effects of increased water temperatures on species distribution or migration patterns, and changes in food availability because of effects of climate change on prey species (Learmounth et al. 2006). For instance, a study in Scotland used whale stranding records to show that formerly abundant cold water dolphin species were lost from the community during the last 10 years and ~2 new warm water species showed up each decade during the last ~20 years (MacLeod et al. 2006). In Madagascar, humpback whales use bays as a wintering and breeding areas (Rosenbaum 2003a, 2003b). For example, Antongil Bay, where more than 1,200 whales winter each year, is a preferred habitat for calving females. Anthropogenic climate-change induced changes in SST may cause humpbacks to alter the location of their breeding grounds or their migration patterns. Climate change may also affect Madagascar's upwelling regimes, which could influence humpback feeding grounds and might in turn have effects on ecotourism.

Anthropogenic climate change induced acidification may also affect planktonic calcifers such as coccolithophores, foraminifera, and shelled pteropods (Kleypas et al. 2006). Decreased calcification in plankton in turn would influence marine food webs and, combined with other climatic changes in temperature, salinity, and nutrients, could substantially alter the biodiversity and productivity of the ocean. The suite of planktonic calcifers includes larval stages of many benthic invertebrates. However, little information exists on how these early calcifying stages may be affected by decreased carbonate saturation state. In a laboratory experiment, larval stages of two sea urchins showed smaller calcite skeletons, as well as decreased developmental rates and larval size, under high pCO2 conditions (Kurihara and Shirayama 2004).

Implications of anthropogenic climate change impacts on marine and coastal ecosystems for human communities

The negative effects of anthropogenic climate change on Madagascar marine and coastal ecosystems will have repercussions for the people that rely on these natural habitats for food, livelihood or other services such as protection from storms. Nearly half (43%) of the fisheries yield in Madagascar comes from its coral reefs (Westmacott et al. 2000). Because of the almost unavoidable increase in the frequency and intensity of coral bleaching in Madagascar (Sheppard 2003), and the negative consequences of coral bleaching for associated fish communities (Wilson et al. 2006), Malagasy reef-based fisheries are certain to suffer under future climate change scenarios. Pelagic fisheries, such as the longline tuna fishery, may also be influenced by changes in ocean circulation (e.g. ENSO and IOD events) that result from anthropogenic climate change. The longline fishery occurs throughout Madagascar and brings in >50,000 tons per year of billfish and tuna in the south and skipjack and yellowfin tuna in the north (Cooke et al. 2003). The purse seine fishery operates in northwestern Madagascar and brings in >11,000 tons year of skipjack and yellowfin tuna (Cooke et al. 2003). In addition, if increases in thermal stress and sea level (Field 1995) degrade mangrove and estuarine habitats as expected with increased greenhouse warming, the services provided by these ecosystems in Madagascar will decline as well. The economic and cultural value of mangroves and estuaries in Madagascar are many. For example, the mangroves in Tulear support 44 species of commercially-valuable fish species (Laroche et al. 1997), and penaeid prawns, which occur in mangroves as juveniles, are the most important fisheries export in Madagascar (Cooke et al. 2003). Malagasy mangroves are also important sources of timber, firewood, and medicine (Roger and Andrianasolo 2003). Estuaries, together with mangroves, are used for salt production and shrimp farming (Roger and Andrianasolo 2003). Last, but perhaps most importantly, mangroves and coral reefs fulfill the irreplaceable function of coastal protection (Gable et al. 1991, Gabrie et al. 2000), as witnessed in the Indian Ocean following the 2004 tsunami (Danielsen et al. 2005). The potential for anthropogenic climate change to directly eliminate the suite of ecosystem services provided by these coastal habitats poses serious threats to the well-being, economic and otherwise, of the Malagasy people.

Unfortunately, current human impacts on the marine and coastal ecosystems of Madagascar may interact with anthropogenic climate change to increase the rate and extent of their decline. One of the most pressing threats is overfishing and the cascading effects from fishing-induced loss of top predators on nearshore reefs could be aggravated by climate change. In 1972, carnivorous fishes were dominant in Tulear, making up 74% of the species and 63% of individuals (Harmelin-Vivien 1979). However, the number of fishers on Tulear's reefs increased by 57% between 1972 and 1988 (Laroche and Ramananarivo 1995), and by 2000, carnivorous fishes (such as groupers) made up only 2.5% of individuals (Gabrie et al. 2000). At the same time, the average size of captured fish declined in Tulear and is comparable to overfished reefs on Mauritius (Laroche and Ramananarivo 1995).

Appendix II. English Literature Review

Across all of Madagascar, fishing effort has increased fivefold between 1977 and 1994 (Westmacott et al. 2000). Overfishing of predators on coral reefs will cause loss of top-down control, and may interact synergistically with increased bleaching-induced coral mortality produced by anthropogenic climate change. The almost universally expected outcome is a shift toward the domination of reefs by seaweeds, most species of which are not biogenic, reef-building organisms (Hughes et al. 2003, Obura 2005). Though not as well-discussed in the peer-reviewed literature, habitat loss due to trawling, increased sedimentation in coastal drainages as a result of continued deforestation, and the magnified effects of agricultural pollution on decreasing ocean pH (e.g. near Nosy Be in northwestern Madagascar) may also interact with anthropogenic climate change to further degrade costal and marine ecosystems in Madagascar (Gabrie et al. 2000, Sheppard 2001). Place-based management strategies (e.g. no-take areas), such as those that have been implemented on the Masaola Peninsula (Cooke et al. 2003), may serve well to increase the resistance and resilience of these habitats to human-induced climate change (West and Salm 2003).

Appendix

We used a two-pronged approach to review the peer-reviewed English literature on the potential impacts of anthropogenic climate change on Madagascar's biodiversity. First, we searched Web of Science (1945-2007) for publications that explicitly linked climate change with expected ecological responses of terrestrial biodiversity in Madagascar. We did not perform a review of the general ecological literature on key Malagasy flora and fauna, nor did we systematically review the general literature on the effects of climate change on terrestrial environments worldwide. Our search terms were: "Madagascar AND climate AND biodiversity", "Madagascar AND climate AND change", and "Madagascar AND climate". After identifying key papers, we also performed a forward and backward search of the cited references section and of other publications citing them. Finally, we searched for publications by authors known to study anthropogenic climate change issues in Madagascar, including B. Fisher, C. Kremen, D. Lees, C. Raxworthy, M. Stiassny, M. Tadross, and P. Wright (L. Hannah, *personal communication*).

Second, we used Web of Science (1945-2007) to find peer-reviewed literature relevant to anthropogenic climate change and Madagascar's marine and coastal ecosystems. The marine literature review focused on major marine habitat types occurring in Madagascar: coral reefs, mangroves, estuaries, seagrass beds, sandy beaches, rocky intertidal, and pelagic. We proceeded in a hierarchical manner, with priority given to published literature directly related to anthropogenic climate change impacts in Madagascar, followed by publications relating to climate change impacts in East Africa and/or the West Indian Ocean regions, and where necessary, publications on climate change impacts predicted for similar marine habitats elsewhere around the globe. Specifically, we searched for publications that contained the word 'Madagascar' plus any of the following terms: benthic, coelacanth*, coral*, dispersal, dolphin*, dugong*, El Niño, ENSO, estuar*, fish*, grouper*, intertidal, invasive species, *Kappaphycus* [an invasive algae], lobster*, Mananara-Nord, mangrove*, marine AND endemic, ocean*, Pacific Decadal Oscillation, PDO, pelagic, phytoplankton, prawn*, recruit*, salinity, salt marsh*, sawfish, sea bird*, sea cucumber*, sea level rise, seagrass bed*, shark*, shrimp, subtidal, tuna, turtle*, upwelling, wetland*, whale*, zooplankton. We also searched for publications containing the phrases "global warming AND Indian Ocean", "global warming AND East Africa", and "climate change AND Indian Ocean dipole." As above, after identifying key papers, we also performed a forward and backward search of the cited references section and of other publications citing them.

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Appendix III. French Literature Review

REVUE DE LITTÉRATURE SUR LES IMPACTS DES CHANGEMENTS CLIMATIQUES SUR LA BIODIVERSITÉ TERRESTRE ET MARINE DE MADAGASCAR

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Mai 2007

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1. Introduction

Le terme de **changement climatique** correspond à la variation durable, et cyclique, du climat global de la Terre ou de ses divers climats régionaux. On peut ainsi décrire des changements de la variabilité ou de l'état moyen de l'atmosphère sur des échelles de temps allant de la décennie au million d'année. Ces changements peuvent être dus à des processus propres à la planète Terre, à des forces extérieures ou, plus récemment, aux activités humaines.

Dans le contexte récent de la politique écologique, le terme "changement climatique" ne correspond qu'aux changements du climat actuel, apparus au long du vingtième siècle et attendus pour le vingt-et-unième siècle.

Dans les travaux du GIEC, le terme "changement climatique" fait référence à tout changement dans le temps, qu'il soit dû à la variabilité naturelle ou aux activités humaines.

Au contraire, dans la Convention cadre des Nations Unies sur le changement climatique, le terme désigne uniquement les changements dus aux activités humaines. La Convention-Cadre utilise le terme "variabilité climatique" pour désigner les changements climatiques d'origine naturelle.

Ces changements sont dus à l'industrialisation de la planète et à l'utilisation massive de combustibles fossiles. Alors que les changements climatiques naturels se font sur de très longues périodes, ce qui implique une certaine adaptation des espèces animales et végétales, les changements anthropiques sont très rapides et par conséquent menacent énormément les écosystèmes souvent fragiles (GIEC-II, 2002).

