Building Resilience to Climate Change

Ecosystem-based adaptation and lessons from the field

Edited by Ángela Andrade Pérez, Bernal Herrera Fernández and Roberto Cazzolla Gatti

Ecosystem Management Series No. 9

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This publication is a contribution of IUCN CEM to the Ecosystems and Livelihoods Adaptation Network (ELAN). ELAN is an international network working across the scientific, policy and practitioner communities to enable and promote the integration of sound ecosystem management in human adaptation to climate change. Further information on ELAN can be round at www.ELANadapt.net

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Preface

We increasingly hear about the negative impacts of climate change - whether on the world's biodiversity, or people. Despite media interest in controversy, there is now near consensus on the basic science of climate change – that the planet is getting increasingly warmer, and that anthropogenic emissions are mainly responsible for this recent warming. The question is not therefore whether the world is warming, but rather how much change will there be, and what can be done about it?

Clearly there is an imperative to reduce the extent of the warming through efforts to reduce greenhouse gas emissions, and to sequester more greenhouse gases in the world's ecosystems through habitat regeneration and restoration. But also there is a need to adapt to the changes that are already in the climate system, and to which we are committed in the coming decades. Such changes vary enormously in different parts of the world. Some will be drier, some wetter, most warmer, and many affected by increasing uncertainty and variation in weather patterns and seasonal change.

The uncertainties associated with the impacts of climate change make adaptation all the more complex, and require that we make the most of "no-regrets" adaptation approaches – those that will bring cost-effective benefits to nature and people under a range of longer-term climatic changes. The management of our local ecosystems to provide benefits on which people depend in the face of climate change, such as for flood protection, water flow regulation in dry spells, wind breaks and as shade, often provides such no-regrets responses, and in doing so, can contribute more broadly to building the resilience of local communities to climatic and other changes.

Many of the lessons we are learning in adaptation are from success stories from the field – learning by doing. This contribution from IUCN's Commission on Ecosystem Management (CEM), the latest in the CEM Ecosystem Management Series, adds to our knowledge and understanding of the many ways in which ecosystem management can support both people and nature to adapt to the adverse impacts of climate change.

We hope that it will inspire further learning, and the further application of ecosystem-based responses to climate change.

Julia Marton-Lefèvre
Director General
IUCN

Piet Wit
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Chapter 1

Introduction

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Purpose and Scope of this Book

This book is one of the main contributions of the Commission on Ecosystem Management (CEM) of the International Union for the Conservation of Nature (IUCN) to the international discussions on how we should address climate change impacts on natural and human systems, including ecosystems and the services they provide to society and communities. It was produced through contributions of CEM members worldwide and those from other scientists with key experience in research on, and implementation of climate change adaptation measures. Eleven case studies were selected by a team of editors, covering different ecosystems and regions around the world. The criteria for selection included the availability of an impact assessment of climate change on local communities, or biodiversity at ecosystem level, a clear analysis of the climate change vulnerability of ecosystems and human communities, a proposal for adaptation measures or set of actions being implemented – all based on the concept of ecosystem management – and, ultimately, an analysis of implementation results with future prospects.

BOX 1. DEFINITIONS OF TERMS

Vulnerability	Degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes (IPCC, 2007).
Exposure	Represents the important climate events and patterns that affect the system, but it also includes other changes in linked systems that might be induced by climate effects. In a practical sense, exposure is the extent to which a region, resource or community experiences changes in climate. It is characterized by the magnitude, frequency, duration and/or spatial extent of a weather event or pattern (IPCC, 2007).
Sensitivity	The degree to which a system is affected, either adversely or beneficially, by climate-related stimuli. The effect may be direct (e.g. a change in crop yield in response to a change in the mean, range or variability of temperature) or indirect (e.g. damages caused by an increase in the frequency of coastal flooding due to sea level rise (IPCC, 2007).
Adaptive Capacity	The ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences (IPCC, 2007).
Adaptation	The adjustments of natural or human systems in response to actual or expected stimuli, or its effects to moderate the harm or exploit beneficial opportunities (IPCC, 2007).

Adaptation – the adjustments of natural or human systems in response to actual or expected stimuli (IPCC 2007, Box 1) – is becoming an increasingly important part of the development agenda, especially in developing countries most at risk from climate change (World Bank, 2010; Eakin and Lemos, 2010). It is now at the forefront of scientific inquiry and policy negotiations.

One of the main challenges in current adaptation work is to understand and demonstrate how adaptation works and what the implications of adaptation for resilience are (Tschakert and Dietrich, 2010). This dynamic notion of adaptation allows promoting resilience of both ecosystems and human societies, beyond mere technological options mainly focused at building hard infrastructure and other similar measures.

Recent studies have shown a negative impact of many adaptation strategies on biodiversity, especially in the case of *'hard defenses built to prevent coastal and inland flooding'* (Campbell et al., 2009). This could result in so-called "mal-adaptation" in the long term if the ecological attributes that regulate the modified ecosystems are disturbed.

On the other hand, adaptation strategies that incorporate natural resource management can result in positive feedbacks for both people and biodiversity (Campbell et al., 2009; CBD, 2009).

In this context, there is a strong need in the biodiversity and natural resource management sectors to advance the development of adaptation strategies (Campbell et al., 2009; Heller and Zavaleta, 2009). This is critical, not only for achieving biodiversity conservation goals, but also for maintaining the contribution of biodiversity and the ecosystem services it provides for societal adaptation (Campbell et al., 2009).

Heller and Zavaleta (2009) stressed the need to have more operational examples of adaptation principles and recommended the development of a practical adaptation planning process that feeds existing policies and programs and enhances greater integration of social science into adaptation planning frameworks. Additionally, Hagerman et al. (2010) pointed out that policy adaptation in conservation should be based on existing scientific information and value-based commitments.

This book intends to contribute to fill the afore-mentioned gaps, specifically by compiling a set of current operational case studies from around the globe and by highlighting some practical adaptation planning processes that may advance the development of Ecosystem-based Adaptation (EbA), and conservation adaptation strategies. Here, eleven case studies from different parts of the world covering a variety of ecosystems are presented and discussed. Between them, the case studies cover a range of adaptation interventions, some focused on adaptation for conservation purposes, and some focused on supporting people to adapt to climate change, through Ecosystem-based Adaptation. Many of the case studies have both elements, in recognition of the fact that in order to continue to provide services to enable people to adapt to climate change, ecosystems themselves also will need to adapt.

This publication intends to summarize some current applications of the EbA concept and its tools used around the world, and also draw lessons from experiences in conservation adaptation. We do not intend to provide an exhaustive list of applications, but it is expected that the experiences presented in this book will help address the current challenges in climate change adaptation and stimulate future research to advance adaptation for both people and ecosystems globally.

Climate Change and Biodiversity: Summary of Impacts

The 4th Report of the Intergovernmental Panel on Climate Change (IPCC) published in 2007 projects that the global temperature of the planet's atmosphere will likely have increased 1.1° to 6.4° C by the end of this century, relative to 1980–1999 baseline data. At the same time, temperature rises are linked to changes in precipitation patterns. Depending on the location of any particular region of the world, the amount of precipitation it receives will increase or decrease. An increment in the incidence and severity of extreme events (e.g. hurricanes and floods) has been reported as very likely as well (IPCC, 2007).

The same report, together with recently published evidence, states that climate change will have significant impacts on biodiversity at different levels of organization (CBD, 2009). Studies that model these impacts on biodiversity have shown significant changes in ecosystem and species distributions, principally due to increasing temperatures and altered precipitation regimes (Parmesan and Yohe, 2003). Modeling has also shown that the expected shift in species distribution will lead to an increase in species extinction rates (Thomas et al., 2004). Some examples of expected, potential impacts of climate change on main biomes and regions on Earth are given in Table 1.

Furthermore, it is expected that climate change will affect the species composition of many ecosystems, affecting the continuity of ecosystem functioning as a result of reductions in species richness. The expected invasion of non-native species in numerous ecosystems has also been pointed out as a major driver of ecosystem change as a result of climate change (Hellmann et al., 2008). All these changes will definitely lead to changes in ecosystem functioning around the world (Campbell et al., 2009).

The impacts mentioned above will undoubtedly affect the provision of ecosystem services to local communities and society in general. Studies in different parts of the world have already demonstrated that climate change impacts affect fisheries, water flow regimes, and carbon sequestration processes (McCarty, 2001).

Climate change is likely to affect ecological interactions, including competition, predator-prey relations, diseases and host-parasite interactions, pollination, and herbivory (Campbell et al., 2009). There is also solid evidence that warming will alter the known patterns of plant, animal and human diseases (Harvell et al., 2002).

Nations are now starting to develop and implement adaptation policies to cope with the above-mentioned impacts. According to Campbell et al. (2009) adaptation strategies tend to focus on technological, structural, social, and economic developments and the linkages between biodiversity and adaptation are often missed. However, an in-depth review now demonstrates clearly the link that exists

Table 1. Examples of reported potential impacts of climate change in some main biomes and regions on Earth. Adapted from IPCC (2007) and Leadley et al. (2010).

ARCTIC TUNDRA
Continued and widespread increases in dominance of deciduous shrubs in tundra communities.
Decreases in abundance of herbaceous, bryophyte and lichen species.
Boreal forest will heavily invade tundra over large areas by the end of the century. Permafrost melting.
Changes in game availability with serious impacts on some indigenous populations.
MEDITERRANEAN FOREST AROUND THE WORLD
Significant reduction in species diversity.
High heterogeneity in land use will be reduced if fire brings about more uniform vegetation cover.
Higher costs and negative impacts on infrastructure, health and ecosystem services due to e.g. expansion of successional communities.
AMAZONIAN FOREST IN SOUTH AMERICA
Higher reductions in species abundance and increased number of extinctions of plants and animals associated with diEBAck of humid tropical forest.
Massive degradation of ecosystem services due to widespread fires and forest diEBAck.
Losses of carbon stored in vegetation and soils would be large enough to significantly influence global climate.
SAHARA, SAHEL AND GUINEAN REGION IN WEST AFRICA
Reduction in species richness due to land degradation in semi-arid areas.
Negative impacts of massive ecosystem degradation on human population.
MIOMBO WOODLANDS IN SOUTHERN-CENTRAL AFRICA
Climate change, rising CO_2, altered fire regimes and increased herbivory could shift savannas (grasslands) with sparse woody cover to dense forest.
COASTAL TERRESTRIAL SYSTEMS
Loss of nesting, nursery and forage habitat for numerous species groups (e.g. fish, shellfish, seabirds, sea turtles, crocodiles, manatees).
By the end of 21st century, 10 to 20% of total estimated losses of mangroves on Pacific Islands will be lost due to sea level rise.
Coastal hazards to human settlements and water quality will increase due to reduced coastal ecosystem cover and changed conditions.

between biodiversity and climate change (CBD, 2009). Campbell et al. (2009) point out that these links are mainly expressed in three ways: a) biodiversity can (and should) play a role in societal adaptation; b) biodiversity can be impacted by societal adaptation strategies; and c) biodiversity conservation is a sector that requires adaptation strategies in its own right.

Vulnerability Assessments

Vulnerability is defined by the IPCC (2007) as the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes (Box 1). Hence, vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity and its adaptive capacity (CBD, 2009; Eakin and Lemos, 2010; see Fig. 1).

Vulnerability assessments are fundamental instruments to understand where climate change will have impacts and which ecosystems are more susceptible to change (IPCC, 2007). Assessments of the impact of climate change on natural and socio-economic systems should encompass the full scope of climate change. Naturally, impact assessments of climate change and vulnerability that focus at understanding the various components and how they interact can help shed light on this key issue (Fig. 1, Box 1; Marshall et al., 2009). Such assessments should at least:

a) Assess the nature and magnitude of the climate change threat;

b) Identify the key sources of climate change vulnerability;

c) Identify, analyze and evaluate the impact of climate change and variability on natural resources, ecosystems, socio-economic systems and human health;

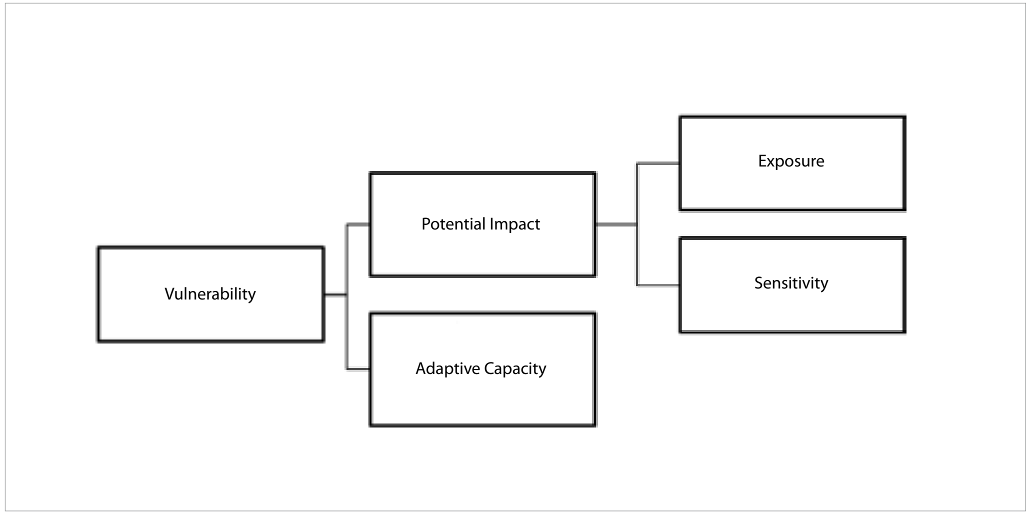
d) Understand the vulnerabilities that relate to institutional capacity and financial resources of affected communities (e.g. farmers, foresters, and fishermen);

e) Assess the possible adaptive responses of human and ecological systems;

f) Develop technical, institutional and financial strategies to reduce vulnerability levels for ecosystems and human populations.

A vulnerability assessment is the foundation for any EbA strategy. Certainly, any adaptation activity will miss its goal, without a well developed framework that explains the possible effects of climate change on a given area, ecosystem, or community. If well conducted, vulnerability assessments are the key to developing successful adaptive solutions that give people a chance to adapt, and nature a chance to "adjust" itself in the best way possible and in a timely manner, enabling it to cope with the rapid changes that occur in its climate patterns.

Figure 1. Vulnerability elements and links. Adapted from IPCC (2007).



Adaptation *sensu lato* and Ecosystem-based Adaptation (EbA): Conceptual Frameworks and Scope

Adaptation to climate change is not a new phenomenon. Throughout human history, societies have adapted to climate variability alternating settlements, agricultural patterns, and other sectors of their economies and lifestyles (Lovejoy and Hannah 2005). Adaptation in human history has been mostly successful. Nevertheless, the record of collapsed societies shows that not all cultures have had the possibility to change their patterns of life in a timely manner, and were not successful in surviving in face of climate and environmental changes (Pointing, 2007). Societies and their environments are vulnerable depending on the exposure to climate variability and change, and the cultural capacity of a society to adapt. More precisely, the vulnerability of a society depends on the nature of climate variability and its ability to adapt (Burton et al., 2006).

In 1992, climate change and its impacts on sustainability of today's society gave rise to the United Nations' Framework Convention on Climate Change (UNFCCC), signed in Río de Janeiro, Brazil. Early efforts of the UNFCCC were directed towards creating and implementing mitigation measures. However, knowing that the effects of climate change are inevitable in the short and medium term – and in fact already occurring – adaptation is now seen in the UNFCCC as an equally important strategy, next to mitigation. Unfortunately, the theory and practice of climate change adaptation is only very incipient and much remains to be done to ensure adaptation measures are well designed and implemented successfully. This is in contrast with all the knowledge that has been developed, resources that have been invested and global actions that have implemented in the field of climate change mitigation.

Adaptation is important in all countries, but particularly in least developed countries (LDCs), small island developing states (SIDS) and in those countries that have economies that depend on climate-vulnerable sectors such as agriculture, tourism and fisheries (IPCC, 2007). Additionally, IPCC (2007) states that climate change affects poor human communities disproportionately. These communities are often marginalized and receive only limited services or support from governments. This condition has given rise to the concept of "Community Based Adaptation", which describes a set of activities aimed at climate change adaptation by local communities and the poorest people (Kotiola, 2009).

In terms of biodiversity, successful adaptation is an adjustment that prepares an ecosystem or community for a new or different environment without simplification or loss of its structure, functions and components (CBD, 2006).

The natural responses of biodiversity to changes resulting from new environmental situations are called "autonomous adjustments" (CBD, 2006). These include properties such as resilience, recovering capacity, vulnerability and sensitivity. It is considered, however, that autonomous adaptation, naturally managed, is not sufficient to halt biodiversity loss and ecosystem services. Therefore, development of activities proposed by societies and known as "planned adaptation" are required (CBD, 2009). These actions should be implemented in different sectors such as agriculture, water resource management, development, and infrastructure, among others, and applied to different planning levels: local, regional, national and international. "Adaptive management" provides criteria from the Convention on Biological Diversity (CBD), on how "planned adaptation" should be addressed, prioritizing actions based on the maintenance of natural infrastructures and the ecological integrity of ecosystems (CBD, 2009).

Ecosystem-based Adaptation (EbA) is an approach that builds resilience and reduces the vulnerability of local communities to climate change. Through considering the ecosystem services on which people depend to adapt to climate change, EbA integrates sustainable use of biodiversity and ecosystem services in a comprehensive adaptation strategy (CBD, 2009). Adaptation is seen as a key element in creating a resilient society. EbA puts special emphasis on ecosystem services that underpin human well-being in the face of climate change. This approach suggests that ecosystem-based solutions can contribute to address climate change through providing social benefits and ecosystem conservation. EbA approaches consider that both natural and managed ecosystems can reduce vulnerability to climate-related hazards and gradual climatic changes. The sustainable management of ecosystems can provide social, economic and environmental benefits, both directly through a more sustainable management of biological resources and indirectly through the protection of ecosystem services (World Bank, 2010). In this way, EbA provides for community-based adaptation objectives, giving a broader ecological context to an adequate implementation.

It is important to highlight that the principles of the ecosystem approach adopted by the CBD (2000) are taken into consideration within the broader perspective on ecosystem management for climate adaptation. The ecosystem approach of the CBD (and equivalent approaches, such as the Wise Use of wetlands of the Ramsar Convention) recognizes that man and society are integral parts of ecosystems. This view is similar to the concept of "social-ecological systems", which are linked systems of people and nature (Berkes and Folke, 2000). The term emphasizes that humans must be seen as part of nature and recognizes the interdependencies between social and ecological systems.

The concept of EbA complements and supports the already mentioned concept of "community-based adaptation". It unifies approaches to ecosystem management in terms of adaptation. It includes a wide range of strategies at local and landscape scales, enabling communities and nature to address climate change in an effective way. It should be applied appropriately, as part of a broader adaptation strategy that might also include education, training, awareness rising, and the development of early warning systems and technology measures as required.