La température moyenne sur terre a augmenté de 0.6 degrés depuis la fin des années 1800. On s’attend à ce qu’elle continue d'augmenter de 1,4 à 5,8°C d’ici à l’an 2100 (GIEC-II, 2002) -- ce qui constitue un rapide et profond changement. Même si la prédiction minimale venait à se produire, elle serait supérieure à toute autre tendance sur 100 ans au cours des 10 000 dernières années.

Les principales raisons de cette montée de température peuvent être un siècle et demi d’industrialisation avec la combustion de quantités de plus en plus élevées de pétrole, d’essence et de charbon, la coupe des forêts ainsi que certaines méthodes agricoles.

Ces activités ont augmenté les quantités de "gaz à effet de serre" dans l’atmosphère, en particulier le dioxyde de carbone, le méthane et l’oxyde nitreux. Ces gaz sont naturellement et sont essentiels à la vie sur terre; ils empêchent une partie de la chaleur solaire de retourner dans l’espace et, sans eux la terre serait un endroit froid et aride. Mais en quantité toujours croissantes, ces gaz sont en train de pousser la température globale à des sommets artificiellement élevés qui altèrent le climat. Les années 1990 passent pour avoir été les plus chauds du dernier millénaire avec l'année 1998 étant l'année la plus chaude.

Les changements climatiques peuvent être difficiles -- les dinosaures en seraient les témoins, s'ils n'avaient disparu. La théorie prévalant est qu'ils n'ont pas survécu à un météorite géant qui s'est abattu sur la terre il y a 65 millions d'années, répandant tellement de poussière dans l'air que la lumière solaire s'en est trouvé grandement réduite, les températures ont plongé, les plantes ne poussaient plus et la chaîne alimentaire s'est brisée.

Ce qui arriva aux dinosaures est un rare exemple de changement climatique beaucoup plus rapide que celui que les humains sont maintenant en train de s'infliger . . . mais pas le seul. Les recherches sur les carottes glaciaires et les sédiments des lacs montrent que le système climatique a souffert d'autres fluctuations abruptes dans un passé lointain -- le climat semble avoir des "pics" pouvant lui faire faire de brusques écarts et rebonds. Bien que les scientifiques soient toujours en train d'analyser ce qu'advint lors de ces événements antérieurs, il est clair qu'une terre chargée de 6,3 milliards d'habitants est un endroit risqué pour réaliser des expériences incontrôlées sur le climat.

La tendance actuelle du réchauffement est prévue pour causer des extinctions d'espèces. De nombreuses espèces de plantes et d'animaux, déjà affaiblies par la pollution et la perte de leur habitat, sont à appelées à disparaître dans les 100 prochaines années. Les êtres humains, bien que n'étant pas menacés de cette manière, vont probablement faire face à des difficultés de plus en plus grandes. Les récentes tempêtes, inondations et sécheresses, par exemple, ont tendance à démontrer ce que les modèles d'ordinateurs prédisent comme fréquents "événements météorologiques extrêmes".

Le niveau de la mer a augmenté de 10 à 20 cm au cours du 20^{e} siècle et une hausse supplémentaire de 9 à 88 cm est prévue d'ici l'an 2100 (GIEC-II, 2002). (Des températures plus élevées causent l'expansion du volume des océans et, la fonte des glaciers et des calottes glaciaires ajoute encore plus d'eau.) Si le sommet de cette échelle est atteint, la mer pourrait déborder dans des zones côtières fortement peuplées de pays tels que le Bangladesh, causant ainsi la disparition de nations entières (tel que l'Etat-île des Maldives), polluant l'eau fraîche de milliards de personnes et poussant à des migrations massives (GIEC-II,2002).

Dans la plupart des régions tropicales et sub-tropicales, les productions agricoles sont prévues de chuter -- et dans les régions tempérées, aussi, si les températures augmentent de plus de quelques degrés C. Est également prévu un assèchement des zones intérieures continentales, telles que l'Asie centrale, l'Afrique sahélienne et les Grandes Plaines des États-Unis. Ces changements pourraient causer, au minimum, des perturbations dans l'usage des sols et les ressources alimentaires. Et la portée de maladies telles que le paludisme pourrait s'étendre.

Le réchauffement global est un problème "moderne" -- compliqué, impliquant le monde entier, emmêlé à d'autres sujets difficiles tels que la pauvreté, le développement économique et la croissance de la population.

Madagascar a connu plusieurs événements extrêmes liés aux variabilités climatiques actuelles et passées durant ces dernières décennies. Les plus importants sont les cyclones, les inondations et les sécheresses. Ces perturbations deviennent de plus en plus fréquentes et intenses et génèrent des impacts importants notamment en matière de pertes de vie humaine, de diminution de production agricole et animale, de destruction des infrastructures, de dégradation des ressources naturelles (eaux, sols et forêts) et d'érosion côtière, rendant ainsi précaires la sécurité alimentaire, l'alimentation en eau potable et l'irrigation, la santé publique et la gestion de l'environnement et du mode de vie. Ces impacts mettent la population malgache et ses activités de développement en situation de vulnérabilité répétitive et croissante.

2. Contexte Générale

Madagascar fait partie du continent africain. Elle est localisée au sud-ouest de l'océan indien entre 11°57'-25°35'S et 43°14'-50°27'E. A l'ouest, le canal de Mozambique la sépare du continent africain, et à l'Est, l'océan indien du continent Asiatique.

Elle a une longueur de 1600Km du Nord au Sud, une largeur de 580Km et une superficie de 587 041 km^2 avec des côtes de 5603 km. Elle est la quatrième plus grande île du monde après le Groenland, la Nouvelle guinée et Borneo.

Le relief de Madagascar est très varié et souvent accidenté bien qu'aucun sommet ne dépasse 3000 m. L'axe principal de l'île s'étend dans la direction Nord-Nord Est – Sud-Sud Ouest et le relief suit cette direction malgré le fait qu'il y ait une forte asymétrie dans la région du centre. La falaise orientale fait suite au rivage de la côte est et atteint une altitude comprise entre 800m et 3000m. Cette falaise est par endroit surplombée de massifs, tel que le massif de Tsaratanana ou celui d'Ankaizina. Le versant ouest est dominé par de vastes plaines et des plateaux, ainsi que de vastes zones deltaïques comme le delta de la Betsiboka sur la côte Ouest de l'île, près de Mahajanga (CCNUCC, Communication nationale initiale, 2003).

Dans l'ensemble, Madagascar est caractérisé par des climats[1] tropicaux à deux saisons nettement tranchées : l'été et l'hiver.

La température moyenne annuelle, varie entre 23°C à 27°C avec une amplitude thermique moyenne annuelle passant d'environ 3°C au Nord à 7,5°C dans les régions sèches du Sud-Ouest. L'altitude a un effet significatif sur les températures. Ce qui fait que sur le plateau central, la moyenne annuelle des températures se situe entre 16°C à 19°C.

La quantité annuelle de précipitation diminue d'Est en Ouest avec un maximum de 3700mm par an et du Nord au Sud avec un minimum de 350mm par an, tandis que la saisonnalité augmente dans les mêmes directions. De l'Ouest vers le Sud, la saison sèche devient plus longue et de plus en plus marquée. Là où la saisonnalité est marquée, les saisons sèches et fraîches coïncident et elles se situent entre juin et octobre.

[1] Le climat actuel de référence est le climat pendant la période normale (1961 – 1990) définie par l'Organisation Météorologique Mondiale (OMM) et recommandé par l'IPCC (1994) (Smith, J. B et M. Hulme, 1998)

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Ainsi, à l’extrême Sud-Ouest, le climat est de type semi désertique, tandis que dans la région de la côte Est, le climat est du type tropical humide.

Quant à la circulation générale atmosphérique, le pays est caractérisé d'une part par la présence de l'alizé venant du Sud-Est en hiver et de la mousson du Nord-Ouest et d'autre part par l'affaiblissement relatif de l'Anticyclone subtropical du sud-est des Mascareignes et l'installation progressive des basses pressions équatoriales ainsi que la zone de convergence intertropicale aux alentours de la latitude 10°S en été. Des fronts polaires défilent assez rapidement, deviennent actifs et provoquent des situations orageuses sur l'ensemble du territoire national. C'est pendant cette période que des dépressions et cyclones tropicaux se forment dans l'Océan Indien.

3. Changements climatiques observés à Madagascar

Des perturbations des régimes climatiques pourraient se manifester par un raccourcissement de la saison sèche, un allongement des périodes de sècheresse, une augmentation de la pluviosité dans les régions des tropiques où la pluviométrie est déjà élevée, des tempêtes plus fréquentes et plus violentes découlant de l'augmentation de la température et de l'humidité de l'air.

De par sa position géographique, située dans la zone tropicale, Madagascar est régulièrement confrontée à une grande diversité de cataclysmes. Localisée dans l'Océan Indien, Madagascar est classée parmi les pays ayant un niveau de risque global très élevé dû au passage des perturbations cycloniques. Les principaux risques climatiques sont les cyclones, les sécheresses et les inondations.

Au cours des cinquante dernières années (1955 – 2005), les tendances climatiques observées à Madagascar par le service de la Météorologie font ressortir une hausse des températures moyennes annuelles, autant estivales que hivernales. Les précipitations varient en fonction des régions et des mois considérés (Raholijao, 2007).

Les premiers travaux de recherches sur la climatologie remontent à 1932 et les recherches se poursuivent jusqu'à maintenant.

On peut citer des ouvrages de références comme l'Atlas Climatologique de Madagascar (Jacques Ravet, 1948) qui a utilisé des données provenant de 119 stations sur la période 1937 – 1944. Il y a également Les Pluies à Madagascar (Jacques Ravet, 1950), ouvrage de référence au moment de sa publication. Cet ouvrage donne pour Madagascar, les Comores et la Réunion, dans 57 stations et pour 15 ans, la moyenne des pluies mensuelles, les isohyètes mensuelles, les coefficients pluviométriques, la variabilité des pluies mensuelles et annuelles, la variabilité des pluies décadaires et la variation diurne et le maximum horaire.

Plusieurs études ont suivi ces ouvrages. On peut citer entre autre, l'Essai De Modèle à Filtre Linéaire pour une Prévision Mensuelle et Saisonnière de la Pluviométrie à Madagascar (Razafindrakoto Léon Guy, 1988) ; Quelques Variations Régionales et Temporelles du Climat Actuel de Madagascar (Williams J.B, 1990) ou encore The Climate Of Madagascar and Relationships To Southern Africa (M.R. Jury, Raholijao, 1991).

3.1. Température

Sur l'ensemble de l'île, on note une hausse des températures moyennes annuelles autant pendant les mois estivales (Décembre, Janvier, Fevrier) que pendant les mois hivernales (Juin, Juillet et Aout).

Cette augmentation varie selon les régions considérées.

En général, pendant la saison estivale, la température augmente de 0,2°C à 1,5°C. On note le maximum de hausse dans les régions Analamanga (1,5°C), Atsimo Andrefana (1°C) et Atsinanana (1°C). Le minimum de hausse est enregistré dans les regions Melaky et Ihorombe.

Les températures hivernales ont augmenté de 0,1°C à 1,2°C. Les hausses maximums ont été relevés dans les regions Analamanga (1,2°C), Atsinanana(1,2°C), Menabe(1,1°C), Atsimo Andrefana(1°C). L'augmentation minimum a été relevé dans la région Ihorombe (0,5°C) (N. Raholijao, 2007).

Tableau 1 : Tableau récapitulatif des variations de températures selon les régions

	Mois estival	***Mois hivernal***
Variation (°C)	0,2 – 1,5	0,1 – 1,2
Maximum (régions)	Analamanga, Atsimo Andrefana, Atsinanana	Analamanga, Atsinanana Menabe, Atsimo Andrefana
Minimum (regions)	Melaky, Ihorombe	Ihorombe

3.2. Précipitations

Les précipitations augmentent ou diminuent selon la période de l'année et aussi les regions concernés.

*Octobre/Novembre :

Des augmentations de la précipitation ont été enregistrés dans les regions Sofia, Melaky, Boeny, Ihorombe, Atsimo Andrefana et Androy

Par contre, les regions Diana, Sava, Analanjirofo, Betsiboka, Analamanga,Itasy, Bongolava, Vakinankaratra, Alaotra-Mangoro, Atsinanana, Vatovavy Fitovinany, Atsimo Atsinanana et Anosy ont subi une diminution de la précipitation.

D'autres regions comme Menabe et Haute Matsiatra n'ont pas subi de changements notables (N. Raholijao, 2007).

*Décembre/Janvier/Février :

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Les régions Analanjirofo, Alaotra Mangoro, Betsiboka, Atsinanana, Melaky, Menabe, Anosy et Androy ont vu leur précipitation annuelle augmentée alors que les régions Diana, Sofia, Boeny , Vakinankaratra, Amoron'i Mania, Haute Matsiatra, Ihorombe, Vatovavy Fitovinany, Atsimo Atsinanana et Atsimo Andrefana.

Les régions Sava, Analamanga, Itasy et Bongolava ne sont pas affectés par des changements de précipitations (N. Raholijao, 2007).

*Juin/Juillet/Août

Pendant ces mois, on observe une baisse généralisées des précipitations sur toutes les régions, excépté dans la région Atsinanana (N. Raholijao, 2007).

Tableau 2 : Tableau récapitulatif des variations de précipitations selon les régions

Mois	***Octobre/Novembre***	***Décembre/Janvier/Février***	***Juin/Juillet/août***
Augmentation	Sofia, Melaky, Boeny, Ihorombe, Atsimo Andrefana, Androy	Analanjirofo, Alaotra Mangoro, Betsiboka, Atsinanana, Melaky, Menabe,	-
Diminution	Diana, Sava, Analanjirofo, Betsiboka, Analamanga, Itasy, Bongolava, Vakinankaratra, Alaotra-Mangoro, Atsinanana, Vatovavy Fitovinany, Atsimo Atsinanana, Anosy	Diana, Sofia, Boeny, Vakinankaratra, Amoron'i Mania, Haute Matsiatra, Ihorombe, Vatovavy Fitovinany, Atsimo Atsinanana, Atsimo Andrefana	Toutes sauf Atsinanana
Neutre	Menabe, Haute Matsiatra	Sava, Analamanga, Itasy, Bongolava	-

3.3. Elévation du niveau moyen de la mer de 1955 à 2003

Le niveau marin a connu une élévation sur toutes les zones côtières de l'île (GIEC-I, 2007, Raholijao, 2007). Les différentes valeurs d'élévation de niveau marin relevés le long des côtes de Madagascar sont reportées dans le tableau suivant :

Tableau 3 : Tableau récapitulatif des élévations du niveau marin

Zones	***Elévation***
De Nosy Be au Cap Saint André	1,6mm/an à2mm/an

Du Cap Saint André au Cap Saint Vincent	0,8mm/an à 1,2mm/an
Du Cap Saint Vincent à Taolagnaro	1,6mm/an à 2,4mm/an
De Taolagnaro à Cap Masoala	0,8mm/an à1, 6mm/an
Du Cap Masoala à Nosy Be	1,2mm/an à 1,6mm/an

3.4. Elévation de la température de surface de la mer

L'élévation de la température du niveau de la mer (Surface Sea Température, SST) est une des conséquences des changements climatiques. Cette élévation est provoquée par des phénomènes climatiques naturels comme El Nino.

Cependant, dans l'Océan Indien, il existe un autre phénomène participant également à l'élévation de la température de l'eau de mer. Il s'agit du Dipôle de l'Océan Indien ou IOD (Indian Ocean Dipole).

On connaît peut d'informations actuellement sur l'IOD[2]. Cette variation du climat a des impacts importants sur le climat de l'Inde et des pays aux alentours suivant les anomalies de la température de la surface de l'Océan Indien. Ce phénomène de IOD touche également la partie nord de Madagascar.

Le Dipôle Océan Indien est un phénomène du lien entre l'océan et l'atmosphère dans l'Océan Indien. Il serait indépendant d'El Nino (ENSO) comme seulement 35% des événements du Dipôle Océan Indien se produisent avec ENSO. De plus en 1961, un IOD+ s'est produit sans EL Niño dans le Pacifique et en 1967, un IOD+ a coïncidé avec la Niña et le dipôle positif de 1997 s'est produit avec un fort EL Niño.

Le Dipôle Océan Indien est positif (IOD+) quand la température de la surface de l'eau de l'océan Indien est supérieure à la normale à l'ouest et inférieure à la normale à l'est.

Quand on a un IOD+ dans le centre-ouest de l'océan Indien tropical des précipitations supérieures à la normale ont lieu alors que dans l'est de l'océan Indien tropical et dans l'ouest de l'océan Pacifique tropical les précipitations sont inférieures à la normale.

Le Dipôle Océan Indien est négatif quand la température de la surface de l'eau de l'océan Indien est inférieure à la normale à l'ouest et supérieure à la normale à l'est.

Quand on a un IOD- dans le centre ouest de l'océan Indien tropical des précipitations inférieures à la normale ont lieu alors que dans l'est de l'océan Indien tropical et dans l'ouest de l'océan Pacifique tropical les précipitations sont supérieures à la normale.

[2] L'IOD a été découvert en 1999 par le Dr Toshio Yamagata, directeur de programme de recherche de variations de climat, professeur à l'Université de Tokyo.

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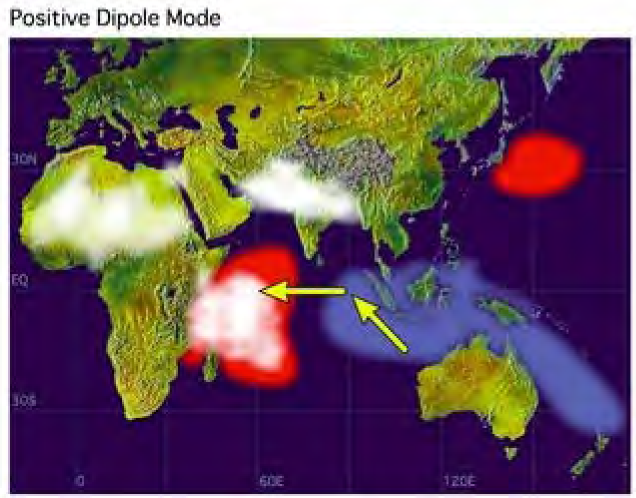
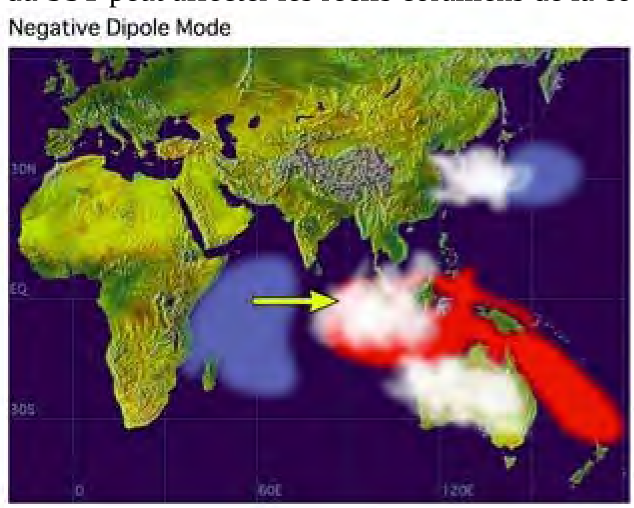


(Source: UN Atlas of Ocean)

Figure 1 : Schéma des anomalies de la SST (en rouge SST se réchauffant ; en bleu se refroidissant) pendant un événement positif du Dipôle Océan Indien. Les taches blanches indiquent l'activité nuageuse et pluvieuse. Les flèches indiquent la direction du vent.