In this context, the main objectives of EbA are to promote community resilience through ensuring the maintenance of ecosystem services, support adaptation of different sectors, reduce disaster risks, among others (Coll et al., 2009), and prevent "mal-adaptation" which may be the result of a lack of information and high levels of uncertainty.

The cornerstones of EbA are: intervention in the areas of policy-making and planning, institutional capacity building, implementation of ecosystem-transformation actions (Box 2), and management of residual effects. One way to achieve such objectives is through the formulation and implementation of pilot actions (Andrade, 2010).

The possibilities of implementing EbA actions depend on several considerations (Colls et al., 2009). The first is related to the ecological opportunities available to build resilience. Beyond about 2º and 3º C temperature increase from pre-industrial levels, impacts on many ecosystems (and social and economic systems) are likely to be irreversible (IPCC, 2007). As such, EbA in a warmer world will require new approaches and increasing intensive management of ecosystems to maintain ecosystem services. There are also constraints to implementing EbA that have to do with a lack of information, the uncertainty of how ecological processes will react to both climate change and management, the tipping points of socio-ecosystems, a lack of adequate institutions, technology and funding, and the need to deal with extreme events that affect local communities and sectors (Colls et al., 2009).

Current Policy Context for Climate Change Adaptation

Climate change adaptation is being discussed globally in several bodies of the United Nations (UN), from which the most relevant is the UNFCCC. The issue of adaptation is included specifically under the UNFCCC in Article 4.1(e), which calls on all countries to *"cooperate in preparing for adaptation to the impacts of climate change, develop and elaborate appropriate and integrated plans for coastal zone management, water resources and agriculture, and for the protection and rehabilitation of areas, particularly in Africa, affected by drought and desertification, as well as floods."* Articles 4.8 and 4.9 also refer to the need to address vulnerability to the adverse effects of climate change and take into account the needs of the LDCs.

People and biodiversity are already being affected by climate change. The Arctic is seeing some of the greatest impacts, where species such as the Arctic fox *(Alopex lagopus)* are especially vulnerable.

During the process of negotiating the decisions of the UNFCCC, adaptation appears as a cross-cutting issue. However, only after the Marrakesh Accord in 2001, was it seen as an important area in need of action (UNFCCC, 2002). Since the 7th Conference of the Parties (CoP-7) of the UNFCCC, the political interest in adaptation has increased to complement mitigation activities, which were until then the main theme of the negotiations. During the UNFCCC CoP-11 the UNFCCC Subsidiary Body on Technical Advice (SBSTA) was mandated to develop a Programme of Work (PoW) on technical and socio-economic impacts, vulnerability and adaptation to climate change. Currently, adaptation is one of the main areas of discussion during the multilateral processes that address the climate change issue globally.

One of the principal means for supporting adaptation under the UNFCCC is through the implementation of the 2005–2010 Nairobi Work Programme (NWP). The objective of this Programme is to assist all Parties, particularly in developing countries such as the LDCs and SIDS, with: a) improving their understanding and assessment of impacts, vulnerability and adaptation to climate change; and, b) making informed decisions on adaptation actions and practical measures to respond to climate change on a sound scientific, technical and socio-economic basis, taking into account current and future climate change and variability. The NWP is undertaken under UNFCCC's SBSTA. The NWP disseminates knowledge and information on adaptation including outcomes of programme implementation and action by partners as widely as possible through a variety of knowledge resources and publications.

The UNFCCC's Bali Action Plan highlights the significance of adaptation and strongly recognizes the tight linkages between climate change adaptation and Disaster Risk Reduction (DRR), as well as the need for integrating adaptation actions into sectoral and national planning. Almost all LDCs have prepared National Adaptation Programmes of Action (NAPAs), which identify priority activities that respond to their urgent and immediate needs to adapt to climate change.

With respect to the Convention on Biological Diversity (CBD), the link between biodiversity and climate change has been discussed since 2000. The Convention's first commitment to adaptation activities concerns the recognition of the impact of climate change on various ecosystems such as coral reefs and the inclusion of adaptation in the Programme of Work (PoW) on mountains, forests, islands and protected areas (CBD, 2000).

In 2004, the CBD recognized that adaptation is the main issue that links the CBD with the UNFCCC and the United Nations' Convention to Combat Desertification (UNCCD) (CBD, 2004). In 2005 an ad hoc technical group was established in order to begin the identification of actions to understand the biological factors that contribute to ecosystem recovery and the integration of biodiversity and adaptation.

The CBD Secretariat has published four technical reports (CBD Technical Series Nos. 10, 25, 41, and 42) on biodiversity and climate change to support the implementation of relevant adaptation activities (CBD, 2003, 2006, 2009 and 2009a). These publications identify possible impacts of adaptation activities on biodiversity and suggest ways to minimize negative impacts while maximizing benefits.

The CBD further promotes research on climate change response activities related to biodiversity, in the context of the Ecosystem Approach, environmental impact assessments, and principles of sustainable use. It also calls for mainstreaming, to the extent possible, of biodiversity considerations into the design, implementation and monitoring of adaptation activities.

It is important to highlight that especially poor people depend highly on ecosystem services. It is estimated that three-quarters of the world's poor who live on less than US $ 2 per day, directly depend for their well-being of the environment. Thus, EbA strategies that promote resilience of ecosystems and their dependent human communities to climate change through ensuring the continued supply of goods and services are of particular importance to the world's poor and most vulnerable.

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Chapter 2

Ecosystem-based Adaptation

Lessons from the Chingaza Massif in the High Mountain Ecosystem of Colombia

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In the Colombian Andes, the high mountain ecosystems located above 2,740 m, are very vulnerable to the anticipated impacts of climate change. Existing models have predicted that 56% of the Andean moorlands could disappear by 2050. The associated loss of many ecosystem services such as soil protection and water supply and regulation, together with a reduction in the area's hydropower potential, will affect cities like Bogotá. The latter relies heavily on water provided by the Chingaza highland massif. To cope with these threats, Colombia is implementing its Integrated National Adaptation Plan (INAP), a GEF project developed with support from the World Bank. It makes use of ecosystem-based adaptation approaches and policy interventions necessary to address climate change impacts in specific pilot areas. Four adaptation measures are currently being implemented locally with participation of local communities. These projects are embedded into national, regional and local policy making efforts and spatial planning. It is suggested that these adaptation measures might be replicated in other areas of the country, as well as in high mountain ecosystems in other countries along the tropical Andes.

Keywords: Climate change, Colombia, Ecosystem-based adaptation, Ecosystem services, High mountain ecosystems, Tropical Andes

Introduction

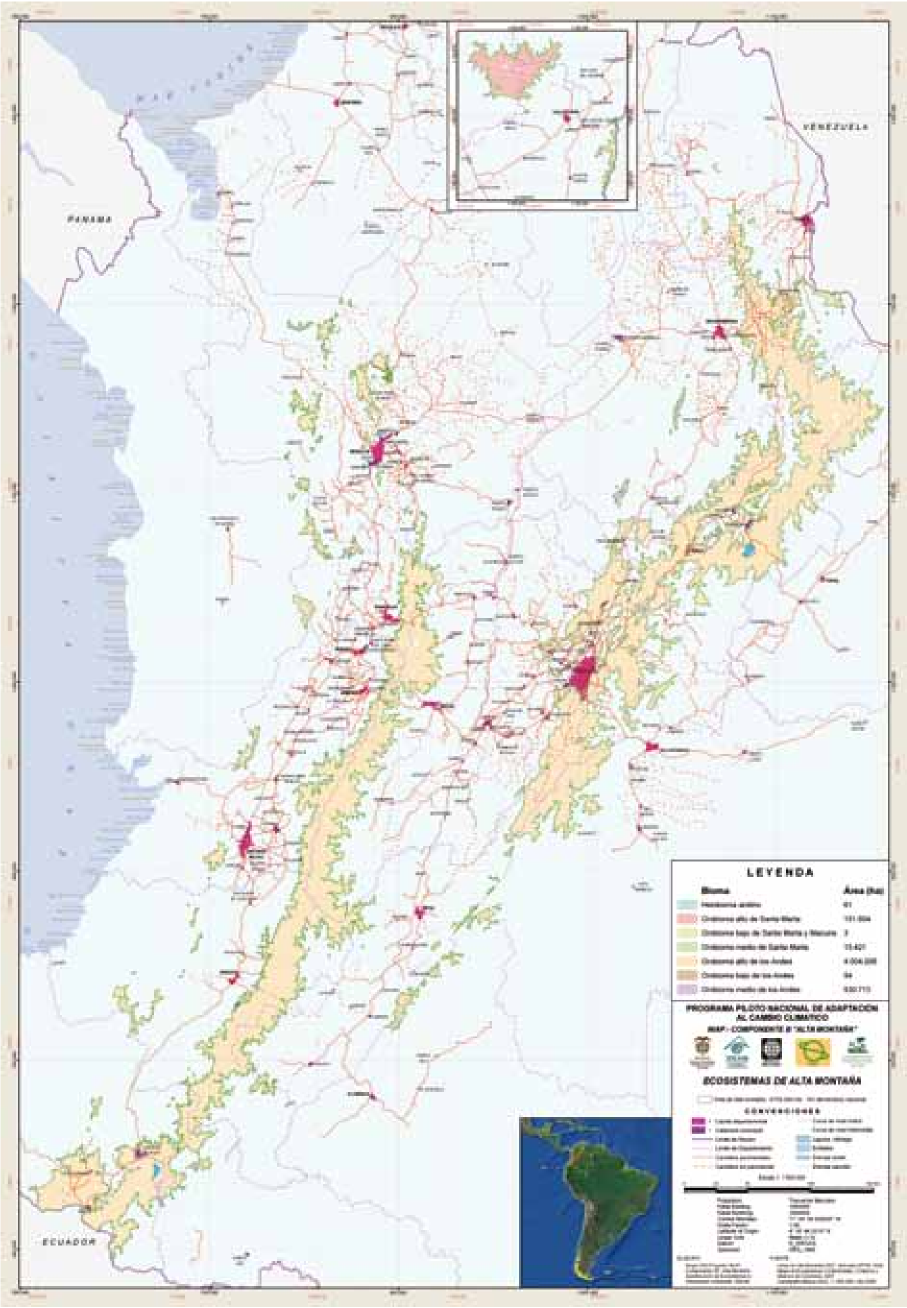
Background

Currently, there is a global discussion going on, regarding the benefits of using ecosystem-based adaptation (EbA) as a conceptual framework to climate change adaptation and to demonstrate that ecosystem-based solutions are more cost-effective, generate benefits for society, contribute to the conservation of biodiversity and reduce populations and ecosystems vulnerability to climate change.

The government of Colombia, through its Institute of Hydrology, Meteorology and Environmental Studies (IDEAM), and with the participation of several organizations such as the Colombian unit of Conservation International (CI), the Institute of Marine and Coastal Research (INVEMAR), the Corporation for the Sustainable Development of the San Andres, Providencia and Santa Catalina Archipelago (CORALINA), and the National Institute of Health (INS), is developing its Integrated National Adaptation Plan (INAP) to address climate change, implemented through the World Bank.

The overall objective of INAP is to implement both specific pilot adaptation measures and policy interventions in order to proactively address the impacts of climatic change.

Figure 1. High mountain ecosystems in Colombia. Data source: INAP Project.



Research Priorities

To achieve its objective, INAP develops a series of activities in several Colombian ecosystems including the *Páramos*[1] and High-Andean Ecosystems, both highly vulnerable to climate change (IDEAM, 2001). In this context, INAP's main research questions related to climate change are:

a) What is the current and projected climate variability at regional scale and how can we best deal with the uncertainties of climate change trends?

b) What are the effects of climatic variability in high mountain ecosystems (Glaciers, High Andean Forests and *Páramos*)?

c) How can we best maintain or increase the resilience of high mountain ecosystems (Glaciers, High Andean Forests and *Páramos*) in a context of climate change and climate vulnerability?

d) How can we best prepare social actors for managing resilience and proactively adapt to global change and climate vulnerability in high mountain ecosystems? and

e) How can we best influence public policies that focus on implementing environmental management processes?

Before starting to answer these questions, we made the following assumptions:

a) A decrease in threat levels will allow natural ecosystems to become more resilient to increasing climate variation;

b) The incorporation of ecosystem-based adaptation approaches in spatial planning efforts (e.g. in land management plans, local development plans, watershed management plans, and departmental development plans) is the best way to ensure that local governance takes climate change into account;

c) Adaptation of high-mountain farming systems decreases the pressure on natural ecosystems such as *Páramo*;

d) Solutions based on ecosystem-management concepts are more cost-effective and successful when facing climatic change challenges; and

e) A decrease in climate change vulnerability of local communities will occur once information on the effects of climatic variation is available, progress in local organizational processes is made, and a better reconnaissance of the land has been done.

High Mountain Ecosystems in Colombia

In Colombia, high mountain ecosystems (Fig. 1) are the territories located above 2,740 m elevation (Van der Hammen, 2000). They represent about 4% of the national territory. According to studies conducted by IDEAM and information obtained through INAP, climate change is affecting High Mountain Ecosystems and *Páramos*, expressed in, and leading to: a) a reduction in water retaining capacity and soil carbon stock, as a result of increased temperature and decreased rainfall; b) losses in biodiversity and ecosystems services such as the reduction of the national hydropower potential; c) a change in rainfall frequency and intensity; d) increased recurrence of extreme weather events (hail, frost, torrential downpours, waves, and variation in rainfall/drought periods); e) a change in water quantity and quality; f) a decrease in crop yield by changes in cropping periods, and the disappearance of some crops and occurrence of diseases including pests; g) changes in forest structure, composition and geographic ranges; and h), changes in cultural patterns, among others.

Conceptual Framework

The conceptual framework of INAP is based on the Ecosystem Approach as defined by the CBD (2000). The main contributions of this approach are the following:

[1] *Páramos* are tropical Andean ecosystems present in the Northern Andes, ranging from northern Peru to Ecuador, Colombia and Venezuela, and occur in isolated patches in Panama and Costa Rica. They are usually located above the Andean forests, at elevations over 3,000 m above sea level.

a) Broader understanding of ecosystem management, given both space and time dimensions, including adaptation in spatial management;

b) Identification and inclusion of relevant sectors throughout the process;

c) Definition of long-term goals with broad social participation;

d) Identification and implementation of ecosystem-management actions that can increase ecosystem resilience and reduce vulnerability of both farming systems and local human communities;

e) Providing adaptation strategies that are relevant for specific ecosystem services;

f) Strengthening of a long-term monitoring system; and

g) Advocacy to cultural and social processes.

Methodology

The definition of adaptation measures begins with the identification of those ecosystem services that are most vulnerable to climate change, and the relationship of these services with ecosystem structure and function. High Mountain Ecosystems and *Páramos* provide ecological services that are essential to local populations and people living in the surroundings of Bogotá, the capital of Colombia. For instance, eighty percent of the people rely on the water that is provided by the Chingaza Massif.

According to the Millennium Ecosystem Assessment (WRI, 2005), ecosystem services most likely to be affected by changes in land cover, land use, and climate in high mountains are:

a) Support Services: CO_2 fixation, with 70% in soils and 30% in above-ground living biomass; soil formation; biodiversity; nutrient cycling; and pollination;

b) Provision Services: Water (access and distribution); agricultural and livestock products; wild food; medicinal products; fuel and building materials;

c) Regulation Services: Hydrological regulation; erosion control; water quality and quantity; reduction of natural risks; water retention in soil, and aquifer recharge; and

d) Cultural Services: Spiritual and religious values; recreation, and tourism.

Regarding adaptation measures, IPCC (2001) proposes a number of adaptation types to climate change. For this study, the "Planned Adaptation" type was selected, taking into account the IPCC recommendations on planning and human intervention. This adaptation type is the result of a deliberate decision making policy, based on raising awareness on how conditions have changed or are about to change, and on how action is required to return to a desired state, maintain it or continue as is.

Regarding the Ecosystem Approach (CBD, 2000), the most relevant principles considered to formulate adaptation measures are:

a) Principle 3. Take into account the effects (both real and potential) of the activities which occur on adjacent ecosystems and other related ecosystems;

b) Principle 5. Conserve ecosystem structure and function to ensure the maintenance of relevant ecosystem services, beyond biodiversity conservation;

c) Principle 6. Manage ecosystems within functioning limits of operation, including the cumulative effects of previous interventions;

d) Principle 7. Apply to appropriate space and time scales; and

e) Principle 9. Recognize that change is inevitable: disturbances can affect ecosystem structure and function.

Processes and ecosystem functions are complex and variable. Their level of uncertainty is increased by the interaction with social structures which should be better understood. Ecosystem management is based on a learning process that helps to adapt methodologies and practices to the ways in which these systems are managed and monitored. It is already acknowledged that the diversity of social and cultural factors influence the use of natural resources. Ecosystem-based adaptation (EbA) is conceived as a long-term experiment that incorporates the information and results of its application. This "learning by doing" approach is a source of information that helps gain knowledge about the best way to monitor performance of management activities and assess whether established goals will be achieved or not.

In this regard, the INAP Project (World Bank, 2006) identified four adaptation measures which are currently being implemented. The next section presents the results achieved so far.

Results

Chingaza Massif Climate Change Assessment for Planning, Management and Maintenance of Ecosystem Services, including Hydropower Potential
This adaptation measure answers the first research question: "What is the current and projected climate variability at regional scale, and how can we best deal with the uncertainties of climate change trends?" An answer to this question will help determine the level of climate change risk faced by ecosystems and local human communities.

In 2009 and as part of INAP Project, IDEAM generated knowledge of ecological and climate processes at national levels, as well as local scales such as in the Chingaza Massif. During that exercise, two nationwide scenarios were assessed, following parameters established by the Intergovernmental Panel on Climate Change (IPCC): the A2 "Pessimistic" scenario, and the B2 "Optimistic" scenario.

Results from both the optimistic and pessimistic scenario revealed a tendency to more intense droughts in High Mountain and *Páramo* ecosystems, with a projected 10 to 30% increase regarding the driest periods in comparison to the present situation. This would imply an increase in dry area of more than 4 million hectares for the period 2071–2100.

For that same period, the pessimistic scenario (A2) demonstrated an addition of some 500,000 hectares to be affected by very dry conditions (low precipitation regimes), compared to the

Figure 2. Mean annual precipitations

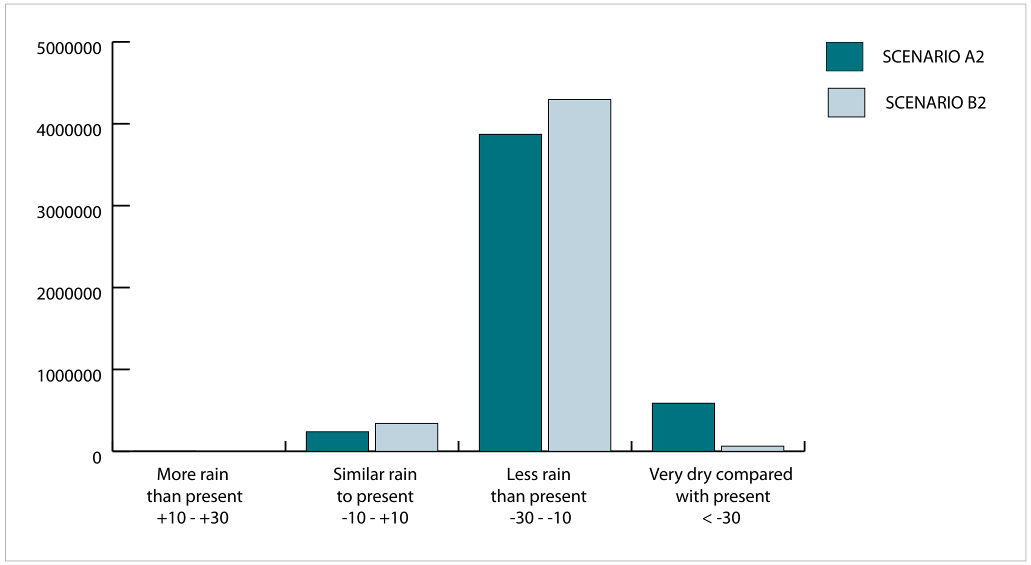
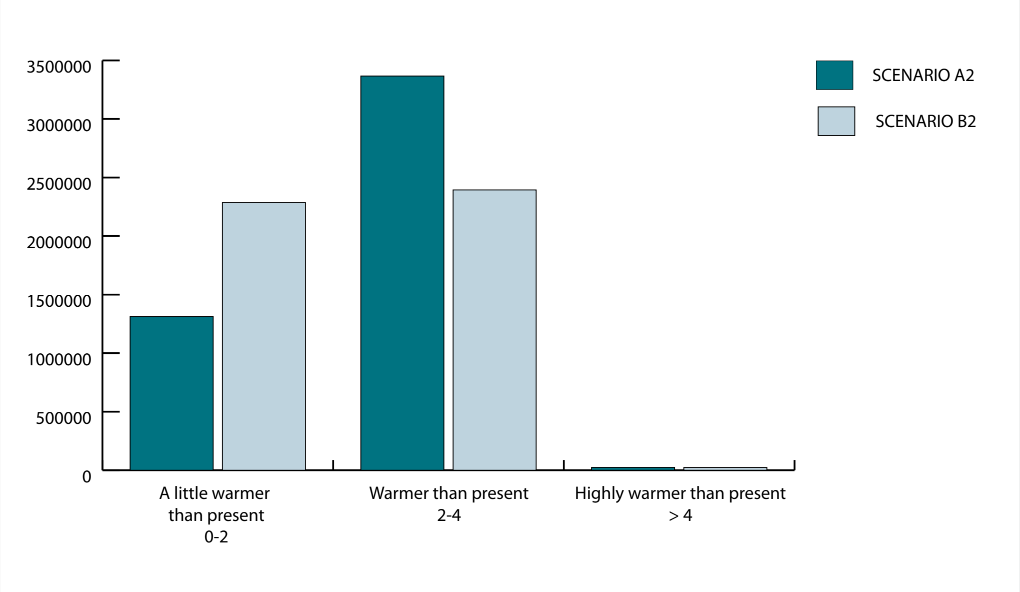


Figure 3. Mean annual temperature



current situation. Similarly, under both scenarios precipitation during 2071–2100 is expected to reduce with 10 and 30% (Fig. 2). Additionally, both scenarios show that during that same period there will be a temperature increase of 2 to 4ºC in nearly all high mountains and *Páramo* ecosystems (Fig. 3.). Moreover, temperatures in the Río Blanco watershed study area are expected to increase as well, during that period and under both scenarios. This watershed provides nearly 80% of all the water that is used in Bogotá. Here, projections show a temperature increase of about 2 to 4ºC when compared to the present, while rainfall is expected to decrease around 30%.

The here presented information provides the basis for modelling ecological processes in the study area and is used to understand impacts on water and carbon cycles and associated biodiversity. To do the water cycle modelling, IDEAM installed with INAP support two meteorological satellite stations and three automatic hydrometric stations. They all provide real time data that are integrated into the national hydro-meteorological network. Furthermore, to understand the carbon cycle, IDEAM developed a protocol that is being implemented in four different areas: intervened forest, non-intervened forest, intervened *Páramo* and non-intervened *Páramo*. All together, these data will make it possible to understand the carbon cycle in a variety of ecosystems under different types of intervention. Next to these modelling exercises, the Colombian unit of Conservation International developed a specific protocol to monitor biodiversity in relation to climate change.

The applied methodology is based on a participatory action-research approach that allows the generation of relevant, timely and efficient information to be interpreted and handled by different people, communities and institutions that are involved. This methodological approach can be replicated and allows for monitoring at different scales (national, regional and local) with a high level of accuracy. It recognizes local knowledge and experiences in climate change adaptation, especially regarding adaptation measures under implementation. The information obtained during these processes is used in practical ways by IDEAM and national partner institutes involved in the project. Information is also applied to consolidate adaptive planning models at a local basis in the study area. Examples are municipal management plans, watershed management plans, and community planning at farm level. Additionally, participating local communities obtain first hand information on climate variability, early warning and risks (fires, landslides, floods). Information is organized in such a way that it can be used for risk prevention by local and landowners committees.

To answer the second research question related to understanding the effects of climatic variability in high elevation ecosystems, a High Mountain Research Plan for Adaptation to Climate Change has been formulated. Its main objectives are:

a) To monitor the climate variability dynamics of the high mountains of Colombia;

b) To understand climate change dynamics and how it affects water and carbon cycles and other components including soils;

c) To predict the effects of climate change on natural ecosystems and associated goods and services in the country's high mountains;

d) To monitor the effects of climate change on high mountain agro-ecosystems;

e) To understand the linkages between climate change threats and vulnerability of both human populations and high mountain ecosystems;

f) To understand the impact of proposed adaptation measures in addressing the above-mentioned issues; and

g) To monitor the effectiveness of adaptation measures.

Reduction of Adverse Impacts on Water Regulation in the Río Blanco Watershed, Chingaza Massif

Reducing adverse impacts on water regulation in the Río Blanco watershed requires detailed knowledge of land-cover and land-use transformation dynamics, as well as of basic ecological indicators of ecosystem functioning during a specific period of time.

Progress has been made in land cover-land use characterizations at a scale of 1:100,000 by using the Corine Land Cover methodology (IDEAM et al., 2007). Since the 1950s additional detail is available at a scale of 1:25,000. Based on this analysis, information has been developed for the identification of suitable land use types that might respond successfully to climate change threats under different scenarios, such as prevention of natural risks and threats to ecosystems and communities due to increases in avalanches and landslides.

Available information for the period 1990–2000 shows that the greatest changes in land cover and land use are a reduction of dense forest areas and an increase of fragmented forest areas, pasturelands and croplands. This land use change scenario along with an increase in temperature and changes in precipitation regimes will increases climate change vulnerabilities of local communities and ecosystems.

If information on the effects of climatic variation is available for a specific area, and if progress in local organizational processes and a better reconnaissance of the land is made, we can assume that a reduction in the vulnerability of local communities to climate change is likely. In this context, climate change adaptation actions will occur in the areas of cultural adaptation and spatial transformation. Such actions will contribute a reduction in the vulnerability of ecosystems and local populations to the adverse effects of global climate change (GCC).

In fact, in the long term, cultural adaptation will be the most important strategic adaptation measure to climate change. Definitely, developing activities to reduce vulnerability and adopt appropriate measures will require a cultural change in terms of how the land is used and will be used.

Cultural adaptation is implemented through the joint development of "Adaptation Life Plans", which are conceived as documented processes and social-participatory formal initiatives around climate change adaptation. These adaptation life plans gather lessons learned from the pilot program and are formalized by social agreements to reduce vulnerability of both communities and ecosystems. On the other hand, Adaptation Life Plans have already been used as a social-participatory formal instance for both local communities and institutions, and provide a framework for discussions on planning and spatial adaptation.

The joint development of Adaptation Life Plans has been made through a process of 'self-reflection discussions' around the weaknesses and strengths that each local community presents. This has been done in order to reduce climate change vulnerability, and understand and reconstruct climate change history in each area. It begins with a social reconnaissance of both the land and the community, and the making of a personal commitment to change itself. Adaptation Life Plans are based on the reconnaissance and acceptance of natural and cultural values in each local area and seek to strengthen both organizational processes and spatial adaptation. In this way, life plans are meant for the long term and are jointly developed by local communities and institutions involved. Today, they are recognized as a strategy to give sustainability to the project. The processes are related to spatial planning, while adaptation measures are developed within the framework of adaptation life plans. Currently, a total of eight Adaptation Life Plans have been developed.

The third research question deals with the maintenance or increase of the resilience of high mountain ecosystems (Glaciers, High Andean Forests and *Páramos*) in a context of climate change and vulnerability. To answer that question, an analysis of land cover and land use change data (as indicated earlier) was done. It now serves as the basis for the formulation and implementation of a Strategy for Participatory Landscape Ecological Restoration. Additionally, using this information the Colombian National Parks Strategy for Participatory Ecological Restoration (Camargo, 2007) was adapted to incorporate the climate change context and subsequently adopted by INAP. Its focus is to ensure good water regulation and increased carbon sequestration by restoring the attributes associated with the ecological integrity of the (agro-) ecosystems. This strategy is carried out by implementing specific interventions regarding biodiversity and land management. The participatory strategy for ecological restoration itself is developed on basis of participatory agreements with local communities and counts with signed documents recognized by the Community Action Boards and Municipal Governments (Medina, 2009).

High mountain ecosystems, such as here in Colombia, are particularly vulnerable to the impacts of climate change.

Currently, there are 27 restoration processes being implemented, including in upper watersheds, along riversides and in landslides areas. These restoration processes are developed by applying the "Simulation of Natural Succession" approach in patches of isolated vegetation, with three types of soil treatment and five different mixtures of native plant species. Native plants were selected by local people through educational workshops. Plants were obtained in the field through recruitment processes. In addition, native plant germination and propagation protocols were developed jointly with the community.

Participatory ecological restoration process of the landscape are strongly linked to risk prevention plans, taking into account that the frequency of threats like fire and landslides will increase with temperature rise, extreme events of drought and rain, and variations in the intensity and frequency of precipitation.

Adapting Land Use and Spatial Planning Models to Climate Change Impacts

The main objective of land use and spatial planning in the context of biodiversity conservation and climate change adaptation is the creation of resilient lands, in order to reduce the vulnerability of ecosystems and communities and conserve relevant ecological services (Andrade and Vides, 2009).

In Colombia, land use and spatial planning is regulated since 1997. To this end, the Ministry of Environment identified a number of criteria that serve as the basis for the definition of "Environmental Determinants for Land Use Plans" (POTs), supported by existing regulations and requirements for the maintenance of relevant ecosystem services. In the case of Bogotá, covering the INAP study area, Van der Hammen (2000), developed the concept of "Major Ecological Structure" for integrating protection zones and protected areas, generating an environmental value function of higher hierarchy. The city of Bogotá adopts this concept and defines the "Major Ecological Structure" (EEP) as *"a network of spaces and corridors that sustain and lead biodiversity and essential ecological processes through the territory of Distrito Capital (DC) in its various forms and intensities of occupation, while providing environmental services for sustainable development"*.

In an attempt to move forward and articulate these concepts to climate change adaptation, INAP proposes an "Adaptive Territorial Ecological Structure" (EETA, in Spanish) as a geographical network of spaces that support essential ecological processes necessary to guide adaptation beyond mere biodiversity conservation and towards the maintenance of ecosystem structure and functioning. The main EETA objective is to maintain ecological integrity and ecosystem health on the long run.

The proposed EETA include all relevant structural elements of the landscape to ensure the conservation and recovery of ecosystem services in *Páramo* and High Mountains, which are highly vulnerable to climate change: water cycle regulation, water quantity and quality maintenance, ground water recharge, reduction of risks and natural hazards, and erosion control. These processes are present in ecosystems that make up the bulk of the hydrological network. They influence the structure and functioning of the hydrological cycle itself, which is embedded in a broader spatial matrix.

The proposed EETA seeks to contain, *inter alia,* components such as: a) recommendations for

Storm damage from water or wind is one of the impacts of climate change affecting communities around the world in mountain and coastal ecosystems.

land use and land occupation in the framework of ecosystem functioning thresholds; b) patterns that include key elements to promote natural connectivity, including ecological restoration processes; c) identification of information gaps that need to be addressed in order to contribute to ecosystem resilience; d) promotion of appropriate mechanisms of social organization; e) proposals of compensating mechanisms such as clean development mechanisms (MDL); and, f) reduction of emissions from deforestation or forest degradation (REDD).

Currently, INAP is supporting the review of the POTs, from the La Calera and Choachí municipalities located in the Río Blanco watershed area. Furthermore, an EETA proposal is supported by the Chingaza-Sumapaz corridor, proposed by Conservation International, Colombia, in 2009. It includes a wider land area and can help elevate EETA to regional levels.

Adaptation of Productive Agro-Ecosystems

Land use in the study area is dominated by crop and livestock systems. At the same time, the main adaptation actions proposed aim to maintain its ecosystem services, plans to include soil and water conservation practices in productive systems, and urges the data retrieval on traditional practices. From a social perspective, it seeks to develop mechanisms that ensure the survival of communities in the land, and guarantee their active participation in the process.

The INAP project itself has characterized around 100 farms which have been geo-referenced and introduced into the National Environmental Information System. This characterization includes ecological, social, economic and cultural data, as well as the perceptions of local people on climate change, and the ecological conditions of the land. The farms were grouped into 4 farming systems in which grazing systems and livestock production predominate. Sustainable management practices have been proposed for each farming system and were adopted through "farm plans" developed by local farmers themselves.

These plans aim to build social resilience by improving living conditions of local populations and reducing their vulnerability, in order to be able to respond more effectively to climatic variations. Actions such as implementation of tree fences, organic fertilizers, home gardens with organic farming, diversification of products, soil and water conservation practices, soil and land cover restoration efforts, as well as recovering local knowledge and building capacity to face climate variability, are all being considered. Finally, we have to be aware that all these proposed adaptation measures have their own monitoring protocols and follow-up mechanisms, which depend on an extensive participation of the communities.

Conclusions: Advantages of EbA Approaches and Future Priorities

Advantages of Adopting Ecosystem-based Adaptation (EbA) Approaches

a) Developing an integrated vision of the land, based on fundamental ecological processes and beyond political-administrative boundaries;

b) Maintaining the ecological integrity of ecosystems in specific areas that are relevant to ecological services;

c) Investing in ecosystem-based watershed management, soil and vegetation restoration, land use planning and research on farming systems;

d) Investing in conservation through terrestrial and marine protected and managed areas and through the promotion of ecological corridors;

e) Investing in research and monitoring, e.g. data gathering and analysis, particularly related to ecosystem services and functioning, and climate change scenarios;

f) Improving governance of the region through regional planning processes that integrate concepts and actions for climate change adaptation, e.g. through a Land Adaptation Ecological Structure (EETA); also, through catalyzed public participation via mechanisms like the Land Use Spatial Plans (POT) and Watershed Management Plans, among others;

g) Achieving outcomes relevant for the management of "Global Commons" not yet incorporated in formal policy making process; an example are the "Adaptive Land Use Plans": local agreements for building ecological and social resilience, including activities such as watershed management, land restoration, farm planning, ecological monitoring and social networking;

h) Developing a vision of climate change adaptation within a cultural dimension; and

i) Contributing to public policy development at multiple management levels, e.g. National Policy to Climate Change Adaptation, Sector Policies, Local Development Plans, and POTs.

Future Priorities

Main priorities for future action that have been identified so far are:

a) To identify and agree on adaptation goals and resilience indicators for social-ecological systems under different scenarios of climate change and variability;

b) To consolidate a strategy for biodiversity research and monitoring;

c) To view impacts of climate change within a broader territorial context (that is, beyond project areas), including the two Andean mountain slopes and associated ecosystems;

d) To develop integrated vulnerability and resilience scenarios at watershed levels (beyond the farm level, and beyond specific, delimited topics);

e) To conduct modelling of soil systems, including spatial and temporal dynamics;

f) To propose objectives and indicators for ecological restoration in a comprehensive manner;

g) To develop ecological scenarios at a detailed level to identify more accurately climate change conditions and farming systems requirements;

h) To assess the costs and benefits of modelling ecosystem management vs. other approaches; and

i) To involve effectively the benefits of ecosystem-based adaptation (EbA) in planning and policy making at different levels of governance.

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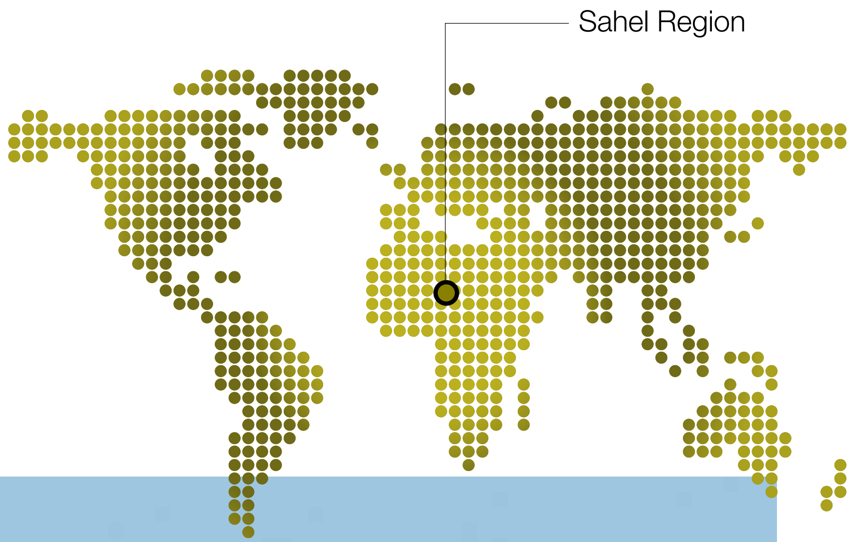
Chapter 3



Climate Change in Dryland and Wetland Ecosystems in the Sahel Region

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"We used to wait with sowing our millet until we found the soil had been wetted to the depth of our elbow when we dug a hole by hand. Now, we sow when the soil has been wetted only to the depth of our wrist. The way the rains are now, we cannot afford to wait any longer than that. We feel that drought periods during the rainy season are also more common than they used to be." (Quoting an old farmer in south-west Niger in 1994, previously cited by Brouwer and Bouma, 1997).

"When the millet yield has been bad, we put more effort into recession agriculture near the wetland. We can also dig up lungfish and water lily tubers there."

Dryland and wetland (agro-)ecosystems are closely intertwined. Trying to develop one ecosystem without taking into account the other will likely lead to problems. So far, relatively little has been done to prepare both drylands and wetlands in southern Niger for climate change. The situation in other parts of the Sahel is arguably little different. What is needed is development of participative integrated natural resource management (PINReM) of individual wetlands and their associated drylands, or the other way round. However, even more important is the PINReM of entire systems of wetlands and drylands, since links between drylands and wetlands are often unclear, and because of the varying importance of wetlands as a result of differing rainfall from place to place and from year to year.