D'après ce schéma, la partie nord de Madagascar est affectée par le phénomène de IOD. L'augmentation du SST peut affecter les récifs coralliens de la côte nord ouest de l'île.



(Source: UN Atlas of Ocean)

Figure 2 : Schéma des anomalies de la SST (en rouge SST se réchauffant ; en bleu se refroidissant) pendant un événement négatif du Dipôle Océan Indien. Les taches blanches indiquent l'activité nuageuse et pluvieuse. La flèche indique la direction du vent.

4. Changements climatiques projetés à Madagascar

Les changements climatiques globaux projetés pour Madagascar incluent une augmentation des températures, une diminution des précipitations moyennes annuelles, même si une augmentation des précipitations est à prévoir pour diverses régions de l'île ainsi qu'une hausse généralisée du niveau de la mer.

Un rapport sur les scénarios des changements climatiques à Madagascar a déjà été réalisé, dans le cadre de l'élaboration de la Communication National Initiale de la CCNUCC[3] (Projet MAG99G31).

Trois scénarios d'émissions de gaz à effets de serre - IS92a, IS92c et SRES98 A2 - ont été couplés avec trois GCM (General Circulation Model) à savoir HadCM2 (de Hadley Center of Climate Prediction), CSIRO-TR (de l'Australian Commonwealth Scientific and Industrial Research Organisation) et l'ECHAM4 (du German Climate Research Centre) pour avoir une projection du futur état du climat de Madagascar.

Pour les projections rapportées dans ce document, l'auteur n'a pas encore communiqué les détails sur les scénarios utilisés.

On prévoit une augmentation des températures de 0.5°C à 1°C au cours des deux prochaines décennies, de 1°C à 1.5°C au milieu du siècle et de 2,5°C à 3°C à la fin du siècle, aussi bien en Eté qu'en Hiver (Raholijao, 2007).

Les précipitations moyennes annuelles diminueront de 5% à la fin du siècle sur l'ensemble de l'île. On prévoit néanmoins une augmentation de 5% à 10% des précipitations en Decembre/Janvier/Fevrier. Le maximum de hausse (10%) sera observé sur les régions Atsimo Andrefana, Anosy et Androy (Raholijao, 2007).

Une diminution de 5% à 30% des précipitations sera par contre envisageable en Juin/Juillet/Août. Le maximum de baisse (20% à 30%) est prévu sur les régions Atsimo Andrefana, Anosy , Ihorombe et Androy (Raholijao, 2007).

Quant au niveau marin, une hausse de 0,1m du niveau moyen de la mer sur la majeure partie des côtes de Madagascar est envisagée, à l'exception des côtes centre Est où les variations ne seront pas significatives (Raholijao, 2007).

Les tendances futures des cyclones tropicaux seront identiques aux tendances globales (augmentation de l'intensité des vents et précipitations associés).

Selon le modèle et le scénario utilisé pour la projection, les changements climatiques envisagés pour le futur varient. En effet, le manque de données pour alimenter les modèles pour les régions australes du continent africain dont fait partie Madagascar, rend difficile une

[3] Convention Cadre des Nations Unies sur les Changements Climatiques.

projection fidèle des changements climatiques pour le futur. Par exemple, pour les trajectoires des cyclones, selon le scénario utilisé, on peut s'attendre à une hausse de leur fréquence pouvant aller jusqu'à 3 à 4 fois leur fréquence normale (Hudson et al, 2002) (Landman et al, 2005).

5. Impacts et vulnérabilités

Le climat est le principal facteur contrôlant la structure et la productivité végétale ainsi que la composition des espèces animales et végétales à l'échelle mondiale. Un grand nombre de végétaux ne peuvent se reproduire et croître que dans une plage de températures spécifiques, réagissent à des volumes et des profils saisonniers de précipitations spécifiques, risquent d'être déplacés par la concurrence d'autres végétaux ou de ne pas survivre à des changements climatiques. De même, les espèces animales nécessitent des plages de températures et/ou de précipitations spécifiques et dépendent de la présence continue d'espèces nécessaires à leur alimentation (GIEC-II, 2002).

5.1. Biosphère terrestre

5.1.1. Faune

Cas des lémuriens

Les zones les plus proches des pôles seront les plus affectées par les changements climatiques. Madagascar fait partie de ces zones et, de plus, se trouve dans une situation faisant en sorte que les écosystèmes qu'elles abritent soient susceptibles aux moindres changements. En effet, l'île a perdu plus la majeure partie de sa couverture forestière. Cette situation, couplée avec les effets globaux des changements climatiques, constitue une menace sérieuse pour une des espèces les plus emblématiques de Madagascar, les lémuriens.

Quatre espèces de lémuriens sont parmi les 25 espèces de primates les plus menacés de la planète : *Prolemur simus, Eulemur albocollaris, Propithecus perrieri, Propithecus candidus* (UICN, WCU-SSC, IPS, 2005)[4].

Les variations de la précipitation font partie des impacts les plus importants du changement climatique, pouvant affecter les lémuriens. Cette variation se comprend, pas plus en terme de quantité que de distribution tout au long de l'année. Elle peut se traduire par moins de précipitations que la moyenne durant certaines périodes de l'année, et plus pendant d'autres périodes.

Des chercheurs, ayant étudiés les lémuriens à Madagascar, ont découvert que des liens existent entre la détérioration des dents des lémuriens les plus âgés et la reproduction et

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[4] WCU-SSC : The World Conservation Union's Species Survival Commission
IPS : International Primatological Society (IPS)

la survie de jeunes lémuriens et suggère que la quantité de précipitation joue un rôle important dans la pérennité des espèces de lémuriens (Wright et al, 2005).

Les primates vivent relativement longtemps et peuvent se reproduire même à des âges avancés. Cependant, cette reproduction se trouve affectée par la détérioration de la dentition au fil du temps.

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Les chercheurs rapportent qu'au delà d'un certain âge, environ dix huit ans, la survie des bébés lémuriens est conditionnée par une précipitation élevée durant la période de lactation. En effet, une équipe de chercheurs a étudié une population de lémuriens, les « sifaka », durant les vingt dernières années. Ils ont procédés à des analyses de la dentition des sifaka et ont corrélés ces analyses à des systèmes d'informations géographiques (Wright, J. Jernval, 1999). Ils ont découvert que la couronne dentaire de ces derniers s'amenuise considérablement vers l'âge de dix huit ans. A partir de ce moment, les femelles les plus âgées ont plus de difficultés pour produire le lait nécessaire pour la croissance de leurs portées (Wright et al, 2005). Ces difficultés sont d'autant plus appuyées que les précipitations sont faibles pendant la période où ces femelles doivent allaiter. La nourriture principale de ces lémuriens est, en effet, constituée de jeunes pousses et de feuillages. Or, l'apparition de ces derniers est étroitement liée à la précipitation et à d'autres facteurs comme la température.

Malgré cela, on a noté des sifakas qui survivent et se reproduisent encore pendant une dizaine d'années aussi longtemps que les précipitations sont abondantes pendant la période de lactation.

Les chercheurs ont conclu que, au-delà d'un certain point, le succès de la reproduction de ces lémuriens est étroitement lié aux fluctuations de l'environnement.

Cela suggère que des changements moindres au niveau du climat peuvent affecter la survie de l'espèce.

Cas de la faune aviaire

Les données (références bibliographique ou littérature grise) ou les études ayant trait aux éventuels impacts des changements climatiques sur la faune aviaire de Madagascar sont pratiquement inexistants. Néanmoins, d'après les études effectuées par le GIEC (GIEC-II, 2002) les changements climatiques peuvent être un facteur accentuant les pressions déjà exercées sur les espèces menacés.

Les changements climatiques peuvent entraîner des bouleversements qui affectent l'habitat et/ou directement la physiologie de nombreuses espèces d'oiseaux endémiques de Madagascar.

Le réchauffement climatique a une influence sur la biologie des oiseaux migrateurs. En effet, certains oiseaux migrateurs reviennent de plus en plus tôt et repartent parfois plus tard, voire changent complètement leurs habitudes : ils écourtent leur migration en faisant l'impasse sur la traversée du Sahara et hivernent sur le pourtour méditerranéen ou le long des côtes atlantiques (Oiseau magazine, 80, juillet-aôut-septembre 2005).