Keywords: Agriculture, Climate Change, Drylands, Participative integrated natural resource management (PINReM), Pastoralism, Risk reduction, Sahel, Wetlands

Introduction

Rainfall, Soils and Agriculture

'Sahel' comes from the Arabic word for coast. The Sahel is like the inland coast of sub-Saharan Africa, bordering the sea of sand formed by the Sahara to its north. In climatic terms, the Sahel is generally defined as the region that stretched from Senegal to Ethiopia and that has an average annual rainfall of 200 mm at its northern limit and 600 mm at its southern limit. The rains commence in May-July, when the atmospheric Inter-Tropical Convergence Zone (ITCZ) moves north, and then end in September-October when the ITCS starts moving southward. Therefore all rain falls during the summer period, when the evaporative demand is very high. In addition, most of the rain falls in a small number of very high intensity storms (>50 mm/hr, sometimes >100 mm/hr). As a result, during the rainy season, longer periods without significant rainfall, or intra-season droughts, are common.

The generally high rainfall intensity in the Sahel causes surface crusts to form on soils pounded by them. This happens even on very sandy soils that contain only a couple of percent of clay. As a result a significant proportion of the rain in the Sahel does not percolate the soil where it actually falls, but runs off instead (Gaze et al., 1997). Large parts of the Sahel are covered by such wind-blown sand deposits. The soils formed here have a very low Available Water Holding Capacity: the soil layers in which the crops have their roots cannot retain much water that crops need to use over a longer period. In combination with surface crusting, this results in drought-sensitive soils in a drought-prone region. This is not a good combination for farming in the Sahel.

The windblown sands are also low in nutrient content and nutrient retention capacity (cation exchange capacity and phosphorus retention capacity). Growing crops on such soils is a bit like growing crops on glass beads in greenhouses. If you regularly add water nutrients, yields can be excellent. But if you add a lot of nutrients at a single moment, for instance at the start of the rainy season, in the form of manure, compost or fertiliser, many nutrients will leach beyond the root zone and will no longer be available for crops.

Since soil fertility is so low, farmers in the Sahel have developed ways to concentrate nutrients over centuries. The simplest way is by leaving fields as fallows for a number of years, so that dust coming in from the atmosphere can accumulate. Measurements have shown that, in south-west Niger, ten years of accumulation of wind-blown dust contains enough phosphorus for three millet crops, the local staple food. Thus, the average cropping-fallow cycle in this region is about seven years of fallow followed by three years of millet.

Average above-ground millet dry matter production achieved in this way is some 1,000–2,000 kg ha-1 yr-1. When the millet crop is at its tallest, 2–3 m in August-September, one might wonder what the problem is since the fields are so verdant. It turns out that local millet raises only have a harvest index of 20%. This means that, out of each 1,000 kg of above-ground dry matter produced, only 200 kg is grain. As a result, average millet yields in south-west Niger, and much of the rest of the Sahel, are only 250–400 kg ha-1 yr-1. This is strikingly different from wheat production in north-west Europe, where harvest indexes are 50% and grain yields are of the order of 12,000 kg ha-1 yr-1 (Brouwer, 2008).

A more elaborate way to increase millet production is to use livestock to bring nutrients to the crop fields, a technique also used in many other parts of the world, either now or in the recent past. Cattle, goats and sheep graze in areas away from the fields during the day, and spend the night at the millet fields, depositing nutrients in the form of manure and urine. If there is enough manure and urine, and the rains are well distributed, millet grain yields can average 700–800 kg ha-1 yr-1 (Brouwer and Bouma, 1997). There is, however, not enough manure for all the fields. Those fields that are fertilised by livestock are generally found closer to the village, to make it easier to watch over the livestock during the night. Farther from the village, management is less intensive and yields are generally lower (Brouwer, 2008).

The Risk Reducing Role of Variability

As conditions are unreliable, farmers in the Sahel look for risk reduction or a high minimum yield, allowing them each year to make it to the next harvest. They are less interested in high averages (e.g. Ubels and Horst, 1993, p.29; Brouwer and Mullié, 1994a). A strategy aimed at a high average usually means more variability in annual yields and a higher risk of falling below the minimum that they need to survive during the next twelve months. This is because, unlike in NW Europe, farmers in the Sahel have little control over the environment. They mostly cannot irrigate, drain excess water nor control pests, and can improve fertility only to a limited extent. Therefore they reduce their risks by investing in different production strategies, at least one of which, each year, should help them produce enough to survive until the next harvest. Such strategies include mixed cropping of early and late millet varieties, with sometimes cowpea sown in between; mixed cropping of sorghum and millet; and growing high-yielding sorghum in the more fertile spots within a millet field, e.g. around eroded *Macrotermes* termite mounds (Brouwer, 2008).

However, not only do farmer risk avoidance strategies have a risk reducing effect. So do naturally occurring within-field soil and crop growth variability. Even on very sandy soils, local rainfall infiltration can vary from 30 to 340%, depending on the micro-topographic position (top-slope-bottom) and the presence/absence of almost impermeable surface crust (Gaze et al., 1997). This, too, has its effect on nutrient leaching and nutrient availability. Due to uneven and unequal availability of water and nutrients in a field, different parts of a field may give the best yield in different years. For example, some parts of a field may be relatively fertile, but also relatively dry; other parts may be less fertile but wetter. Depending on the rainfall during a particular year, either nutrients or water may be more limiting, and either the most fertile or the wettest parts of a field may produce more (Brouwer et al., 1993).

Crops may also benefit from the amount of water stored in the soil at the end of one cropping season and carried over to the beginning of the next cropping season: where less water was used (and less dry matter was produced) one year, more water may be left in the soil to be used the following year (Brouwer et al., 1993).

In addition, crop growth variability can reduce the yield reducing effects of pests and diseases. Crop susceptibility to different pests and diseases varies according to growth stage. In more fertile parts of the field, crop development will be faster than in less fertile parts. In some years faster development will be an advantage, allowing the plants to avoid peak pest and disease presence during their sensitive growth stages. In other years, a slightly slower development will be advantageous.

If All Else Fails: Isolated Wetlands as a Fall-back for Farmers

Farmer ingenuity notwithstanding, rains can be so poor that the millet harvest is insufficient for a farming family to make it to the next harvest, twelve months later. If they don't want to run the risk of starving, they have two options: find work elsewhere during the dry season so additional millet can be bought, or try to grow a crop during the dry season. For the latter, access to water is obviously necessary, which often means access to frontage on permanent or semi-permanent wetlands.

During the years 1984–1991 the area dedicated to dry season cropping in Niger (but not including rice) varied between 42,000 and 64,000 ha (MAE-Niger, 1993). Dry season cropping was most extensive in 1984 and 1989 (63–64 thousand ha vs < 54.000 ha in other years). These two years were respectively a drought year and a year with only patchy rainfall and poor millet harvests in many parts of the country. It would seem reasonable to conclude that dry season cropping around wetlands is particularly important following rainy seasons with poor, or poorly distributed, rainfall. In a dry season cropping project at Illlela, south of Tahoua, it was found that 70% of income generated by dry season cropping was used to buy grain (Mahatan, 1994). In years of drought, isolated wetlands are also used as places where hunger food such as waterlily fruit and tubers are gathered and lungfish hunted.

Isolated Wetlands as Important Resources in Their Own Right

In Niger alone there are more than 1,000 isolated wetlands of a certain size (10–2,000 ha). They are often located in depressions in the old drainage systems that date from the time when the Sahara was much wetter, as recently as 8,000 years ago. Some are very temporary, and only hold water a couple of months each year. Others contain water much longer. A number are even permanent, and always retain water, or almost always (MHE-DRE-Niger, 1993). These wetlands are enormously dynamic. Some disappear due to siltation (MHE-Niger, 1992; Piaton and Puech, 1992), but new ones appear as well. One such new wetland is found at Dan Doutchi, in a depression that filled up as the drought broke in 1975: it now covers 1,500 ha when full (Brouwer and Mullié, 1994b). By far the greatest number of these isolated wetlands is to be found south of 15° N, in approximately the 300–600 mm rainfall zone, between the line Mali-Tahoua-Lake Chad and the border with Nigeria.

In only two regions of south-eastern Mauritania there are at least 244 such wetlands (Cooper et al., 2006). In other parts of the Sahel their prevalence is without doubt similar.

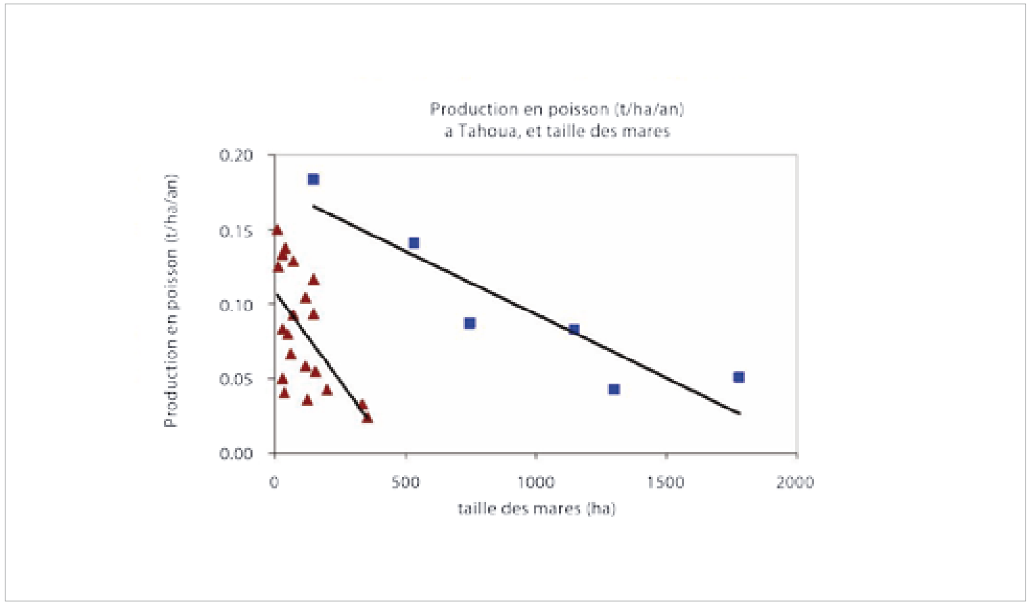
Wetlands are areas where water and nutrients are concentrated. As a result they are areas of high production potential and low production risk, especially in semi-arid regions. Isolated wetlands in the Sahel are thus natural resources that are in great demand not only by upland farmers after a poor millet harvest, but also by market gardeners, pastoralists, fishermen and collectors of natural products. Not surprisingly, that demand is greatest during the dry season, when there is little surface water elsewhere in the landscape of the Sahel. The following description of activities in isolated wetlands comes from southern Niger and is representative of the situation found in other parts of the Sahel.

Dry season cropping concerns crops like onions, tomatoes, beans, sweet potato, cabbage, lettuce and peppers (authors' pers. obs.). These crops have a much higher nutritional value than staple millet, which is important for producers as well as for local buyers. Much of the dry season cropping is done for commercial purposes, with the harvested crop traded as far away as Abidjan. Financial returns per hectare per year varied from 60,000 (low-input *Dolichos lablab*) to 1,300,000 (onions) F CFA, or from $ 200 to $ 4.300 per ha per year (Raverdeau, 1991; Mahatan,1994). An upland millet crop during the same period would have averaged $ 70 per ha per year (Brouwer and Mullié, 1994a).

Pastoralist use of isolated wetlands is much location dependent. Once the rains have ended and surface water has dried up, the wetlands become a very important source of water for livestock. It allows livestock to graze in the surrounding dryland fields, fallow areas and grasslands. Once the grazing is done or the water has been fully used, the livestock migrates further south, in some cases towards wetlands that also provide dry season fodder. If one assumes that livestock production in Niger is about one-third dependent on isolated wetlands for its water supply, as hydrological data suggest, then the value of wetlands for livestock production in Niger probably would have been around $ 35 million per year as early as in the beginning of the 1990's (Brouwer, 2008).

Fishermen utilize isolated wetlands as long as they contain water. Semi-permanent wetlands may be restocked with fish at the start of the rainy season, because only lungfish can survive a dry spell. Fishing mostly takes place during the dry season, after (newly introduced) fish stocks had time to grow. Receding water levels can also make it easier to catch the fish. The main species caught are *Clarias gariepinus* (catfish or 'silure'), *Tilapia nilotica, T. zilii* and *Lates niloticus* (nile perch or 'capitaine'). Other fish caught include

Figure 1. Fish production in the Region of Tahoua in tons/ha/year, as a function of wetland size (after Brouwer and Mullié, 1994a).



Bagrus bayad, Protopterus annectens (lungfish) and *Auchenoglanis* sp. (Brouwer and Mullié, 1994a).

In 1989, the fish catch in the Region of Tahoua, one of the seven rural Regions of Niger, was estimated at 430 tons, with a value of more than $ 250,000 in the wetlands where they were caught (MHE-DFPP, 1991). In the capital city of Niamey the value of fish was 5–10 times higher (authors' pers. obs.). In 1993 it was estimated that, with an investment of about $ 1 million, fish production in the Region of Tahoua could increase to some 1,500 tons per year, with an annual value of close to $ 1 million at price levels prevailing at that time (Fig. 1). A total production of 2,000 tons per year was considered achievable (MHE-DFPP, 1991).

Above a certain minimum wetland size, fish production per ha per year appears to decrease with wetland size. This is probably related to the nutrient loading caused by livestock that visit the wetland to drink. At smaller wetlands manure and urine left at the edge occur closer to the centre of the wetlands, which therefore have a higher nutrient loading per hectare that would stimulate primary production (plant growth) and secondary production (animal growth, from unicellular organisms to fish and water fowl) (Brouwer and Mullié, 1994a).

Hunters and tourists visit wetlands in some parts of the Sahel. In Burkina Faso, tourists from Mediterranean countries come during the dry season to hunt birds, including water fowl (authors' pers. obs. and discussions with public servants, 2006–2008). Tourist organisations in Niamey in 2007 and 2008 did not know of any organised hunting at isolated wetlands in Niger, or knew about organised tourist excursions to isolated wetlands. At local markets in Niger a multitude of animal species, including species found in isolated wetlands, are for sale for medicinal and magical purposes. To what extent these animals are caught in the Niger River itself is not clear (Brouwer and Mullié, 1994a).

Collectors of natural products collect them from their wetland during the whole year. These include wood for cooking; wood for construction (trees around wetlands are often larger than those growing further away from water); clay for brick

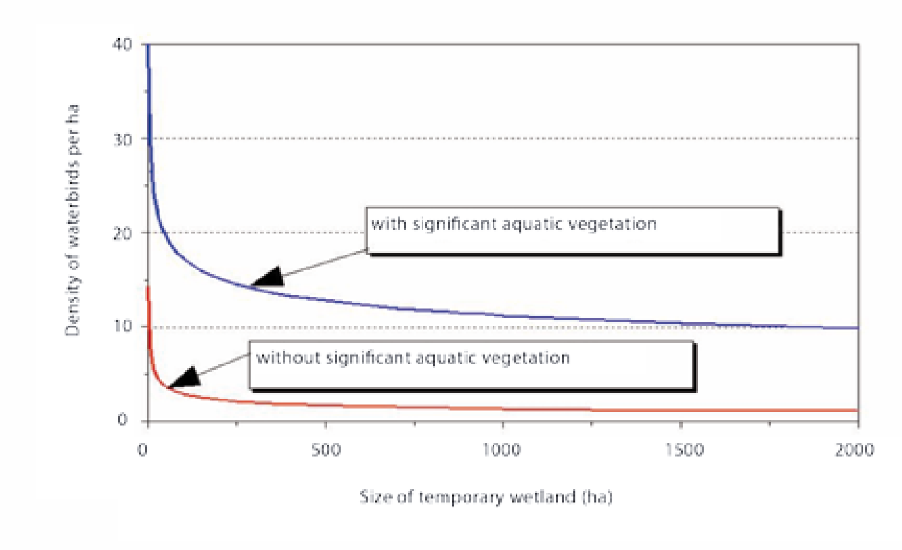
Tilapia nilotica are one of the main species fished in the Sahel, seen here being smoked.

making and pottery; water for domestic purposes, including the washing of clothes; plant (and animal?) products for traditional medicinal and magical purposes (Brouwer and Mullié, 1994a).

Biodiversity is another important aspect of isolated wetlands in the Sahel. Relatively much, but still not a lot, is known about water fowl in Niger during the dry season. During 1992–1997 water fowl counts were conducted every year during January-February, both along the Niger River as well as in isolated wetlands throughout the country. In total more than 100 species of water fowl were observed during those counts, and almost 40 species of raptor. During the dry season Niger is host to an estimated 1.8 million water fowl. Most of these come from Europe or Asia and some fly more than five thousand kilometres to spend the boreal winter in Niger. This country's wetlands are therefore also important to the conservation of European and Asian biodiversity (Mullié and Brouwer, 1994a, 1994b; Mullié et al., 1999; Brouwer and Mullié, 2001). Preference of particular species of water fowl for particular types of wetlands in Niger is discussed in Mullié et al. (1999).

Two thirds of the water fowl in Niger, on average about 1.2 million, use its isolated wetlands. This depends on how much rain has fallen during the

Figure 2. Relationship between isolated wetland size and waterfowl density (from Mullié et al., 1999).



preceding rainy season. The Niger River becomes more important when rains have been poor and isolated wetlands get only partially filled. Just as for fish, the density of water fowl is greater in smaller wetlands than in larger ones, probably due to greater nutrient loads in the former (Fig. 2). Water fowl density is also greater in wetlands that have aquatic vegetation than in wetlands that don't. Apparently, when aquatic vegetation is present there is more to feed on for the average water bird. Additionally, the vegetation provides places to hide (Mullié and Brouwer, 1994b; Mullié et al., 1999; Brouwer and Mullié, 2001).

There is very little quantitative information on water fowl presence available for isolated wetlands in Niger during the rainy season. Also, very little is known about the occurrence of other vertebrates, or invertebrates, in isolated wetlands in Niger at any time of year. In the past large mammals such as antelopes, buffalos, elephants, hyenas, jackals, foxes, and even lions used to come and drink in isolated wetlands in Niger during the dry season (e.g. Nicolas, 1950). However, other than foxes there are now very few large mammals left in Niger, except in 'W' National Park on the border with Benin and Burkina Faso in the south-western sector of the country.

Dryland and Wetland Ecosystems in the Sahel are Intimately Linked

As can be learned from the above, there are many links between dryland and wetland ecosystems in the Sahel. People in the drylands use the wetlands as a fallback following a poor millet harvest, but also use them to grow horticultural crops (high quality food), to provide drinking water to livestock that grazes fallow fields and undeveloped areas, to gather natural products such as wood, herbs and clay for pottery, etc. Production in the wetlands profits from e.g. the nutrients brought in by livestock and as sediment, and from the water that runs off from fields and natural areas. What happens in dryland areas affects what happens in the associated wetland areas, and vice versa. Development programmes in the Sahel, including those aiming to deal with climate change, should therefore look at wetlands and drylands in an integrated manner.