La couverture forestière constitue le principal habitat des ces oiseaux. Cependant, elle est déjà fortement réduite dans l'île à cause des activités anthropiques. Les stress environnementaux -- imputables aux changements climatiques -- qui s'ajoutent à cette dégradation de leur habitat, peuvent voir pour effet d'augmenter le risque d'extinction des oiseaux (GIEC-II, 2002).

Les lacs et autres réservoirs, habitat des certaines espèces d'oiseaux, peuvent également subir une variation de température mais aussi un ensablement, suite à des érosions, et ainsi, le risque d'extinction des espèces qui y vivent augmente (GIEC-II, 2002)

L'avifaune de Madagascar comprend 294 espèces dont 107 endémiques (y compris 2 nicheurs). 30 espèces sont globalement menacées, 6 ont été introduites par l'homme (Lagrand, 1996) (Sueur, 1996).

Il s'agit d'une richesse unique dans la mesure où l'endémisme des oiseaux dans les autres pays s'arrête au niveau des espèces. Partant, la faune aviaire constitue un gros potentiel économique et un important patrimoine pour la Grande île que la majorité des Malgaches l'ignorent.

Les oiseaux jouent aussi un rôle important dans l'équilibre de l'écosystème. Leurs extinctions pourraient donc perturber cet équilibre et mettre en péril d'autres espèces (GIEC-II, 2002).

Les Bulbuls ou Tsikorovana aident à la régénération forestière : ils se nourrissent de graines et de petits fruits dont une partie seulement est digérée. Le reste est dispersé dans la nature avec les excréments et en germant, donneront de nouvelles plantes.

Les Soimanga se nourrissent de nectar et en se nourrissant, ils pollinisent les fleurs visitées, lesquelles vont donc produire des fruits.

Ces quelques exemples nous montrent les liens existant entre divers écosystèmes et la conséquence que peuvent avoir une extinction de ces espèces sur ces écosystèmes. Une perturbation du système climatique aura ainsi des conséquences considérables, non seulement sur la faune aviaire mais aussi sur les différents écosystèmes auxquels cette faune est interconnéctée.

Or, les espèces ayant des aires de répartition climatiques restreintes et/ou des besoins très spécifiques en matière d'habitat et/ou de petites populations sont généralement les plus vulnérables face au risque d'extinction (GIEC-II, 2002). D'une manière générale, les changements climatiques auront ainsi potentiellement des effets sur la faune aviaire de Madagascar.

Désertification

La désertification qui constitue pour le monde entier une menace croissante ne cesse de s'amplifier ces deux dernières décennies. Elle affecte près de un quart de la superficie terrestre et menace l'existence de plus de 900 millions de personnes dans plus d'une centaine de pays. La situation semble s'accélérer partout dans le monde, particulièrement en Afrique où 66% de la superficie sont composés de terres arides et un peu plus d'un million d'hectare, soit 73% du total des terres agricoles sont modérément ou gravement touchés.

Les parties Sud et Sud-Ouest de Madagascar, où sécheresse et famine se succèdent périodiquement, semblent être les plus touchées par la désertification. Ce phénomène touche environ une superficie de 85.000km et menace une population de l'ordre de 1 million de personnes. La rudesse du climat, la prédominance de la sécheresse, l'irrégularité du réseau hydrographique liée à l'irrégularité des précipitations, la paupérisation généralisée font de cette partie du Sud du pays une zone défavorisée sujette aux émigrations périodiques. La désertification se manifeste sous divers aspects qui convergent vers la dégradation accélérée de l'environnement et des ressources de production. Entre autres, aspects, l'accélération du phénomène d'érosion des sols, la perte de fertilité des sols et de la productivité agricole, l'appauvrissement de la diversité biologique, l'aggravation de la pauvreté des populations, l'insuffisance de la sécurité alimentaire, la migration et l'insécurité générale...(Site Web, Biodiversity Reporting, 2004)

Force est de constater que dans l'ensemble, les pays africains touchés par la désertification sont lourdement tributaires des ressources naturelles. La plupart d'entre eux souffrent d'une grande pauvreté et sont classés parmi les moins avancés du monde. Des activités humaines telles que la surexploitation des terres, le surpâturage, la déforestation et les méthodes d'irrigation inadéquates, associés au changement climatique, transforment des terres jadis fertiles en friches stériles et improductives. En effet, la désertification serait aggravée par une diminution des précipitations annuelles moyennes ou une augmentation des besoins d’évaporation moyens (GIEC-II, 2002). Les projections climatiques effectuées par le service de la météorologie montrent que les régions de sud de Madagascar subiront jusqu’à 20 à 30% de précipitations en moins à l’avenir (Raholijao, 2007). Le risque de désertification serait alors accrue.

Cas des amphibiens

Les Amphibiens occupent différents types de niches écologiques et fréquentent aussi bien les milieux ouverts (tavy, marécages, rizières), les voisinages des plans d’eau que les forêts humides (Raxworthy et al, 1994). Ils sont représentés uniquement par des grenouilles dont les formes larvaires, les têtards, sont strictement aquatiques ou liées au milieu aquatique.

La dégradation des habitats constitue la principale menace qui pèse sur les Amphibiens. Les biotopes aquatiques ne sont pas à l’abri des perturbations provoquées par l’ensablement, par l’érosion ou encore la pollution des zones humides et des plans d’eau (Andreone et al, 2005). L’introduction d’espèces nouvelles de poissons carnivores, comme ce furent le cas avec le Black-bass (*Micropterus salmoïdes*) et le Fibata (*Ophiocephalus striatus*), constitue une autre menace sur la population batrachologique, du moins dans la zone d’acclimatation de ces poissons. Enfin, l’ampleur prise par la collecte sauvage de grenouilles dans leurs milieux naturels, pour alimenter le commerce international, peut constituer un réel danger pour leur survie.

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A ces pressions peuvent s'ajouter des pressions environnementales, comme les changements climatiques, qui peuvent augmenter les risques d'extinctions de ces espèces (GIEC-II, 2002)/

Jusqu'à maintenant, très peu de données sont disponible en ce qui concerne les effets des changements climatiques sur les amphibiens. Cependant même si plus de données étaient disponibles, il serait difficile de déterminer des relations entre changement climatique et déclin de population des amphibiens car d'autres facteurs environnementaux varient simultanément.

Plusieurs études, réalisées à travers le monde, essentiellement dans les tropiques, ont démontré des relations entre déclin de population et des conditions climatiques irrégulières.

Par exemple, entre 1979 et 1982, Heyer et al. (1988) ont observé que des gels sévères ont causé l'extinction de 5 espèces d'amphibiens. Au Costa Rica, Pounds et al (2006) ont reporté un déclin de population d'amphibien en fonction de période de réchauffement régionale.

Il est probable que les changements climatiques affectent aussi les populations d'amphibiens par d'autre processus plus complexe. Par exemple, des changements locaux dans les facteurs environnementaux peuvent diminuer les fonctions immunitaires des amphibiens et augmenter leur taux de mortalité. Les conditions environnementales peuvent favoriser l'apparition d'une pathologie. Par exemple, Kiesecker et al. (2001) ont observé que durant les années très sèches, une profondeur de ponte réduite augmente l'exposition des enbryons d'amphibiens aux ultraviolets-B. Or, cette exposition augmente leurs vulnérabilités à une maladie infectieuse, *Saprolegnia ferax,* qui cause une mortalité des œufs. (Kiesecker et al. 2001).

Une équipe de scientifique a évalué les risques d'extinction des amphibiens de Madagascar en évaluant leur distribution, leur occurrence dans les aires protégés, la tendance des populations et la qualité de l'habitat. Ils ont découvert que 9 espèces sont en danger critique d'extinction, 21 sont en danger et 25 vulnérables. La majorité des espèces menacées se trouve dans les plateaux de Tsaratanana-Masoala-Marojejy et les montagnes de l'Anosy. (Andreone et al, 2005).

5.1.2. Forêts et régions boisées

Le changement climatique et les forêts sont indissolublement liés. D'une part, les forêts subissent déjà les conséquences de la modification du climat de la planète par un accroissement des températures annuelles moyennes, une altération des régimes de précipitations et des phénomènes météorologiques extrêmes plus fréquents (UNEP/CBD[5]/AHTEG-BDCC/1/2, 2001).

Deux formes de dégradation sont considérées comme les plus importantes : l'érosion pluviale et l'érosion éolienne des sols des grands bassins versants (PANA-Madagascar, 2006).

Cas de Tampoketsa et des zones arides de l'extrême sud.

Actuellement, les tampoketsa d'Ankazobe, 1,2 millions d'hectares de savanes boisées, sont constamment affecté par l'érosion pluviale. Elle entraîne une perte de terre de l'ordre de 7 à 57t/ha/an dans les parties boisées. Dans l'extrême sud, le flux éoliens véhiculé par les alizés dépose annuellement 13 tonnes par hectares de sables fins sur les 76000

[5] Convention on Biological Diversity

hectares de zones de pâturages et d'agriculture du bassin d'Ambovombe (PANA-Madagascar, 2006).

Une simple augmentation de la température atmosphérique mondiale de l'ordre de 2,5°C suffirait pour provoquer un ensablement total des vallées de Tampoketsa d'ici à 95 ans.
Ce même scénario augmentera de 212% les valeurs actuelles du taux d'ensablements des pâturages du Sud d'ici à 2100 (PANA-Madagascar, 2006).

Forêts et phénomènes climatiques extrêmes

Depuis plusieurs années, les climatologues se posent la question de l'existence et de la nature d'un lien entre l'occurrence et la violence des cyclones tropicaux et le réchauffement climatique. D'après une étude (Webster et al,2005) publiée dans la revue Science par des chercheurs américains de l'Institut de technologie de Georgie et du Centre national de recherche atmosphérique, basé à Boulder (Colorado), le nombre et la durée des cyclones est globalement stables depuis 35 ans à l'échelle planétaire.

Une nouvelle étude, réalisée par Gabriel Vecchi de la National Oceanic and Atmospheric Administration (NOAA) et Brian Soden de l'Université de Miami, montre que cette relation est plus ambiguë. D'après les résultats de leurs simulations pour le 21ème siècle, le réchauffement climatique s'accompagnerait d'une " robuste " augmentation des vents contraires dans l'Atlantique tropical et le Pacifique est. Or cette augmentation, qui se développe également dans l'Atlantique lors des phénomènes El Niño, est historiquement associée à une diminution de la formation de cyclones dans cette région. Selon les auteurs, ces résultats soulignent l'importance de l'intégration de ces paramètres dans les futures prédictions de l'activité cyclonique atlantique.

Le secrétariat de la Stratégie internationale pour la prévention des catastrophes (SIPC) appelle la communauté internationale à investir plus dans les politiques de réduction de catastrophes pour réduire l'impact des évènements extrêmes liés aux phénomènes hydro-météorologiques

" Ce qui se passe actuellement à Madagascar est un bon exemple de ce qui peut se produire dans beaucoup d'autres pays. Madagascar connaît la pire saison cyclonique avec plus de 6 cyclones depuis le mois de décembre, qui ont déjà provoqué la mort de plus de 60 personnes et contraint des milliers d'autres à fuir leurs maisons inondées," explique Sálvano Briceño, Directeur du secrétariat de la SIPC. " L'augmentation de la fréquence et de la sévérité des évènements climatiques extrêmes empêche la population de récupérer rapidement avant l'arrivée d'un autre cyclone, ce qui la rend encore plus vulnérable aux suivants." Ce dérèglement climatique exige des investissements supplémentaires dans le domaine de la prévention des aléas naturels."

Cette affirmation peut également s'appliquer aux écosystèmes perturbés par ces phénomènes climatiques, comme les forêts. Une augmentation de la fréquence des cyclones pourrait donc menacer les espèces qui vivent dans les écosystèmes touchés et appauvrir la biodiversité.

Le récent rapport du Groupe d'experts intergouvernemental sur l'évolution du climat (GIEC – I, 2007), en février dernier a prédit une augmentation des vagues de chaleur et des précipitations ainsi qu'un nombre plus important de cyclones tropicaux. Dans certains pays, les changements climatiques se traduiront par des catastrophes plus intenses et fréquentes, dans d'autres, par des aléas auxquels les communautés devront faire face pour la première fois.

Les cyclones tropicaux se développent au-dessus des endroits où la température est chaude, et précisément dans les régions tropicales où on observe le développement d'anomalies au niveau de la température de la mer, depuis une trentaine d'années.

La plupart des études montrent qu'avec le réchauffement de la planète, ce n'est pas le nombre de cyclones qui augmente, mais leur puissance. Le cyclone s'alimente de l'humidité qui est très forte là où la mer est chaude. Or le réchauffement climatique humidifie et réchauffe encore davantage les basses couches de l'atmosphère et refroidit la haute région des nuages. On a donc un plus grand contraste entre surface et l'altitude, ce qui augmente l'énergie qui peut potentiellement se libérer du cyclone.

Au cours de la dernière saison cyclonique, pas moins de six cyclones ont touché l'île.

Le Service de Météorologie de Madagascar affirme quant à cette succession de cyclones que la fréquence des cyclones résulte des changements climatiques prédominant actuellement sur l'ensemble des pays du monde entier. Une anomalie des climats apparaît dans l'hémisphère Sud. Cela se traduit par le réchauffement de l'océan, dont la température est supérieure de 2°C par rapport à la normale. Ce qui provoque une forte humidité de l'atmosphère, une évaporation des vents humides et une augmentation du taux de pluviométrie. Les différents systèmes dépressionnaires se forment alors.

Ce service affirme également que la grande île n'a pas fait face à un tel phénomène ces cinq dernières années. Les changements climatiques se sont soldés par le réchauffement de l'atmosphère. Les Zones de convergence intertropicale (ZCIT) ont été plus actives dans l'hémisphère Sud depuis le début de la saison cyclonique 2006-2007. Or, les ZCIT se trouvent souvent à l'origine de la formation des cyclones.

5.2. Zones côtières et marines

5.2.1. Cas des Récifs coralliens

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Les coraux sont des animaux marins, vivant en symbiose avec des algues et qui constituent leur propre squelette calcaire. Ces structures coralliennes servent d'abris à des milliers d'espèces qui forment la communauté corallienne (Site web, CORDIO[6]).

Les récifs représentent une grande diversité géomorphologique. On distingue :
- le récif frangeant, étroit, qui borde la côte (les Antilles);
- le récif barrière, séparé de la côte par un lagon qui peut atteindre plusieurs dizaines de kilomètres de large (Australie, Nouvelle-Calédonie);
- l'atoll, qui est un récif annulaire de haute mer entourant un lagon central (atolls de l'océan Indien, des Tuamotu, des Maldives);
- le banc récifal, qui est un édifice corallien construit en pleine mer sur un haut fond.

Les écosystèmes associés aux récifs coralliens sont :
- les herbiers de phanérogames : zones de nutrition, en particulier pour les espèces menacées (tortues marines, Dugong) et frayères qui stabilisent le sédiment et oxygènent les eaux;
- les mangroves: systèmes biologiques très productifs, zones de reproduction et de nourricerie qui fixent les sédiments et les agents de protection des côtes contre les tempêtes et l'érosion côtière.

Ces écosystèmes occuperaient environ le tiers des littoraux tropicaux peu profonds du monde : 15% pour les récifs coralliens, 9% pour les mangroves, 9% pour les herbiers.

Les récifs coralliens sont présents dans plus de 100 pays, recouvrant une surface équivalente à celle de la France.

L'écosystème récifal est, avec les forêts tropicales, l'écosystème le plus riche en biodiversité ainsi que le plus complexe et le plus productif de la planète. Les récifs abritent des dizaines de milliers d'espèces appartenant à tous les groupes zoologiques, poissons, invertébrés marins (mollusques, crustacés, éponges, coraux, vers...), mammifères, et. Dans les zones les plus riches, on peut compter plus de 700 espèces de coraux, plus de 6000 espèces de mollusques et près de 4000 espèces de poissons.

Une prospection sur la côte sud Ouest de Madagascar révèle un blanchissement corallien sans précédent. Quelques récifs ont perdu jusqu'à 99% de leur couverture corallienne (Harding et al, 2006). Le Grand Récif de Tuléar, par exemple a subi des dégradations. Bien que les pentes externes soient restées intactes, le platier est pratiquement dépourvu de corail vivant. Une perte de 40% en terme d'espèces de poissons a également été constatée (Savaivo, 2004).

Le blanchissement corallien est un processus de décoloration des colonies coralliennes résultant soit de la perte des pigments des algues microscopiques (les zooxanthelles) qui vivent en symbiose avec les organismes hôtes (les polypes), soit de l'expulsion de ces mêmes zooxanthelles.

Le blanchissement corallien peut affecter non seulement les coraux durs (madréporaires) mais également d'autres organismes symbiotiques tels que les coraux mous, les anémones de mer, les éponges, les mollusques (bénitiers,..).

S'il affecte généralement les zones peu profondes des récifs, lorsque le phénomène est sévère, il peut concerner des colonies situées à près de 40 mètres de profondeur.

[6] CORDIO : Coral Reef Degradation of Indian Ocean

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Face à des stress d'origine naturelle (élévation de la température, forts coefficients de marée, prolifération d'Acanthasters …) ou anthropique (pollutions, sédimentation terrigène, …), les coraux réagissent de manière variable selon l'intensité de la perturbation et l'espèce considérée. Ainsi, lorsque la température de l'eau de mer dépasse de manière prolongée la valeur maximale de tolérance, l'activité photosynthétique des zooxanthelles devient trop élevée et conduit les polypes à rejeter activement les zooxanthelles.

Les phénomènes " El Niño " et "La Niña" sont des dérèglements occasionnels du climat qui se traduisent par une inversion de grands courants océaniques et dans le cas de " El Niño " une élévation anormale de la température dans les régions où prospèrent les récifs coralliens.

La perte des algues symbiotiques entraîne un ralentissement ou un arrêt des fonctions primaires de la colonie corallienne c'est à dire sa croissance, sa capacité de reproduction etc. Si le stress perdure, il y a mort totale ou partielle des colonies coralliennes, lesquelles sont rapidement recouvertes par des gazons algaux. Les coraux peuvent se remettre d'un blanchissement de courte durée mais un blanchissement de plus longue durée (plus d'une semaine) peut avoir des conséquences irrémédiables allant jusqu'à la mort du récif.

Plusieurs blanchissements ont déjà été enregistrés à Madagascar des années durant, les plus graves ayant été enregistrés en 1998 et en 2000 (Harding et al, 2006). On a noté un mortalité corallienne allant jusqu' à 80-90% dans certaines régions côtières de l'île (McClanahan and Obura, 1998).