Results

Impacts of Global Change on Drylands and Wetlands in the Sahel

In the Sahel it is difficult to separate the effects of climate change from those of other aspects of global change (population increase, migration, and

socio-economic changes). One of the reasons is that it is not clear what climate change has taken place there so far. In addition, predictions of climate change in the Sahel are equivocal, with e.g. less than 66% of models agreeing on future rainfall changes in the Sahel (IPCC, 2007). Impacts of different aspects of global change in the Sahel are therefore discussed together.

Changes in Drylands

The main change that has taken place in the Sahel over the past 60 years is the increase in its population. Annual population growth rates of more than 3.0% are found everywhere. An annual growth of 3.1–3.8% means a doubling of the population in 18–23 years, and a quadrupling in 36–45 years. In Niger, from 1950 to today its population grew from 3.3 to over 15.5 million, an almost five-fold increase in 60 years. This must have had enormous effects on the environment. With a growth rate expected to go down from 3.8 to 2.4% by 2050, the population of Niger is still expected to reach 55 million by the midst of this century, a 16-fold increase in population during only 100 years (http://en.wikipedia.org/wiki/List_of_countries_by_past_and_future_population), based on the US Census Bureau International Database, retrieved in January 2010. Figures for other Sahelian countries are very similar.

Fertiliser use in the Sahel is low, and as such a big increase in population has resulted in a large increase in the area covered by millet. In a recent study it was estimated that, from 1975 to 2000, the area under millet coverage increased from 16 to 23% in the southern part of the country – mostly south of 16° N (USGS, 2010). About half of that area has no millet cultivation to speak of, so in the remaining half the area under millet increased from about 30 to about 45%.

The presence of more millet fields has meant less fallow fields. This would imply less time for atmospheric dust to accumulate, and thus lower soil fertility during millet cultivation. The occurrence of more millet fields also caused a reduction in grazing opportunities for livestock, and less manure and urine deposited on the millet fields close to the villages. Even without decreases in effective rainfall, a decrease in soil fertility means a decrease in millet yields, more frequent (local) famines, and more pressure on other natural resources.

Changes in Wetlands

More frequent (local) famines means a higher temporary pressure on isolated wetlands, which are also affected by other processes. The links between uplands and isolated wetlands during droughts are not just local and temporary. Drought periods can also lead to increased permanent settlements around wetlands. From 1975 to 1988, a period that included two severe droughts, the number of villages along the Nigerian side of Lake Chad increased from 40 to more than 100 (Hutchinson et al., 1992). Similarly, use of the Hadejia-Nguru wetlands in Nigeria for agricultural production increased due to the droughts of the last two decades. This increase was not foreseen and therefore not considered when plans were made for construction of dams and implementation of irrigation projects in the catchment upstream (M.C. Acreman, pers. comm. 1995). In the Tahoua region, Niger, dry periods meant on the whole an increase in migration towards the coast. Wet periods meant migration to the normally drier and less populated northern and western parts of the region; in part, migrating peoples stayed there even when rainfall was less abundant, thus increasing the pressure on the region's natural resources (including the wetlands) (DDE-Tahoua, 1993).

Even now, many – if not most – Sahelian wetlands are suffering from problems of erosion, siltation, vegetation destruction and/or salinization (cf. Brouwer and Mullié, 1994a, 1994b). These problems are in part related to the low rainfall in the 1970's and 1980's, and to the associated decrease in vegetation cover, as well as to increases in population densities, and decreases in vegetation cover in the catchment areas of the wetlands (i.e. more millet fields, less fallow, etc., cf. Reenberg, 1994). For wetlands near Zinder in Niger, Framine (1994) estimated that, without proper counter measures, it would take only 10–20 yr for a change from an aquatic to a marshy ecosystem to be affected, due in part to filling in sections of wetland with soil, meant to increase the cropping area.

On the other hand, too much anti-erosion activity can adversely affect the flow of both water and nutrients towards the wetland, especially during years of poor rainfall. Upstream dams, ranging from very small to very large, can similarly cause wetlands to dry out and/or become more saline as the flushing effect of floods is reduced (Brouwer and Mullié, 1994a). The recent construction of many small dams for local vegetable growing in nearby riverbeds is reputed to have caused the early drying out of Lake Tapkin Sao near Dogon Doutchi in south-west Niger in 2006–2007 (author's pers. obs.).

Isolated wetlands are linked to local grazing areas by local livestock and to more distant grazing areas and wetlands by transhumance livestock. Wetlands are extremely important to the transhumance herding families as a source of water for their animals during the dry season and, further north, also during the rainy season. The larger wetlands are seasonally also very important for grazing activities. The wetlands and grazing areas further south help make it possible to exploit the rainy-season livestock production potential of the northern Sahel: without dry-season watering and grazing in the south, there can be no grazing in the north (cf. Breman, 1992; Dugan, 1990). Conversely, if transhumance livestock rearing becomes impossible in the north, nutrient transfer to wetlands and millet fields may be reduced in the south. The latter may in the longer term adversely affect the dry season cropping itself as well as the fish production. On the other hand, livestock is more likely to damage crops along the fringes of isolated wetlands if agriculture at wetland edges is expanded.

Increased dry season cropping may also lead to a reduction of aquatic and fringe vegetation, and thus to a reduction of habitat for water fowl and other animals. Farmers in the region of Tahoua have cut entire stands of Acacia nilotica trees in order to have more land for agriculture; at the same time there is a lack of firewood production in virtually the entire region (DDE-Tahoua, 1993, p.2 and on). Similarly, increased dry season cropping will lead to an increase in habitat disturbance affecting the birds and perhaps to an increase in hunting, because of increased damage to crops, whether actual or perceived. Increased dry season cropping would make an isolated wetland less attractive for hunting and for tourism, but in providing employment opportunities it may also lead to a reduction in seasonal outmigration of people in search of temporary work elsewhere.

Raising the outflow level of an isolated wetland so that it will hold more water for longer period, for both water supply and irrigation purposes, may affect the aquatic and fringe vegetation in a variety of ways, depending on particular, local circumstances. Some trees may not survive an increase in inundation time, or a reduction in oxygen content of the water. Livestock and water fowl may profit from this situation, when more water is available later in the dry season, but at the same time may adversely be affected by changes in vegetation growth and, for water birds, changes in associated prey species.

An overview of changes observed over a period of 15 yr at a number of isolated wetlands in Niger is given in Table 1.

While all these changes happen, one should be aware that the value of a particular isolated wetland for a particular purpose may vary from year to year. This value not only depends on the precipitation that falls on the wetland and its immediate surroundings, but also on the rainfall occurring in other catchment and upland areas. Rainfall in semi-arid regions does not only vary considerably from year to year at one location, but also may occur in a very patchy distribution. Individual rainfall events can occur quite locally, but annual rainfall totals may also differ considerably over short distances. For example, during a large international experiment in the Niamey area in 1992, rainfall was found to differ

Table 1. Examples of changes happening at isolated wetlands in Niger, from 1992–1997 to 2006–2008. IBA = Important Bird Area according to BirdLife International (Fishpool and Evans, 2001).

Kobadié wetland, 50 km SW of Niamey along the road to Ouagadougou, ca. 20 ha: **1992–1997:** the wetland in October-November with presence of water lilies. **2006:** all large trees (Khaya senegalensis) and most medium size trees (Mitragyna inermis) were cut; more people are present, lots of disturbance, though few birds.
IBA Kokoro wetland, 30 km NE of Téra and 150 km NW of Niamey, max. 2,100 ha: **1992–1997:** up to 13,108 water fowl of 44 species in a glorious setting of flooded grassland surrounded by patches of Acacia nilotica forest, red dunes, huge granite boulders and palm trees. **2008:** large areas of fringing Acacia nilotica forest has been cleared; a lot more vegetable gardens has been constructed; and grazing pressure by livestock on the aquatic vegetation has increased enormously (perhaps in part because of the poor rains the preceding year, but most likely because of an increase in population and livestock size); birds are concentrated in a much smaller area of the original wetland and are less in number.
IBA Namga or Namaga wetland, 40 km NE of Téra and 150 km NW of Niamey, max. 500 ha: **1992–1997:** up to 13,190 water fowl including 54 species of bird. **2008:** the wetland has been mostly dried due to poor rains in 2007, but still quite a few birds are observed; the adjoining village, from which the wetland received its name, has grown significantly.
Mari wetland, 10 km NE of Tillabéri, 100 km NNW of Niamey, max. 270 ha: **1992–1997** up to 4,266 water fowl. **2006:** no water fowl present because an earthen dam had been constructed to raise the level of the outflow of the wetland, while the (former?) wetland had been almost completely taken over by farmers.
Yaya wetland, 40 km W of Birni N'Konni: **1992–1997:** a total of 122 water fowl was counted in this nice little wetland, next to a village. **2006:** although still quite nice and with some water fowl, now there is an apparent increase in population and human activity when compared to the situation ten years earlier.
IBA Dan Doutchi wetland, 80 km NW of birni N'Konni, max. 1800 ha; originated in 1975 after a huge rainfall event which followed the drought of 1973–1974: **1992–1997:** up to 55 species of water fowl. **2006:** an earthen dam had been built to raise the level of the outflow of the wetland; still a lot of water present, with people, fishing activities and vegetable growing and some other human influence, but now with very few water birds present in the area.
IBA Tchérassa reservoir, 6 km NE of Birni N'Konni: **1992–1997:** 15,000 Cattle Egrets and 3,000 other water fowl (mostly ducks) present in January 1994. **2006:** large areas of Acacia nilotica were cut, especially in the areas where the Cattle Egrets used to roost; an increase in human population and activity is obvious.
Galmi reservoir, 60 km E of Birni N'Konni: **1992–1997:** up to 1,033 of water birds. **2006:** few water fowl present, while the population pressure and fishing activities appear to have increased.
Tabalak wetland, 25 km NE of Tahoua along the road to Agadez, max. 1,150 ha: **1992–1997:** up to 5,464 water fowl including 48 species; Tabalak used to have quite a few trees along its northern end (Acacia nilotica, A.albida, Prosopis juliflora, and Balanites aegyptiaca), but in 1993 many of these were cut; in 1993–1994, about 20% of the perimeter was covered by vegetable gardens, while 80% was accessed by livestock. **2007:** much less water fowl, in combination with a big increase in human population and human activities; now, it appears that 80% of the perimeter is covered by vegetable gardens (with some narrow passages for livestock that want to reach the water, and 20% freely accessible to livestock).
The Liptako-Gourma region, where the countries of Niger, Burkina Faso and Mali meet: The Liptako-Gourma is an area with (still) lots of great wetlands, threatened by population increases, migration and climate change. Some of the wetlands are probably also threatened by the construction of a dam in the Niger River at Kandadji, just south of Ayorou, about 80 km south of the Niger-Mali border. Dam construction implies employment and (temporary) settlement of labourers; this condition attracts people that provide goods and services to these labourers, causing, e.g.: - construction of housing, for which timber is cut; in dry areas much of the timber grows in drainage lines and around wetlands; - provision of firewood, for which wood is cut; - growing of vegetables, mostly around wetlands, which means less access to those wetlands for pastoralists and destruction of the bordering vegetation.

Millet growth in the Sahel can vary enormously within a single field. Climate change increases the importance of farm-level diversity to adapt to uncertain weather patterns.

by 275 mm or a factor 1.54 over a distance of only 9 km in a rather flat area: 507 vs. 782 mm (EPSAT experiment; see Lebel et al., 1992). If an isolated wetland received a lot of rain in one particular year but its neighbouring wetlands did not, then the relative value will be small. However, if the next year rainfall in that particular wetland is equally well distributed, while nearby wetlands are not, its relative importance may increase. One of the recommendations resulting from this condition is that one should not look at wetlands in a particular region in an isolated manner, but rather review the whole regional system of wetlands of which it forms part, and the rainfall patterns that occur in that system. Moreover, such a wetland region should be managed in its entirety as a single, integrated system.

Actions Taken to Respond to the Impacts of Climate Change and Their Consequences

Actions in Relation to Drylands

The main aim of farmers is to ensure yield security over a number of years. To this end they try to minimise production risk. To respond to climate change they often adapt what they are already doing to new conditions. One such response has been to sow earlier in the rainy season, i.e. after the first rains have fallen (e.g. see the quotation at the beginning of this chapter). On the other hand, the adoption of fertilisation technologies has been rather slow, because the investment is considerable and the risk appreciable. For instance, during some years the application of fertiliser can have a negative effect on the yield of the crop (Brouwer and Bouma, 1997), which not only implies a poor harvest but also the loss of money invested in purchasing fertiliser. One exception may be the micro-dosing of fertiliser, i.e. the process of adding very small quantities in millet planting holes. The investment to be made for micro-dosing is much less, of course.

The approach that is often applied in agronomic research and extension in the Sahel seems to be an 'increased use of external inputs: if it works well within the fenced research station area, then it must also work outside the station; and if it works well at small scales, it will also work well at large scales: uniformity is desirable'. This approach does not take into account the farmer's production goals, the unlikelihood that fertiliser will soon become widely available in southern Niger, the need to increase the efficiency of using local and external resources, or the positive role that variability can play in Sahelian production systems in the Sahel. Insufficient attention to soil and crop growth variability is without doubt one of the factors highly responsible for the lack of adoption of a number of newly developed, technically promising agricultural production options in the Sahel (Brouwer, 2008).

Other research efforts have shown that farmers in the Sahel already practise 'precision farming', 'site-specific agriculture', or 'farming by soil', to name a few terms. But there is room for improvement, including large increases in resource use efficiency, for local as well as external inputs. To achieve such improvements it is necessary to integrate farmer and researcher knowledge (Brouwer, 2008).

Production technologies that do take into account such elements and that have been proposed over the past 10–15 years, but are still waiting for a response from the research and extension community (see Brouwer [2008], for additional details), include:

a) Recognition of the yield stabilizing role that with-in field variability can play;

b) Suggestions for reduction of over-manuring by farmers

c) Recognition of the need to apply different management approaches to different Aeolian sand deposits, often found side by side in a single field;

d) Suggestions for improving nutrient use efficiency by farmers, through micro-topography-related site-specific management (this is important for the management of local fertility resources such as manure, urine, compost, crop residues, domestic refuse, as well as for the management of mineral fertiliser);

e) Suggestions for improving with-in field rainfall infiltration by applying lime or gypsum;

f) Recognition of the important role that *Macrotermes* termites play in local increases in soil fertility on sandy soils;

g) Recognition of the fact that *Faidherbia albida* seedlings in agro-forestry projects are much more likely to grow well near old *Macrotermes* mounds;

h) Suggestions for better incorporation of short-distance soil and crop growth variability in agricultural research.

Wetland-Related Actions and Results

The changes that have occurred over the past 15 years in isolated wetlands in Niger, mentioned in Table 1, are not considered to be just anecdotic events. They appear to be representative of what is happening in most isolated wetlands in Niger, and most likely elsewhere in the Sahel: an uncoordinated effort that results in a deteriorating wetland quality, affecting all stakeholders including farmers (see Table 1).

Conclusions and Recommendations

From the results of this study it becomes clear that dryland and wetland (agro-) ecosystems in southern Niger are closely intertwined. Developing one system without taking into account the conditions of the other likely will lead to a variety of problems. So far, relatively little has been done to prepare both drylands and wetlands in southern Niger for climate change. Arguably, the situation in other parts of the Sahel is little different. To solve this issue a participative integrated natural resource management (PINReM) approach is necessary: a PINReM of individual wetlands and their associated drylands, or vice versa. However, it would be even better to implement PINReM in entire regional ssystems of wetlands and drylands, taking into account the links that do exist between drylands and wetlands that may be located even far away from each other. Such an approach is also vital in view of the varying importance that wetlands may have, as a result of varying rainfall patterns that change from place to place, and from year to year.

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Chapter 4

Mainstreaming Adaptation within Integrated Water Resources Management (IWRM) in Small Island Developing States (SIDS)

A Case Study of the Nadi River Basin, Fiji Islands

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Fiji and many of the Pacific Island Countries are likely to experience increases in the frequency and height of storm surges as well as other extreme events due to current and projected climate change risks and climate variability. The Nadi River Basin, located in the western division of Fiji suffers from regular flooding, causing serious social, economic and environmental damages in the lower floodplain and coastal area, including the river estuary. The increased frequency of floods over the last few decades, combined with an increasing population pressure and unsustainable urban development has increased the vulnerability of the basin to projected climate change impacts. To adapt successfully to increased flood and water induced changes it is essential for Nadi Basin communities and individual villages to better manage water resources. Management reforms require both changes in catchment land use practices, institutional governance, infrastructure development and the need to mainstream risk management within Integrated Water Resources Management (IWRM). Implementation of a combination of these measures provides a holistic approach to water management and long term adaptation. This paper provides summary perspectives on water-based adaptation through IWRM practices that provides options to address climate change in small island developing states (SIDS) such as Fiji.

Keywords: Catchment Committee, Climate Change Adaptation, Integrated Water Resources Management, SIDS

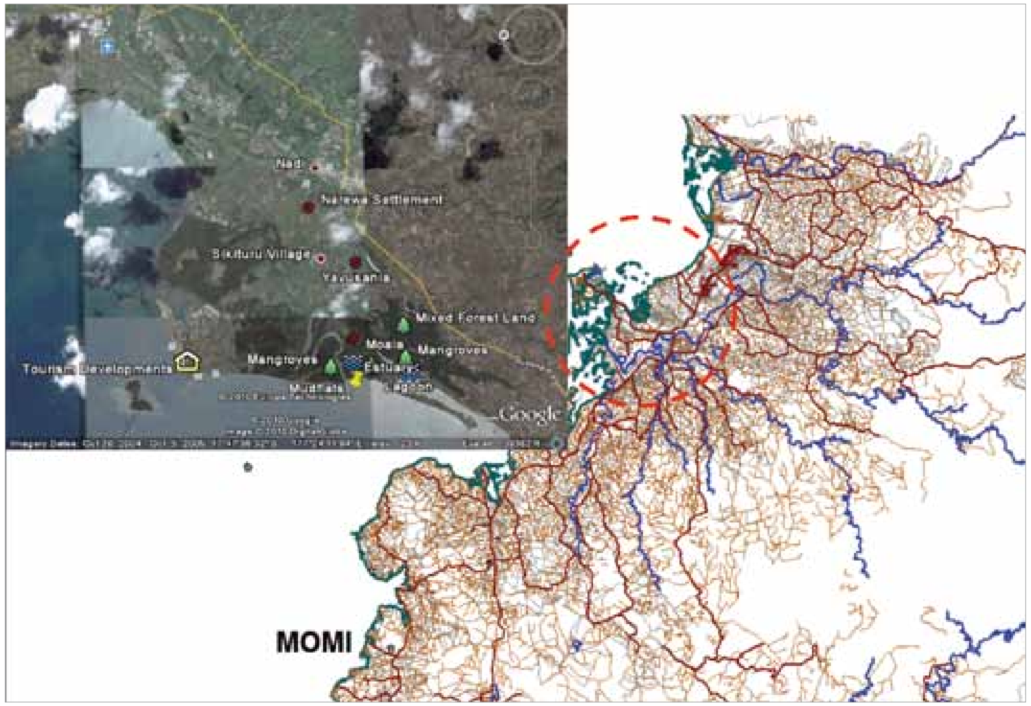
Introduction

The Fiji group is situated in the southern part of the Pacific Ocean, centred near 18° S latitude and 178° E longitude, south of the equator. Fiji is an archipelago, comprising of 320 islands which are scattered across the western Pacific Ocean. Approximately a hundred of these islands are inhabited. The total land area is estimated to be around 18,333 km^2, and the two main large islands are Viti Levu and Vanua Levu. Fiji's marine Exclusive Economic Zone (EEZ) has an area of approximately 1.26 million km^2 (ICRI 2006). The main island, Viti Levu is predominantly mountainous and volcanic. The climate can generally be described as mild tropical, maritime and seasonal. The wet season extends from November to April and the dry season from May to October. The tropical latitude and influence of the nearby warm Southern Equatorial Ocean Current gives Viti Levu a wet/dry tropical climate (Terry et al., 2001).

The area of the Nadi River Basin case study is one of the key commercial areas in Fiji and is valued largely for tourism, agriculture (sugar), and service industries. The frequency of flooding in the basin has caused extensive damage to economic activities and has historically resulted in severe community distress, impacting the socio-economic well-being of local communities. The estimated damage resulting from the January 2009 floods were over FJ$ 113 million (US$ 58.5 million), which excludes private business costs (Government of Fiji, 2009)[1]. The severity of the floods is attributed to increasing variability of climate, changing land-use practices in the upper catchment of the river basin and increased development in the floodplain. Modern flood management practices need to be considered in the basin, as increased development poses increasing risks to livelihoods and economic activities (Pacific Islands Applied Geoscience Commission [SOPAC], 2008). The Nadi River Basin is representative of other coastal river basins in small islands, with social and economic factors at the core of land and water management problems. Problems which are expected to become more challenging when climate change impacts are taken into account. Lessons learnt from this river basin as a research case study can be applied to other Small Island Developing States (SIDS) or other regions where risks of sea level rise, groundwater saline intrusion, coastal erosion, and floods persist presently or in the future.

The case study area is located in the western part of Viti Levu, in the district of Nadi which falls under the province of Ba in the Fiji Islands (Fig. 1). It covers the Nadi River, its entire catchment, residential and business areas, mangroves, mudflats and lagoon associated with the coastal ecosystem. Nadi town is located along the Nadi River, with other tributaries and smaller rivers joining the river immediately downstream of the town. The Nadi River has a catchment area of

Figure 1. Nadi River basin topography and watershed area. Inserted map shows case study area with key marked villages and environmental features (Source: DTCP, 2010).



[1] This World Bank supported Government of Fiji (2000) study of the economic and social implications of climate change and variability for selected Pacific islands concludes that in the absence of adaptation practices, high islands such as Viti Levu, Fiji, could experience damages of US$ 23 million to 52 million/yr by 2050, (equivalent to 2 to 3% of Fiji's GDP in 1998) (IPCC 2007b).

490 km^2 (Terry and Raj, 1999) and an average discharge of 300m^3/s where it enters the sea (JICA, 1998). A substantial part of Nadi town is below 6 m mean sea level and is subject to periodic flooding between November and April (Pacific Islands Applied Geoscience Commission, 2007). Nadi town is Fiji's biggest town and third largest conurbation, the major entry point for tourists and visitors, and as a gateway to other Pacific Island countries (with the location of Fiji's International Airport).

Nadi has a population of over 50,000 people, with several clusters of villages surrounding the main town. Over half of the population lives in rural areas. The lower catchment area has several villages and settlements which include Moala, Yavusania, Sikituru, Narewa, Namotomoto, Narewa Settlement, Navo and Nadi Town. Moala village is the closest to the river mouth, just 2 km from the coastline. Each village has its own traditional social structure of governance headed by the Turanga ni Yavusa (Clan Chief) and Turanga ni Koro (Village Chief). The Narewa settlement has a mixed composition and is predominantly inhabited by Indo-Fijians.

A lagoon is located at the mouth of the Nadi River, extending north into a shallow inter-tidal area bounded by Cuvu Island and the northern extension of Sonaisali Island which hosts a major tourist resort. Nadi town hosts a number of five star resorts in the lower catchment area (towards Denarau Island), with many more tourism development plans in the pipeline. Both the Nadi and neighbouring Ba River catchments cover 15% of Viti Levu and include extensive saline mudflat areas and mangroves supporting productive fisheries and a range of habitats supporting a wealth of fish biodiversity (WWF, 2003). There is a well developed fringing reef system near Denarau and Yakuilau Islands. A barrier reef system also lies off the shores of Navadalalevu Island, Moturuaimalolo Cay and Malamal Island to the west. A mangrove system mosaic is well developed near the Nadi river mouth at the north-eastern side of the town, and consists of grooves, channels, wet riverbank areas, extensive muddy areas and drier areas near villages and resort properties. Observed mangrove channels become more numerous and progressively reticulated as they approached the seaward side. They serve important functions in tidal and sediment circulation and are often characterised by fast-flowing currents (LWRM, 2001).

Mangrove trees in the area vary greatly in size. The most common species are Red Mangroves or Tiri (*Rhizophora stylosa* and *R. samoensis*) which are vigorous around the fringes of the riverbank and coastal areas. Occasional strands of *Bruguiera gymnorrhiza* have been observed inland near Moala village. The *Rhizophora* stands are not continuous, and the habitats of many mud lobsters are common. Part of the coastline area before the entrance to the resort island of Denarau suffers from occasional deforestation of mangroves (Fig. 2). This is a typical example of coastline reclamation and tourist development currently happening in the area. Conversations with local people indicate that almost a decade ago this area held the largest stands of mangroves in the Nadi Bay area, which have been removed recently for development of tourism and residential projects. This dwindling mangrove area and the remaining stands in the Nadi Bay area have been described by Skyes (2007) who stress their significant conservation value. Often such deforestation of the mangrove strands for small scale development goes unnoticed, despite requirements for prior formal approval. The mangrove swamp is a critical habitat for watershed services necessary for flood mitigation in the Nadi River Basin. The Environment Management Act (2005) recognises mangrove swamp as *"an ecosystem of national importance"* and therefore requires that any project seeks prior approval from the Environment Impact Assessment (EIA) Unit of the Department of Environment for any *"proposal that could alter tidal action, wave action, currents or other natural processes of the sea, including… reclamation of … mangrove areas…"* (Government of Fiji, 2005a).

The area around the mangroves (Sikituru, Moala and Yavusania villages) have extensive farm lands

Figure 2. Strands of mangrove cleared for development in the lower catchment area of Nadi River Basin (Chandra, 2010).

composed of cash crops such as dalo, taro, cassava, cabbage and bean. These farm lands and villages are approximately within a 2 km radius from the river banks. Immediate to the lagoon in the southern part of Nadi (near Nawai River), mixed forest occurs, composed of *Cocos nucifera, Pandanus* sp., *Hibiscus tiliaceus, Terminalia catappa* and *Casuarina nodiflora*.

A Government of Fiji EIA study suggests the presence of four distinct habitat types in the mangrove ecosystems of the lower catchment area. This includes inter-tidal estuary, delta, sand and mudflat environments, and sub-tidal litter debris environments (deposited organic refuse from mangrove areas). These different habitat types provide home to some distinct fauna in the lower Nadi River. Some 75% of the river bed is occupied by Kai *(Batissa violacea)*, which is an important subsistence food harvested mainly by women[2] (LWRM, 2001). Other edible molluscs that are commonly found include the ark shell or kaikoso *(Anadara cornea)*. Other species associated with the littoral ecosystem of the Nadi River Delta Area as indicated by local villagers of Sikituru include prawns *(Penaeus canaliculatus, Palaemon concinnus)*, black mangrove crabs *(Metopograspsus messor)*, other crabs *(gari, mana, lairo)* and mud lobster *(Thalassina anomala)*.

Local villagers engage in a wide range of subsistence activities which is dependent on the river and coastal waters. Land based subsistence activities contribute to their livelihood. The main source of subsistence activities includes shellfish collection, crab collection, crop farming (mostly vegetables) and animal husbandry. Fishing in the Nadi River as well as the reef and coastal areas is an important activity for the villagers and Nadi community. This is an important source of protein in the daily diets. Women are predominantly engaged in net fishing, with men using line and spear fishing. Many species of plants in the catchment area are grown for use as traditional medicine to treat common illness. For example Bau leaves are used for sprains and simple dislocation, uci is used for inhalation and wild ginger is used to treat stomach upsets and diabetes (LWRM, 2001). Tourism is the largest industry in terms of source of income for people in Nadi, with many people employed by resorts and hotels, the international airport, and businesses and retail outlets. Employment in the public sector (health, education, police) is another common occupation, together with the sugarcane industry as the largest export crop from the Fiji Islands.

Like many other parts of Fiji, land in Nadi is customarily owned, and the Vanua (land, people and custom)[3] defines amongst other things people's association with the environment, each other and a sense of their cultural identity. These provide what Lane (2008) calls 'a flow of cultural process values' and their belonging to customs and way of life termed commonly as the 'Pacific Way'. Coastal lands and seas are often designated as informal protected areas or *'qoliqoli'* by the chiefs of villages. The villages of Narewa, Namotomoto, Navoci as well as several others are connected to the coastal areas through customary land ownership and fishing rights (Veitayaki, 2002). This also includes the right to use the mangroves for traditional purposes, e.g. for firewood, dyes and medicines.

The unique form of land tenure in the area has important implications for both economic development and environmental management of the Nadi River Basin. The main natural resources managed by the government and others are largely those that belong to local village clans. Consultation on development proposals usually involve consulting with the villagers and the Native Land Trust Board. In many cases development cannot proceed without approval or consent of the local villages, with benefits (compensation, employment and small village development grants) promised to them. Providing local communities the opportunities for environmental planning in their locality, by utilising the very complex systems of traditional leadership, community cohesiveness and land ownership, is essential for sustainable management of the resources and the livelihoods dependent on them (Levett, 2004).

Vulnerability to and impacts of climate change

Fiji's location in the Pacific makes it vulnerable to both seasonal and inter-annual variations in climate. Expert analysis of recent climatic trends reveal an array of anticipated impacts of climate change which includes a number of scenarios that have been made both at national and regional level in recent decades. A judicious review of literature on the different scenarios for temperature, precipitation and sea level suggests that there is no single projection that could be cautiously interpreted for the purpose of planning (Feresi et al., 2000; Government of Fiji, 2005b; Agrawala et al., 2003; IPCC, 2007a). There is a high degree of variation and uncertainty in making projections for these three parameters for the Fiji and the Pacific region, which is reflected across different scenarios ranging between mid-range to high emissions scenarios. While in general these projections suggest that sea level will rise and temperatures will increase in Fiji and the rest of the Pacific, there is variability both spatially and temporally.

Of importance is the phenomenon of floods and storm surges in Fiji, which may experience changes in frequency and intensity as a direct result of climate change, accelerated sea-level rise and increased frequency and intensity of cyclones. Floods have often been associated with cyclones. Over 160 floods from 1840 to 2000 have been recorded by the Fiji Meteorological Service (2001), an average of ten floods per decade. From 1970 through 2005, 53 tropical cyclones tracked through Fiji's waters, of which 79% occurred between 1980 and 2005. From an island biogeographic and geomorphologic perspective this is a frequent occurrence. Similar observations have been made by Ravuvu (1993) who reports that the frequencies of cyclones increased with as many as ten cyclones affecting Fiji between 1981 and September 1989, an average of 11.4 per decade. This increase, which is similar for most other parts of the Pacific islands region, may be related to increasing sea surface temperatures.

[2] Shellfish forms an important diet and source of protein for local villages and settlements and a regular sale commodity at the Nadi market. It is customary for women and young children to take the lead role in the collection, marketing and sales of shellfish. Conversations with locals reveal that kai is now in decline after regular floods, siltation of the river and presence of waste oil and plastic litter in the Nadi River.

[3] The term Vanua refers to the connection of Fijians with the land through their ancestors, customs and guardian spirits.

Cyclones in Fiji often produce extreme rainfall events resulting in severe floods. Terry and others (2003) explain that the strength, longevity, proximity of track to land and organisation of cyclones determines and delivers contrasting total rainfall patterns and maximum intensities. In general, with greater intensities of cyclones, higher magnitudes of rainfall are imminent, which produce big flows in Fiji's rivers.

Another concern is the higher rate of lateral seawater inundation in some coastal villages around south-western Viti Levu. Observations made by Nunn (1993) indicate that the villages of Namoli, Natunuku and Navutu suffer from lateral inundations of 5.61 cm/yr, 4.17 cm/yr and 4.09 cm/yr respectively. These rates of lateral inundation, however, cannot be related to vertical sea-level rise due to insufficient precise data linking trends of rising sea level with the warming occurring in the Pacific. Nunn (1993) however, remains adamant that the rate of vertical sea-level rise will increase by a factor of 2 or 3 in the next 40–80 yrs due to global warming.

Flooding resulting from cyclones, storm surges and sea-level rise today tends to extend beyond major catchment and floodplain areas to residential areas and townships. It is also expected that the progressive removal of forest cover across catchment areas may cause peak and extreme floods in the future (see Waterloo et al., 2007). According to JICA (1998), deforestation in the basin creates an estimated soil loss of 87 ha/yr. Gravelle and Mimura (2008) evaluated the extent of inundation and flooding taking account of tide and return intervals of possible storm surges for the entire island of Viti Levu under different IPCC projections (IPCC, 2001, 2007a) using Digital Elevation Models. The results of their analysis indicate that most of the major towns and cities in Viti Levu, which includes the capital Suva, Nadi, Lautoka, Navua, Likuri Harbour, Nailaga (near the town of Ba) and Tavua, are at high risks of flooding resulting from climate change, sea-level rise and occasional storm surge events.

The above vulnerability to flooding is due to the location of the towns and cities along the prime coastal and watershed plains. Protecting local areas from floods by such small townships has high financial costs (both at municipal and national level). Gravelle and Mimura (2008) conclude from their work that for such reasons it is often the smaller rural communities like Tavua and Nailaga that find it harder to take adaptive measures. Furthermore, if development is allowed to proceed in areas subject to relatively frequent flooding, the damage to property and the economy will increase. The rise in global mean sea level and intensification of extreme weather events will be one of the most significant effects for island nations like Fiji, with its reliance on coastal resources. In addition, the above projections for Viti Levu makes many coastal villages as well as those living in the lower outer islands more vulnerable to rising sea levels, intensified coastal erosion and flooding.

With the increased intensity of floods throughout various parts of the country over the past years as well as future projections, flooding has become a high priority issue for the Government of Fiji. What appears to be a regular occurrence (almost as an annual event), floods are often associated with episodes of severe weather phenomena, such as slow moving tropical depressions and cyclones that are characterised by high intensity rainfall[4]. Floods have caused loss of life and significant damage to property and infrastructure as well as disrupted economic activity and affected the lives of communities on the Fiji Islands. On average Fiji is estimated to suffer a mean of 10 fatalities and around FJ$ 20 million worth of total damage to infrastructure, agriculture and homes per year from flooding (SOPAC and MRD, 2008).

[4] Most rivers and streams in Fiji are relatively small in size (<1,000 km²) and flow from steep mountainous terrain. High intensity rainfall together with the small size and steepness of streams and rivers lead to a swift rise and fall of water levels. The time between rainfall and floods can be as short as three to four hours. Flash floods are thus pretty common especially during the wet season (November to April).

In January 2009, a slow moving tropical depression resulted in heavy rain causing flooding in the Western, Northern and Central Divisions of Fiji. This was reported as one of the worst floods in Fiji since the 1930's, with most of the low lying areas experiencing flood levels of up to 3–5 metres (Government of Fiji, 2009). The impact was greatest in the Western Division with costs estimated at about FJ$ 81 million. Nadi was one of the most affected towns, where businesses suffered a loss of over FJ$ 200 million (Government of Fiji, 2009). Lal et al. (2009) estimate the total economic cost of the January 2009 floods on the sugar industry (infrastructure, losses to growers and millers) to be FJ$ 24 million. The authors further add that the floods only worsened the situation of Fiji's sugar industry due to loss in price 'subsidies' and National Adaptation Strategy aid[5] from the European Union (EU). With such vast devastation of major townships, visitor arrival numbers declined. The total rehabilitation cost was about FJ$ 73 million, diverting a major portion of government budget. Additionally, humanitarian costs of about FJ$ 5 million were incurred. Most rehabilitation works are still continuing, with assistance from donors and development partners.

The floods had a devastating impact on the national economy as well as the lives of Fijians. A key interpretation in post disaster assessments was that economic loss was of great significance to the community, representing their greatest loss (Lal et al., 2009; Government of Fiji, 2009; FMS, 2009). Holland (2009) argues otherwise and states that apart from monetary losses, extensive trauma arose from the floods within communities, and possessions of intangible and cultural benefit to communities were lost. Items such as *masi*, wedding tapes and photos, which hold sentimental value, had been lost forever by people. At the height of the January 2009 floods, 169 evacuation centres were established, which catered for 11,458 people (Government of Fiji, 2009). A total of 146,725 people (about one-fifth of Fiji's population) of which 58,401 of were children, were directly affected by the floods in the Western and Central Divisions. Nationwide, 11 fatalities occurred. As such the Government of Fiji declared a 30 day state of natural disaster for the western parts of Fiji.

The January 2009 floods increased community hardship. Lal et al. (2009) report that about 42% of flood-affected farmers struggled to meet their family's basic food need following the 2009 floods. This represents 77% of the flood affected sugarcane families that are now moving below the basic needs poverty line. This suggests that the flooding has pushed many below the poverty line, while further increasing the hardship of those already living below the poverty line. As such, current social vulnerabilities of many people in certain localities of Fiji may be perpetuated, or exacerbated by their temporary living conditions which are susceptible to environmental shocks, such as further flooding, and socio-economic challenges such as rising food prices.

A survey of the Nadi area by LWRM (2001) indicates that most villagers are concerned with the negative impact of floods on the sources of livelihood. They expressed concern about the impact of floods on the populations of prawns, crabs, fishes and shellfish. Other impacts mentioned by the villagers included erosion of the river banks, channel sedimentation, loss of fertile crop lands, loss of property, impacts on river health and biodiversity, disruption in water supply and electricity, and constant water logging of low-lying areas. In 1999, the estimated cost of damages from floods amounted to FJ$ 200 million, with about FJ$ 296,900 worth of damage done alone to cash crops. The report adds that there is a degree of frustration amongst the villagers, settlements and businesses in Nadi, as despite several surveys and meetings, little has been done to address the issue of floods. Similar impacts have resulted in the 2009 floods, where

[5] These funds are subject to release to Fiji by the European Union based on the election of a democratically elected government.

total losses inclusive of business and household are estimated to be FJ$ 244 million (Holland, 2009). These costs include loss of income, evacuation, relocation, loss of assets, medical and structural damage. Flood hazards are also putting major pressure on current and planned developments. This also has ramifications for the whole Pacific region given Nadi's key position as a gateway to the Pacific, commercial link to other islands and regional hub for tourism and weather forecasting.