Cependant, la côte nord ouest de Madagascar a été épargné par les blanchissements (McKenna et al, 2005), à cause notamment de l'existence de courant marins froids provenant de la proximité de l'océan profond. La condition récifale, terme relatif à la « santé » globale d'un site, a été évalué sur une trentaine de site récifaux du Nord-Ouest de l'île à proximité de l'île Mitsio, du Cap Saint Sébastien et de Nosy Be. Les signes de pression par le blanchiment étaient peu nombreux pour les sites étudiés. Les dommages les plus fréquents sur le corail étaient occasionnés par un prédateur (*Acanthaster plancii*).

Sur la côte sud ouest, en sus des blanchissements sus cités, on note que les récifs touchés sont recouverts par des algues et que la diversité de poissons trouvés dans ces zones sont plus basse que dans les zones où les récifs sont en bonne santé.

On peut envisager ainsi, comme conséquence indirecte, des changements climatiques, une diminution de la biodiversité marine.

Une exploration de la région d'Andavadoaka a rapporté l'existence de 386 espèces de poissons (Allen, 2005) le long des récifs coralliens de la côte sud ouest de l'île. 20 espèces n'ont jamais été repérées et on pense qu'une espèce peut constituer une découverte pour la science.

L'équipe d'exploration pense que plus de 529 espèces de poissons (Allen, 2005) peuvent être découverts suite à des recherches plus poussées alors que 576 espèces sont envisagés sur les côtes nord ouest de l'île (Allen, 2003).

L'équipe a également enregistrés 164 espèces de corail (Fenner, 2005) dont 19 n'ont jamais été trouvés à Madagascar auparavant. En outre 4 espèces coralliennes n'ont pas été identifiés et peuvent être des espèces totalement nouvelles pour la science. Néanmoins, le nombre d'espèces trouvées sur les côtes sud ouest est largement inférieur à celui trouvé sur les côtes nord ouest, qui est de 323 espèces (Veron and Turak, 2003)

Le nombre total d'espèces découverts sur la côte sud ouest de Madagascar est considérablement moins élevé que celles découvertes sur la côte nord ouest. On pense que cette différence est directement imputable aux blanchissements massifs des années 1998 et 2000.

5.2.2. Cas des mangroves

Le terme « **mangrove** » désigne le groupement de végétaux principalement ligneux qui se développent dans la zone de balancement des marées appelée estran des côtes basses des régions tropicales. On trouve aussi des marais à mangroves à l'embouchure de certains fleuves. Ces milieux particuliers procurent des ressources importantes (forestières et halieutiques) pour les populations vivant sur ces côtes. Les mangroves sont les écosystèmes les plus productifs en biomasse de notre planète. Les espèces ligneuses les plus notables sont les palétuviers avec leurs pneumatophores et leurs racines-échasses.

La dégradation rapide de certaines mangroves est devenue inquiétante parce qu'elles constituent des stabilisateurs efficaces pour certaines zones côtières fragiles qui sont maintenant menacées, et parce qu'elles contribuent à la résilience écologique des écosystèmes après les cyclones et tsunamis.

Les mangroves sont menacées par l'élévation du niveau marin. La capacité d'adaptation des mangroves face à l'élévation du niveau de la mer variera régionalement**.** Les mangroves occupent une zone de transition entre la mer et la terre qui est le résultat d'un équilibre entre les processus d'érosion par la mer et les processus de dépôts d'origine terrestre. Les effets des changements climatiques sur les mangroves dépendront donc de l'interaction entre ces processus et l'élévation du niveau de la mer.

Cependant, il faut noter que les mangroves font partie des écosystèmes géographiquement limités donc sont très vulnérables aux effets des changements climatiques (GIEC-II, 2002).

La mangrove est très liée à l'herbier (ou littoral) et aux récifs. Une dégradation des récifs (déjà observés sur certaine partie de la côte ouest suite à des élévations de la température de surface de l'eau de mer) pourrait alors avoir un effet dévastateur sur ces écosystèmes et la biodiversité qu'elle abrite.

En effet, elle a besoin pour se développer d'une eau calme, dénuée de houle. C'est le récif, en brisant la houle, qui protège et offre à la mangrove un environnement favorable. La mangrove est aussi une excellente barrière entre l'océan violent et la côte fragile, particulièrement pendant les ouragans, qui peuvent provoquer une montée subite des eaux sur les rivages. Le système racinaire des palétuviers est tout à fait efficace pour absorber l'énergie des vagues. Ainsi, la mangrove est une excellente protection face au tsunami et réduit sensiblement les destructions occasionnées à l'arrière de cette zone de protection.

En contrepartie, la mangrove filtre et stabilise la sédimentation, évitant aux récifs d'être recouverts de vase et donc de dépérir. Ces systèmes racinaires empêchent également l'érosion côtière. L'écoulement des eaux des marées est ralenti assez sensiblement de sorte que les sédiments se déposent au pied des racines des palétuviers. En conséquence, les palétuviers maintiennent leur propre environnement. On note également que ces trois biosystèmes : mangrove, herbier et récifs, jouent chacun un rôle dans le développement de la faune : les poissons naissent à l'abri dans la mangrove et s'y cachent pendant leur développement, une fois trop gros pour se cacher dans la mangrove, ils se cachent dans l'herbier où ils sont encore protégés par le récif. Ils vivent une fois adultes dans les récifs ou au delà.

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La déforestation et l'affectation des terres augmentent le taux d'érosion. Le taux de sédimentation augmente ainsi dans les rivières, dont la plupart se déverse sur la côte ouest de l'île qui abrite 98% des récifs et des mangroves (Roger and Andrianasolo, 2003), et constituent une autre menace pour les mangroves en modifiant le taux de salinité et augmente la quantité de matière en suspension dans l'eau (Cooke et al, 2003). Cette menace rend cet écosystème plus sensible aux fluctuations environnementales.

Cette interconnectivité entre ces différents écosystèmes rend l'ensemble vulnérable en cas de dégradation d'un élément. Ainsi, l'élévation de la température de surface de l'eau de mer, menaçant les récifs coralliens et la biodiversité qui s'y abritent, aura des répercussions sur la faune et la flore des mangroves.

Les palétuviers sont à la base d'écosystèmes uniques, particulièrement autour de leurs systèmes racinaires complexes. Là où les racines sont en permanence submergées, les palétuviers sont les hôtes d'algues, de bernacles, d'huîtres, d'éponges et de cnidaires. Ils exigent tous des substrats durs pour s'ancrer tandis qu'ils filtrent leur alimentation.

La mangrove est donc par définition un type de formation végétale composée d'essences particulières, halophiles (ou Palétuviers) installé sur les marais maritimes : au niveau des estuaires, des deltas, des lagunes, des baies, etc.

A Madagascar, la côte Ouest, basse, plate, assez découpée, sujette à des fortes différences de marée, et présentant des eaux calmes, est favorable à l'extension de ces formations (Gachet, 1959).

La côte Est de configuration presque rectiligne, avec peu d'estuaires importants, un faible retrait des eaux souvent agitées et formant une "barre" qui affouille les sables en permanence, offre peu de possibilités pour leur installation.

Madagascar compte de 300.000 à 400.000 ha de mangroves selon les auteurs (Perrier de la Bathie, 1921 ; Kiener, 1972; Lebigre, 1990). Les nouvelles estimations tiennent compte de l'ensemble des mangroves et tannes (Lebigre, 1990) : environ 425.000 ha pour l'ensemble des marais maritimes dispersés sur 6.597 Km de littoraux, et dont 99% sont cantonnés à l'Ouest de l'île.

La faune y est abondante et susceptible d'être utilisée à des fins alimentaires. La plupart des espèces inféodées à ce milieu sont adaptée aussi à la forte salinité.

La majorité des Mammifères, Oiseaux et Reptiles des mangroves n'est pas inféodée à ce milieu. Ils proviennent souvent des milieux voisins et y séjournent pour s'alimenter. Les Mammifères y sont d'ailleurs rares à part les Chauve-Souris (*Pteropus, Epomorphus*). Plusieurs oiseaux réputés menacés y trouvent refuge : Héron de Humbolt, Sarcelle de Bernier, Aigle pêcheur, crabier blanc, Ibis à cimier, Pluvier à bandeau noir, Les Echassiers

(Ardéidés, Flamants roses) migrateurs comme les endémiques fréquentant les mangroves pour chasser les mollusques, crustacés et petits poissons.

La faune aquatique est beaucoup mieux représentée par les Poissons et les Crustacés, en particulier par les espèces qui constituent une ressource alimentaire très prisée : le crabe *Scylla serrata*, et les Crevettes (*Penaeus indicus, Penaus monodon, Alpheus crassimanus, Alpheus edwardsii*...).

Des gastéropodes rares sont présents dans certaines mangroves de la région de Toliara : *Oncidium verruculatum et Cassidulia labrella*.

Ainsi, les mangroves abritent une diversité exceptionnelle. Cette riche biodiversité est dépendant de facteurs environnementaux très précis et est ainsi susceptible au moindre changement environnemental. L'élévation du niveau marin menace la stabilité de l'écosystème « mangrove » (Field 1995) et pourrait avoir des conséquences notables sur sa biodiversité. Les mangroves de Madagascar abritent plus d'une soixantaine d'espèces de poisons (Laroche et al, 1997) et sert aussi de lieu de croissance pour les jeunes poisons. Les fermes crevettières (aquaculture ou sauvage) dépendent aussi des mangroves. La présence périodique d'eau douce dans les mangroves est importante pour le cycle nutritionnel des crevettes. (Cooke et al, 2003). Les effets des changements climatiques sur la salinité par l'intermédiaire de déversements d'eau douce plus abondante peuvent réduire l'abondance de crevette dans les mangroves.

5.2.3. Cas des poissons [7]:

Les poissons sont sensibles à la température quant à la reproduction, spécialement les poissons endémiques de Madagascar. Une augmentation de la température pourrait entraîner ainsi une baisse du taux de reproduction des espèces endémiques. Cette augmentation peut par contre être favorable aux espèces introduites, la population de ces espèces introduites sera alors plus élevé, ce qui entraînera une compétition plus âpre pour les espèces endémiques. Cette compétition défavorable peut causer un appauvrissement de la diversité génétique des espèces marines.

« *Les changements climatiques accentuent la pression sur les populations de poissons déjà affaiblies par la surpêche, la pollution et la destruction des habitats* » indique Katherine Short, spécialiste de la pêche au WWF International.

Madagascar recèle 58 espèces endémiques d'eau douce et 6 espèces endémiques d'eau saumâtre. Sur ces 64 espèces, 13 ont été retrouvées dans les îles soeurs, voisines de la Grande Ile.

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[7] Cas recueillis en totalité auprès du Département Biologie Animale de Faculté des Sciences de l'Université d'Antananarivo

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Qu'ils soient d'eau douce ou d'eau de mer, les poissons de Madagascar sont aujourd'hui menacés d'extinction. Leur endémisme est proche de 100 % et l'inventaire très récent a révélé une diversité extraordinaire et rare. La distribution exacte de nombreuses espèces n'est pas toujours connue et leur disparition progressive rend leur étude difficile. Les poissons sont les plus menacés des vertébrés malgaches.

Les lagons et l'océan Indien qui entoure Madagascar recèlent plusieurs dizaines de poissons dont l'habitat de prédilection est limité aux ***récifs coralliens***. Ces récifs étant menacés par l'élévation de la température de surface de la mer, les espèces de poissons qu'ils abritent sont aussi menacées d'extinction. Quelques espèces se raréfient du fait de la pêche qui s'intensifie, cependant beaucoup de lagons restent encore de véritables aquariums multicolores d'une extraordinaire beauté.

La pêche est le principal type de prélèvement des espèces, essentiellement pour l'alimentation. La pression sur les zones de pêche continentale s'est beaucoup accrue en raison de l'augmentation de la population. En outre, elle est aggravée par l'utilisation d'engins et de méthodes de pêche peu sélectifs dans les milieux naturels, caractérisés par leur faible rendement de la production piscicole. Cette situation a amené à l'introduction et à l'acclimatation de plusieurs espèces nouvelles plus productives, à partir de la fin du 19ème siècle et, notamment, pendant la première moitié de ce siècle : *Carassius auratus* (Trondro gasy ou Cyprin doré), *Cyprinus carpio* (Carpe miroir, Besisika), *Salmo irideus* et *Salmo fario* (Truites), *Micropterus salmoïdes* (Black-bass), cinq espèces de Tilapia (*Cichlidae*) et *Heterotis niloticus*. *Gambusia bolbrooki* ou Gambusie (Pirina) a été introduite en 1951 pour lutter contre les larves d'Invertébrés aquatiques, vecteurs du paludisme.

Les espèces introduites ont fini par supplanter plus ou moins la faune ichtyologique locale, en raison du peu de compétition des espèces endémiques, en particulier de la famille des Cichlidae, qui sont déjà peu abondantes dans des aires de répartition souvent fragmentées ou très localisées pour certaines d'entre elles : *Paratilapia polleni* (Marakely, Fony), *Ptychochromoides betsileanus* (Trondro mainty), *Ptychochromoides oligacanthus* (Saroy), *Oxylapia polli*, *Paretroplus dami* (Damba), *Paretroplus kieneri* (Kotso vato), *Paretroplus petiti* (Kotso), *Paretroplus maculatus* (Damba mipentina) et *Paretroplus polyactis* (Masovoatoaka).

Par ailleurs, l'introduction volontaire ou involontaire d'espèces carnivores ont accentué encore davantage les déséquilibres écologiques dans les peuplements de poissons : le Black-bass en 1951 ; le "Fibata" ou *Ophiocephalus striatus*, originaire de l'Asie du sud-est, introduit clandestinement en 1975 et qui a pris un développement extraordinaire dans les plans d'eau du pays au dépens des insectes aquatiques, des batraciens et des poissons dont il se nourrit.

L'introduction de ces nouvelles espèces accentue ainsi les effets des changements climatiques sur les espèces endémiques. Ces changements climatiques deviennent alors une menace pour l'existence des ces espèces et peut entraîner un appauvrissement de la biodiversité.

Un exemple peut être cité sur les impacts des changements climatiques sur la concurrence entre des espèces introduites et des espèces endémiques. Des espèces de poissons introduites en Nouvelle Angleterre ont fini par supplanter les espèces autochtones au fil des années à mesure qu'on a enregistré une augmentation de la température de l'eau (Stachowicz et al, 2002).

5.2.4. Inondations de zones côtières et conséquences

L'élévation du niveau marin induira une inondation des zones côtière basses et entraînera ainsi le recul des côtes. Cela entraînera une disparition des écosystèmes côtiers.
Selon une modélisation réalisée pour la ville côtière de Morondava, se situant sur la côte sud ouest de l'île, une tendance d'élévation annuelle du niveau marin de plus de 7mm entraînera l'inondation d'une superficie de 76,99 km² pour l'année 2025, 82,69km² pour l'année 2050 et 91,29 km² pour 2100 (Raharijaona, 2002).

On a estimé qu'en 1997, le recul des côtes a varié de 5,71m à 6,54m. Environ 225m de côte risque ainsi d'être englouti à l'horizon 2100. Cela laisse envisager la disparition d'une bonne partie du littoral de Morondava. Un cas a été signalé à Mahajanga. La côte Est malgache connaît aussi le même phénomène car une partie de l'avenue bordant la plage de la ville de Toamasina est détruite. À Manakara, un boulevard de la ville se trouve également menacé (Raharijaona, 2002).

Les éléments les plus touchés par les changements occasionnés seront les écosystèmes côtiers incluant la mangrove, les récifs coralliens et la forêt littoral.

Les effets de l'élévation du niveau marin se manifestent ainsi sous diverses formes :

- accélération de l'érosion,
- inondation des zones basses,
- intrusion d'eau de mer.

6. Méthodologie :

Deux approches ont été utilisées pour réaliser cette revue de littérature.

Premièrement, une recherche a été effectuée dans les divers établissements en charge de l'environnement du gouvernement malagasy. Les responsables des divers projets ayant trait aux impacts des changements climatiques ont été contactés. Ces derniers ont fournis les documents officiels et les responsables qu'on peut contacter dans divers secteurs pour de plus amples informations.

Ensuite, on est entré en contact avec divers organismes non gouvernementaux, s'occupant de la conservation et de la gestion de la biodiversité de Madagascar. Ces organismes ont fourni des rapports sur les recherches qu'ils ont effectuées ayant trait à la prospection de la biodiversité de Madagascar et les menaces auxquels ils sont confrontés. Ils ont également permis d'avoir une information sur l'état actuel de ces biodiversités et de comparer ces informations aux rapports réalisés auparavant pour pouvoir évaluer l'évolution de la biodiversité malgache au fil du temps et éventuellement de lier les changements observés aux changements climatiques.

Deuxièmement, des recherches ont été effectué dans divers banque de données locaux (Bibliothèque Universitaire, CIDST) afin de voir les études ayant été réalisés pouvant se réferer aux éventuels impacts des changements climatiques sur certaines espèces particulières.

Enfin, on a contacté des universitaires et des chercheurs, pour des renseignements supplémentaires sur les études ayant été réalisés ou pour des précisions sur les documents et les littératures grises recueillis pendant les phases précédentes.

7. Conclusion

La revue de littérature effectuée dans le cadre de l'évaluation des changements climatiques à Madagascar et de leurs impacts, a montré que la riche biodiversité de Madagascar est déjà affectée par les changements climatiques globaux. Ces changements affecteront encore plus dans le futur les diverses espèces endémiques de l'île si des mesures urgents et adéquates ne sont pas prises.

Parmi les impacts déjà relevés sur divers écosystèmes de Madagascar, les plus importants sont le recul des lignes de côte, l'intrusion saline, le blanchissement des coraux ainsi que la diminution de la biodiversité et la dégradation des sols. On peut envisager dans le futur une recrudescence de ces phénomènes, ainsi qu'une extinction de plusieurs espèces endémiques.

La déforestation galopante, problème écologique majeur de l'île, menace l'exceptionnelle biodiversité de Madagascar, aussi bien végétale qu'animale étant donné qu'elle est responsable de la destruction de l'habitat naturel de différentes espèces. L'action conjointe d'un changement de climat, d'une part, et de l'homme, d'autre part (chasse et déboisement intensif par exemple), conduira à la disparition de nombreuses espèces de lémuriens et d'oiseaux. Des espèces d'amphibiens ont également été reportées éteintes suite à des changements relevés au sein de l'environnement de leur habitat naturel.

La situation environnementale globale de Madagascar exerce déjà une pression considérable sur les différents écosystèmes qu'abrite l'île. Les exemples et les cas cités dans ce document montrent que cette pression sera encore plus accentuée par les changements climatiques projetés pour le futur et pourra ainsi provoquer un appauvrissement sans précédent de la riche biodiversité qui fait tant l'attrait de la Grande Ile.

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