Actions taken to respond to the impacts of climate change

The Nadi River Basin is a pilot area for the implementation of the Pacific Integrated Water Resources Management (IWRM) programme. Integrated Water Resource Management (IWRM) is a coordinated approach to manage water, land and their connectivity and ecosystem services through policies, laws and regulation, stakeholder participation, and incorporation of elements such as science, technology, economics, culture and society (UNEP, 2006). The Pacific IWRM programme works with 14 Pacific Island Countries. In Fiji, the main objective is to improve flood preparedness and integrate land and water management planning within the Nadi Basin (SOPAC and MRD, 2008). In Fiji the programme has adopted a stress reduction approach which seeks to implement initiatives such as upgrading of the hydro-climate monitoring system, development of rainfall-runoff prediction and flood warning system models, capacity building for land management, mapping and ecological assessment of mangroves. The aim is to develop the first Nadi Basin Flood Management Plan through stakeholder participation (SOPAC and MRD, 2007).

Following major lobbying by the Nadi community, the Fiji Government has also embarked on an ambitious dredging programme of about FJ$ 3.3 million for the Nadi River mouth. During the first phase of the project a total of 1.8 km of the river mouth was excavated to remove 365,000 m^3 of sediment (The Fiji Times, 2010). Dredging is viewed as the cheapest and most immediate solution to the flooding problem by the Government of Fiji (NTC, 2007). Along with the dredging works, other projects like the rehabilitation of the Mulomulo Dam and the construction of a new dam in the Nadi watershed and repair of river bank protection works are in progress. By virtue of concern, municipal action by the Nadi Town Council (NTC) has also been demonstrated through a series of environmental initiatives included in its Strategic Development Plan. This includes promoting a clean and safe environment of high quality, including managing floods, as a key priority to make Nadi a better town to live in. Together with the Japanese International Co-operation Agency (JICA), the NTC has been working in the basin to allocate flood water areas to collect or store water during floods. The impact, cost-benefit, and effectiveness of the dredging work is yet to be evaluated, especially for large flood events such as those experienced in January 2009.

Despite these actions, progress to address the flooding problem is minimal given the likelihood of repeated and possibly increasing floods in the future. New management awareness and practices are at present restricted to municipal areas, with the vulnerable smaller communities and villages outside the town boundaries left out of the planning and implementation process at present. The escalating social and economic impact of floods in Nadi implies low community and municipal resilience when faced with climatic extremes. This lack of resilience needs to be recognised and understood in order to develop human and institutional capacity through a combination of structural, physical, economic, social, political and institutional responses.

In Fiji, ecosystem-based approaches have largely been applied in marine and coastal initiatives utilizing conservation mechanisms such as marine protected areas (Fiji Locally Managed Marine Area [LMMA] networks[6] and the Vatu-i-Ra Heritage Seascape Project), mangrove rehabilitation (e.g. along the Coral Coast), Integrated Coastal Zone Management (e.g. in Natadola), with a small number of programmes focusing on watershed protection and water purification (e.g. Sovi Basin, which is one of the largest watersheds in Fiji and the source of three major rivers – Nadi, Rewa and Ba) (Lees, 2007). Recent research also calls for Ecosystem-Based Management (EBM) to be applied in rivers and terrestrial systems in Fiji rivers, however, from the perspective of species conservation (Jenkins et al., 2009). It is safe to conclude that EBM approaches have not been popular for adaptation initiatives in Fiji, largely due to a lack of understanding on the practicality of the approach and shared vision amongst stakeholders on the recognition and value of ecosystem services. Although ecosystem-based management approaches may lead to the better management of floods in Fiji, successful implementation depends on improved understanding and stakeholder acceptance. A framework to integrate multi-level scientific knowledge about ecosystems and the services they provide matched to stakeholder preferences is needed.

Results

The Pacific IWRM programme is a new programme and concept for Fiji and the Pacific Island Countries involved. The programme started in 2008 and is in early stages of implementation in Fiji. The programme focuses on identifying and clarifying the risks associated with floods in Nadi and integrates management activities in the river basin with community livelihood needs. An important result of the IWRM process has been the development of a multi-sectoral coordination and governance approach through the formation of the Nadi Basin Catchment Committee (NBCC) (Fig. 3). The NBCC has been viewed as a positive move by all stakeholders and has provided a broad partnership for the basin in the area of agriculture and land use, forestry, urban planning, water quality management and issues on land tenure (Chandra, 2010). Through its activities, the NBCC is designed to evolve into an effective decision-making entity able to work across traditional institutional boundaries and with a wide variety of stakeholders on issues relating to the environment (SOPAC and MRD, 2007. As a platform for collaboration, the NBCC comprises stakeholder institutions which are able to share information on climatologic, hydrological, geophysical aspects as well as best practices across sectors. One challenge the NBCC faces is moving the dialogue beyond predominantly Government agencies in order to secure the active engagement of those most affected by flooding. Efforts must also

Figure 3. Nadi Basin Catchment Committee (NBCCC) meeting comprising multi-stakeholders from national and local levels (Chandra, 2010).

[6] The LMMA is a network of marine conservation projects across coastal communities that began in 2000 in partnership with NGOs and government departments. Traditional taboo or protected areas were established in qoliqoli's and community management groups have worked with scientific researchers to monitor and manage the coastal biodiversity over a period of two to three years. Coral reef rehabilitation and resilience measures have been applied to design a network of marine protected areas to help the marine ecosystems withstand the impacts of a warming ocean and continue to provide food and other resources to local villages and markets (Veitiyaki et al., 2003).

improve on more effective communication and coordination across different sectors.

To better understand climate variability, stakeholders have also engaged in improving monitoring of rainfall and hydrological events for better flood forecasting. A substantial commitment is shown by project partners to raise awareness on flood issues as well as building resilience of local communities through participatory planning at village level. The NBCC and GEF project funded staff will provide technical assistance to local village communities in the identification of water and sanitation, waste management and development priorities. Discussions are also progressing towards development of a Nadi Basin Flood Management Plan, which is a first for Fiji.

As explained by SOPAC and MRD (2008), the process of actively engaging the different stakeholders in climate change adaptation is not straightforward as river catchments in Fiji are arbitrary units varying greatly in size, tenure and livelihood options. Additionally, catchment boundaries and ownership often conflict with traditional, cultural, religious, political and ethnic boundaries (Pacific Islands Applied Geoscience Commission, 2007). This creates institutional problems and makes long-term planning for adaptation difficult. Current management lacks cross-sectoral coordination, collaboration and integrated mechanisms to address the impacts of climate change which has not received until recently adequate attention in Fiji's policy making (Kailola et. al., 2008). In order to address this institutional gap of implementing integrated strategies, there is a need to understand the different stakeholder perceptions on climate change vulnerability and adaptation in the Nadi River Basin.

While management for floods and disasters has been decentralized to provincial level in Fiji, involvement of communities in this process is still very limited. Risk management as regulated in national legislations is still based on the primacy of centralized state authority and is challenged by village level governance. The recent decentralization initiatives still have a long way to go to change this aspect of management.

Intact mangrove systems with grooves, channels, wet riverbank areas, extensive muddy areas and drier areas provide protection for villages and resort properties.

Conclusions and Recommendations

The Nadi River Basin is extremely vulnerable to the current and future impacts of intensified flooding. Current cooperation structures for adaptation initiatives (at community and sector levels) for Nadi are in early stages of responding to the floods that are intensifying in Pacific SIDS. Non-climatic pressures such as development, social change, agriculture, tourism growth and deforestation are increasing the vulnerability of the river basin to climate impacts. Community groups such as farmers, villagers, and squatter settlements are dependent on a range of resources and income derived from the catchment resources. This makes them more vulnerable as they continue to develop and derive livelihoods from natural resources that are at greater risk to extreme events and are often not included in planning and management frameworks.

This brief analysis shows that adaptation to floods and other climate induced hazards has been a slow process, and is not a prominent issue within the broader policy level discussions. For further research and management of the Nadi River Basin and other basins across Fiji, there is a need for more in-depth qualitative and quantitative research on vulnerability factors in the river basin. This includes time series analysis of climatic variables, vulnerability factors, hydrology, mangrove cover as well as development of climate models and collection of demographic and socio-economic data. Scenario-based adaptation plans can be helpful in handling some of the uncertainties (Lebel et al., 2009).

In conclusion, adaptation to climate change impacts in the Nadi River Basin has developed good potential for action. The kind of structure required to build the social networks and enhance capacities to cope with the impacts of increasing intensity and severity of floods may be achieved through the strengthening of the Nadi Basin Catchment Committee. Such an approach needs to ensure that risk reduction, links between knowledge and practice, and capacity to cope and respond will be strengthened via empowerment of people and institutions. The IWRM Programme has an opportunity to showcase the challenges and management improvements required for building adaptive capacity at government to community level. Avenues for regional cooperation and sharing of traditional knowledge, best practices and data to remove barriers to adaptation should be explored and initiated.

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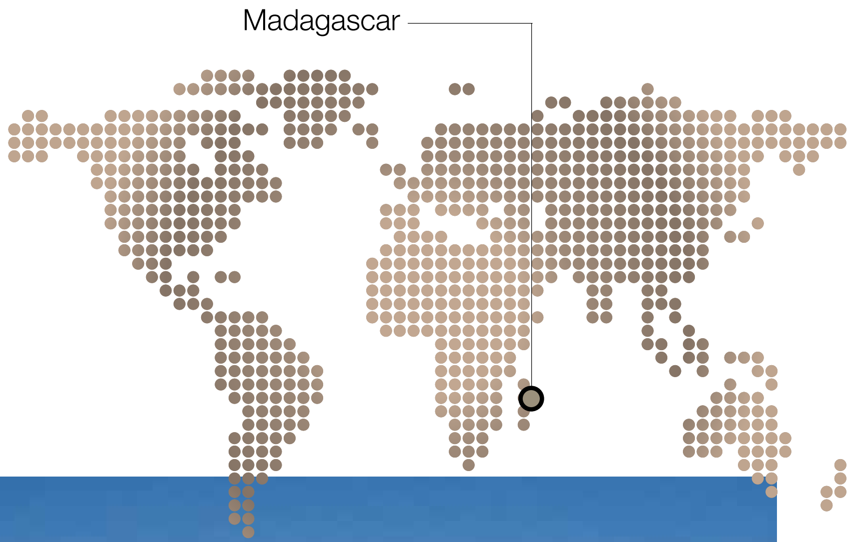
Chapter 5



Climate Adaptation for Biodiversity, Ecosystem Services and Livelihoods in Rural Madagascar

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The project presented in this chapter tests adaptation recommendations emerging from a two year, multi-organizational effort to assess the vulnerability of biodiversity and rural livelihoods to climate change in Madagascar. The focus of the project is a series of pilot tests to further our understanding on ecosystem adaptation and Ecosystem-based Adaptation (EbA) for communities. The highest priority needs for enhancing ecological resilience to climate change for terrestrial systems is to maintain existing habitats and increase forest connectivity throughout Madagascar. This is particularly true for future zones of similar climate areas to allow for species' range shifts and ecosystems critical for the continued provision of vital services. Thus, in addition to protecting existing forests, facilitating species adaptation will involve restoring habitats in degraded landscapes to increase forests connectivity. One of the important zones for protection and restoration identified are riverine forests based upon the hypothesis that these forests could play an important role in facilitating the movement of species in response to climate change. Through this project we are conducting an inventory of the existing riverine forests and the extent of fragmentation to identify those that could serve as potential migratory corridors for species.

We are analyzing lessons learned from different forest restoration efforts implemented across the island to identify the most promising approaches to enable scaling up of restoration efforts. Applying lessons learned on forest restoration costs, techniques and community benefits derived in representative ecosystem types across the country will inform the development of detailed, site specific restoration plans for improving forest connectivity. We assess the effectiveness of sustainable livelihood activities in supporting livelihoods as a means of enhancing socio-economic resilience, and reducing pressure on existing forests. Some of the test activities under review include facilitating market access for farmers, demonstrating the feasibility of eco-agricultural techniques as alternatives to tavy and introducing agricultural diversification options. Finally, our project considers the potential increase in pressure on natural forests as a result of human adaptation needs in response to climate change driven food security risks. This analysis is based upon agricultural crop models of future distributions and community experiences of productivity changes driven by climate change. The results from this component will help identify priority regions where human needs and conservation planning under climate change will need to be addressed jointly.

Keywords: Climate Change Adaptation, Conservation, Biodiversity, Forest Connectivity, Forest Regeneration and Restoration, Madagascar, Sustainable Livelihood

Introduction

Madagascar, the fourth largest island in the world and a nation of over 20 million people, is known around the world for its remarkable biodiversity and considered by many to be a naturalists' paradise (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). A diverse range of bioclimatic zones support unique habitats ranging from the spiny forest of the hot and sub-arid western part of Madagascar to rainforests in the central plateau. At the same time, it is one of the most impoverished countries in the world with over 75 % of its population living in rural areas and subsisting on agricultural production, or on coastal and inland fisheries.

Continued deforestation over the last fifty to sixty years (Harper et al., 2007) combined with many other land use pressures has placed the natural habitats of this island nation under great threat. These land use changes, including mining, and resource extraction pressures compromise the delivery of ecosystem services such as water provision, flood regulation and erosion control, and ultimately undermine the well being of a majority of the country's population. To stem this loss of unique biodiversity and critical ecosystem services, the Government of Madagascar is committed to tripling the nations' network of marine and terrestrial protected areas (PAs) within a period of five years (2003–2008), a plan often referred to as the "Durban Vision". However, the long term success of such a network of protected areas depends upon the continued resilience of the PAs to the direct and indirect impacts of climate change and consequential land use changes.

Madagascar is now faced with the task of understanding the implications of climate change to its ecosystems and economic sectors, and putting in place policies to promote resilience and adaptation. Climate change is expected to exacerbate pressures on human development and food security faced by the people in Madagascar. At the same time, it also enhances the need for habitat protection and restoration, not only to facilitate species migration, but to maintain important ecosystem functions and services under different climate scenarios. With its high biodiversity and high human dependence on agriculture, fisheries and local ecological resources for survival, Madagascar is faced with immediate challenges for both human adaptations to climate change and for adapting biodiversity conservation and ecosystem management.

With these needs in mind a two year vulnerability assessment (VA) and adaptation planning process was initiated in 2007 by Conservation International (CI) and the World Wildlife Fund in the United States (WWF-US). The main goals of the VA and adaptation planning process (referred to as Phase 1, in this paper) were to identify the specific impacts of climate change on Madagascar's ecosystems and tightly interlinked livelihood sectors such as agriculture and fisheries, and to integrate climate considerations into the PA expansion process. This assessment was followed by a second ongoing project (Phase 2) to test the feasibility of implementing several recommended adaptation options and, in some cases, to fill critical information gaps identified during the vulnerability assessment by CI and partners.

While the overall project in Phase 1 and Phase 2 includes a focus on both marine and terrestrial ecosystems and associated livelihoods, here we focus our discussions only on the terrestrial systems. In a second section in this chapter we discuss the results of this assessment and adaptation planning initiative, which the authors led in collaboration with partnering non-governmental organizations (NGOs), the Government of Madagascar, the John D. and Catherine T. MacArthur Foundation, and the United States Agency for International Development (USAID). The third section of this paper focuses on the current phase of our project and details a set of feasibility studies and analyses designed to test the terrestrial adaptation recommendations emerging from Phase I.

The objectives of the vulnerability assessment and preliminary adaptation planning process in Madagascar were to:

1. Identify likely impacts of climate change on specific species and ecosystem types;
2. Identify likely impacts on rural livelihood sectors; and
3. Identify and/or develop adaptation responses.

Results and Discussion

Vulnerability Assessment (VA) and Adaptation Planning

To achieve the objectives mentioned above, an integrated vulnerability assessment (VA) and adaptation planning process was implemented. This process engaged researchers and stakeholders from different focal areas, such as ecologists, rural development specialists, community representatives and conservation practitioners from across Madagascar. Four major focal areas explored during the assessment were the vulnerability of specific taxonomic groups and their critical habitats, and agricultural and fisheries based livelihoods across Madagascar.

The outcomes of this assessment included:

> Provision of the most up to date future climate and oceanographic scenarios for Madagascar;
> An understanding of the implications of climate change in terrestrial and marine species distribution, and their population and habitat shifts in Madagascar;
> Development of recommendations for adapting to the impacts of climate change in Madagascar, to support ecosystem management, protected areas (PA) planning and climate resilient livelihoods.

We first provide a brief description of the methodology used to carry out this assessment followed by a discussion of projected climate change scenarios, key issues of vulnerability for people and biodiversity, and adaptation responses identified during the assessment.

Methodology

The vulnerability assessment (VA) methodology developed for this project involved a series of steps and the use of a variety of tools to aid in qualitative and quantitative information collection and analyses. The assessment started with a detailed scientific literature review to synthesize existing information on expected climate change impacts and the vulnerability of specific habitats and ecosystems types in Madagascar. A review of literature helped identify information gaps and needs, some of which could then be filled by conducting specific analyses, such as modelling future species' distribution. In parallel to the advanced analyses, consultations with communities in three different bioclimatic zones of Madagascar were conducted. These consultations provided necessary information about the vulnerability of local livelihoods and rural production systems to increased climate variability and climate change. A report summarizing community level perceptions, concerns and recommended actions to support communities in responding to climate change impacts is available via USAID's International Resources Group information portal (Combest-Friedman, 2008). The vulnerability assessment culminated in a technical workshop that brought together the diverse expertise and interests of local communities, policymakers and researchers to discuss and validate the results of advance analyses, provide additional insights and recommend adaptation actions to build community and ecosystem resilience to climate change.

Climate Projections

Projected changes in climate for Madagascar by 2046–2065 show warming across the island and areas of both increased and decreased precipitation (Tadross, 2008). Southern Madagascar is projected to have the greatest warming, with the coast and north showing lower projected temperature increases. Precipitation increase is centred in the northwest, while drying is projected in the east. Together the minimum and maximum temperature changes (Fig. 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 southern interior of the country, indicating that the maximum expected change varies more depending on the spatial location than does the minimum expected change.

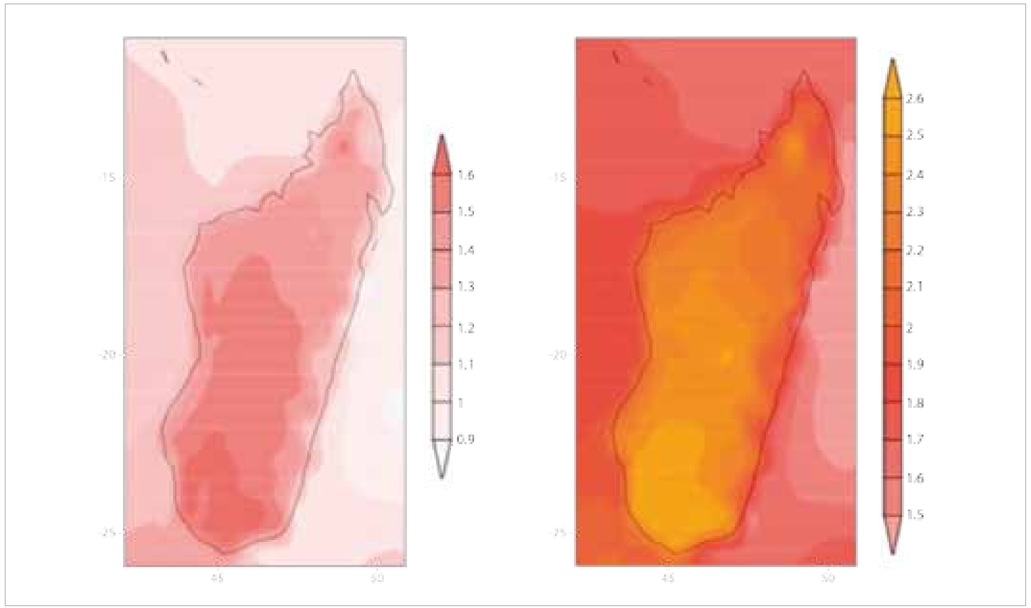
These spatial characteristics are significant because the south is already the driest region in the country, while the eastern forest is highly fragmented and vulnerable to drying. Hence, regions already under stress from an ecological and human livelihoods' perspective are likely to be facing greater climate pressures.

Key Issues of Vulnerability for Ecosystems and Rural Communities

There are several factors influencing biodiversity and human vulnerability to climate change in Madagascar. In Madagascar, like elsewhere, climate change is expected to impact range restricted and high montane endemic species the most. Repeat observations of amphibians and reptiles in 1993 and 2003 suggest that high montane endemics, found within 600 m of the peak of the highest mountains are susceptible to warming (Raxworthy et al., 2008, as cited in Hannah et al., 2008). Additionally, aquatic species utilizing seasonal lakes as habitat in regions projected to experience longer dry seasons are also at risk.

Deforestation has been recognized as the primary threat to the last remaining habitats of many highly endangered and endemic species. Small mammals and primate species with restricted ranges and low dispersal abilities are likely to be even more vulnerable to loss of habitat and fragmentation of forests under climate change, and many species found in the north and west of Madagascar 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. While preliminary analyses of changes in tree phenology correlated to

Figure 1. Minimum and maximum temperature changes projected for Madagascar during the period 2046–2065 (Tadross, 2008). Lowest expected temperature changes are presented in the map at the left, while highest changes are presented in the map at the right. For an interpretation of both maps, please see the corresponding text section.



increases in temperature over a 20 year period in Ranomafana National Park showed no discernible patterns, correlations between lemur survival and a decrease in rainfall has already been observed and recorded (Wright, 2007).

Preliminary models of changes in the distribution of a subset of endemic plant species' indicate significant shifts in suitable climate space by 2080 in nearly all cases (Schatz et al., 2008, as cited in Hannah et al., 2008). In addition to expansion and contraction of certain species' ranges, shifts and migration along altitudinal and moisture gradients are likely scenarios (modelled analyses, cited in Hannah et al., 2008). Hence, a comprehensive assessment of climate change adaptation options for plant species needs to consider the ability of species to migrate as they track suitable climates, for which maximum connectivity of current habitat patches is required (technical workshop conclusions, discussed in Hannah et al., 2008). Regions within Madagascar were identified by experts as a high priority for managing current pressures and future impacts of climate change, either because they were thought to be particularly resilient or vulnerable.

Climate change is likely to increase the challenge of ongoing poverty alleviation efforts in Madagascar and threatens to undermine progress made towards achieving the Millennium Development Goals (MDGs). Social resilience is linked closely with the resilience of ecological communities which is especially apparent for communities dependent more directly on natural resources (Adger, 2000). Survey findings together with expert insights point to a particularly high vulnerability among climate sensitive livelihood systems like agriculture and fishing communities. Madagascar has long experienced widespread slash and burn agriculture (locally known as *'tavy'*), identified as the primary driver 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, together with its low input nature are factors contributing to a perpetuation of *tavy* (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 fed agriculture as more vulnerable to changing seasonal precipitation patterns. Within these mainly subsistence communities, those groups that are even more marginalized, for example, households headed by women, young children, the elderly and the disabled, will be at a higher risk of not being able to weather increase climate shocks (Combest-Friedman, 2008, as cited in the workshop report prepared by CI and WWF-US).

Cyclones are expected to increase in intensity over the long run, as is the intensity and frequency of flooding, and the variation of temperature and rainfall. These changes will negatively impact soil fertility and agricultural productivity, particularly in highland areas where increased rainfall coupled with deforestation is decreasing soil cover through erosion. Increased sedimentation of rivers and coastal waters is also possible, yielding detrimental impacts on fisheries and access to water. Variation in rainfall and temperature (along with increased cyclone activity in some regions) has already led to shifts in the farming calendars of local farmers, and consequently an increase in instances of crop failure. In the South and highland areas, droughts are projected to increase in intensity, frequency and duration. Locust and pest invasions are also expected to increase in the Southern regions of Madagascar, both leading to more pressure on farmers in the region (Conservation International and World Wildlife Fund-US, 2008).

Finally, an issue flagged for further attention was an analysis of potential conflict and/or synergies between regions within Madagascar, considered important for both human needs such as agricultural production changes and priority natural habitats, necessary for maintaining corridors of connectivity to facilitate species' migration as an adaptation response. Where these areas overlap considerably responses to avoid conflict and maximize human welfare and conservation goals are needed, and one potential way forward is the use of Ecosystem-based Approaches (EbA) for adaptation.

Outcomes of the Assessment: Adaptation Responses to Secure Species' Survival and Ecosystem Services for Rural Livelihoods

A central goal of the vulnerability assessment was to develop processes for identifying areas for protection that can serve as important areas for habitat corridors in the future. Biodiversity conservation and rural development in Madagascar are closely interlinked and climate stress is likely to impact both severely. Hence, in addition to understanding the potential direct impacts of climate change on both, our interest is to identify adaptation processes and scenarios where EbA approaches can support both people and nature in adapting to climate impacts.

Specific recommendations from the vulnerability assessment for securing species' survival and the maintaining critical ecosystem services included reduction of deforestation pressures within all remaining natural forests, maintenance of connectivity between forest patches, and restoration of important forest areas, including riverine forests to facilitate species migration. Riverine forests are thought to have played an important role in the survival and dispersal of species under past climate change (Wilme et al., 2006). Thus, a specific recommendation of the assessment was to understand the extent and condition of Madagascar's riverine forest habitats and their potential to serve a similar role under future conditions of temperature and precipitation changes.

Protected area (PA) management over the recent past has been decentralized and communities are now playing an active role in managing both the protection and use of biodiversity and natural resources. In order for communities to benefit from any program that focuses on reduced emissions from deforestation and forest degradation (REDD) or reforestation, land tenure issues near high biodiversity areas need to be clarified. Additional recommendations to build community resilience in the face of climate change included supporting regular risk assessments and management strategies, identifying triggers for climate stress induced migration, supporting ecologically sensitive agricultural yield increasing practices, developing micro credit schemes, and building climate resilient infrastructures (e.g. for grain storage, water harvesting, and irrigation channels).

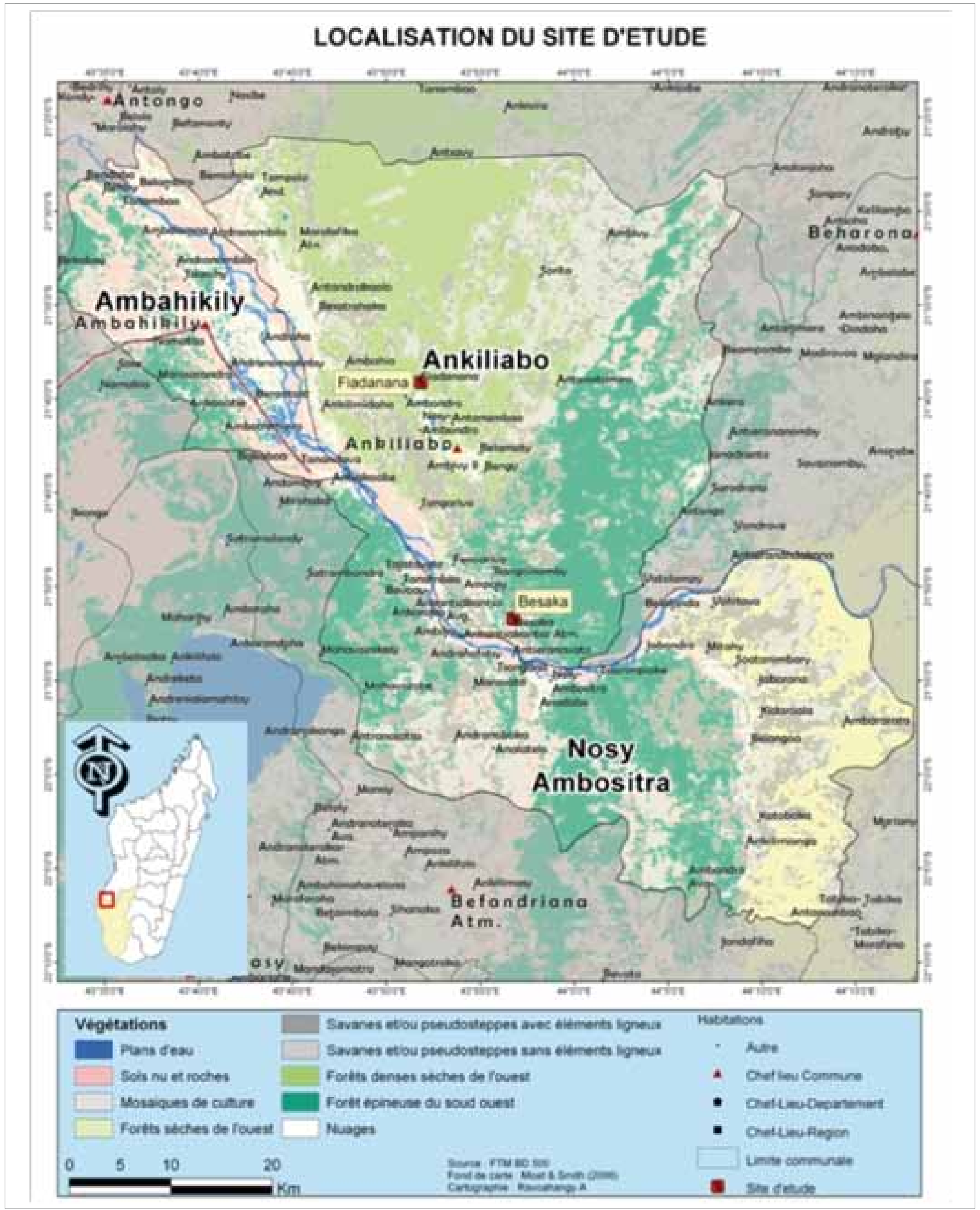
The following section of this chapter is focused on the current project, designed to test the feasibility of the ecological adaptation measures highlighted above, understand the role of sustainable livelihood activities in building agricultural and social resilience, and understand the potential for EbA as a strategy in response to human adaptation needs. The scope of this project does not address issues of land tenure, micro credit schemes and climate resilient infrastructure. Rather our focus is on enhancing our understanding of ecological adaptation approaches and developing supportive ecosystem based community resilience programs that can help both people and nature adapt to climate change.

Enhancing Ecosystem and Livelihood Resilience: Ecosystem-based Approaches for Adaptation

This follow-up project is designed to test the feasibility of recommended adaptation approaches and to develop an action plan for implementing promising strategies.

The most important adaptation response for enhancing the resilience of terrestrial biodiversity and ecosystem services is to maintain existing forests and other unmodified habitats, and increase forest connectivity throughout Madagascar. Maintaining and restoring forests and wetlands are critical for the continued provisioning of vital ecosystem services and for mitigating the impacts of climate change on population centres (for example, reducing water stress by recharging groundwater tables). Within this overarching goal is the implicit connection between functioning ecosystems and the resilience of people living within them. Restoration efforts to increase connectivity should be prioritized particularly for regions of

Figure 2. Map of sites surveyed for riverine forest corridor restoration study and community consultations on forest use, agricultural production and climate change observations.



suitable and similar climate space that species and habitats will need as they adapt to changed environmental conditions under future climate scenarios. Under this objective we also consider the particular challenges of restoring and/or protecting forests that can be considered as riverine habitats.

The provision and uptake of sustainable livelihood options as alternatives to more destructive practices will determine the success of protection and restoration efforts for enhanced forest connectivity. Additionally, through our project activities we plan to further our understanding of how human adaptation needs and responses can interact with existing and future priorities for conservation in Madagascar.

Specifically, we are focusing on the following activities:

1. <u>Feasibility studies to scale up restoration of fragmented forests.</u> This activity includes surveying and testing methods for natural forest regeneration in different habitat types and social settings. The survey includes a detailed evaluation of techniques and effectiveness of restoration projects from each of the major forest types in Madagascar: southern spiny forest, western dry forest and rainforest. In addition, CI has been testing a large scale habitat restoration project in the rainforest region of Andasibe and lessons learnt from this study will inform the development of detailed, site specific restoration plans for improving forest connectivity.

2. <u>A feasibility study to assess the current conditions of riverine forests and their potential to act as migratory pathways for species under climate change.</u> We are conducting an inventory of the existing riverine forests to identify those that could serve as potential migratory corridors for species based on information from updated species' niche modelling analyses and on-the ground surveys. We have identified the remaining forests around rivers, at certain distances from major rivers, based on CI's analysis of 2005 Landsat images. For each of these scenarios we are developing statistics that measure fragmentation and connectivity of the remaining forests. This analysis will provide a scoring of forest connectivity along rivers and can give a useful proxy measurement of the ease with which forest dependant animals and plants might be able to move through a riverine landscape. The statistics are also useful for us to score the effort that is needed to restore a particular riverine corridor and therefore helpful for developing future plans. We used analyses of the current forest connectivity around rivers to identify the Mangoky River as our priority for a more detailed study. Through this process we will have a map of high priority riverine forests and forest fragments for protection and/or restoring connectivity. Another output of this activity will be to develop a detailed restoration plan for parts of the Mangoky River forest corridor in the southwest of the country (Fig. 2).

3. <u>Sustainable Livelihoods Activities (SLA): Testing approaches and evaluating effectiveness of existing measures.</u> Forest restoration activities can only be successful in the long term if the people living around restored areas and areas that are still forested have sustainable livelihood alternatives that provide for their needs without putting additional pressure on natural forests. These sustainable livelihood activities will themselves need to address human adaptation needs in the face of current climate variability and future change. Many conservation projects in Madagascar have tried to develop approaches to reduce anthropogenic pressures on forests, but few have succeeded at scale. This activity is designed to assess the effectiveness of approaches that have been used, test promising approaches and to develop practical outreach materials to promote best practice in the field. Successful uptake of these approaches can support increased community resilience and increase the relevance of restoration efforts for the well being of local forest communities by diversifying livelihood options and providing an additional source of food security. The activities we are evaluating include support for eco-agricultural techniques as alternatives to tavy, introduction of income diversification options such as bee-keeping and fruit trees and efforts to improve market access for farmers living in extremely remote areas. Initial results from a review of various sustainable livelihood activities indicate that farmers recognize both the costs (i.e. more effort initially, to learn techniques) and the benefits (e.g. increased yield and better soil conservation) of these approaches.

4. <u>Human Adaptation Needs: Identifying potential food security issues through community consultations and modelling changes in the distribution of staple crops.</u> Agriculture is a mainstay of Malagasy livelihoods, with rice and cassava being the two most important staple crops in terms of area under cultivation and consumption. Global modelling studies indicate negative yields for major crops in tropical regions, even with moderate temperature increases, and farmers in many parts of Madagascar already experience poor crop yields. This activity is intended to assess the potential vulnerability of staple subsistence and cash crops to changing climate in Madagascar and to improve our understanding of how this might, in turn, drive future deforestation scenarios. Our analysis is based upon both modelling changes in crop suitability distributions and community experiences of changes in agricultural yield and vulnerability under recent climate variability. Community consultations in two sites near the Mangoky River (see Fig 2.) indicate an increased dependence upon forests and forest resources as a result of shorter rainy seasons and much lower rainfall levels over the last two years. While we do not have data over sufficient time periods to conclusively attribute these changes in seasonality to climate change, the actions people are taking currently to cope with reduction in rice and maize yields and their inability to grow staple crops like beans, help us to understand current vulnerability and better plan for future adaptation options. Furthermore, we plan to analyze overlaps between projected crop distribution changes for key crops like rice, and changes projected for species' distributions from updated niche modelling. This analysis, together with information from community consultations and field

Harvesting rosy periwinkle *(Catharanthus roseus)* for use as anti-cancer medicine provides income for communities in the Berenty Private Reserve, Madagascar.

studies, will help inform the identification of priority regions where there is considerable need to manage land use, so as to avoid conflict between human needs and conservation efforts under climate change.

The key outputs from the components discussed above include a comprehensive action plan for enhancing forest connectivity by protecting and restoring forest habitat, including riverine forests, and for supporting the uptake of promising sustainable livelihood activities. Additionally, our second main output will be an analysis of changes in crop distribution patterns and implications for community adaptation needs, and an analysis of the role EbA can play in overcoming food security challenges for priority regions.

Conclusions

Madagascar is now faced with the multiple pressures of meeting critical human development needs and stemming the degradation and loss of habitats and species. Human well-being, functioning ecosystems and climate change are interlinked: conserving natural ecosystems can moderate the impacts of climate change on human communities by maintaining supportive ecosystem functions and services. As biodiversity and habitats decline, so does the resilience of entire ecosystems in many cases, and thus many of the services they provide to humanity (e.g. Adger et al., 2005).

The work discussed here was initiated as, and remains, a collaborative effort on many fronts: between various non-governmental organizations (NGOs), donor aid agencies, the Government of Madagascar, international, national and regional scholars, development practitioners and conservationists. The community engagement aspect of the pilot implementation phase is a critical factor influencing success and future direction. Adaptation responses necessarily need to be and in many cases will be community driven and centred. Integrating biodiversity and ecosystem resilience into adaptation planning can help communities monitor changes in their environment and their access to natural resources. Additionally, EbA approaches to build community resilience can be one way of also supporting adaptation of species and critical habitats.

The vulnerability assessment and adaptation planning phase was conducted at the national scale and thus produced high level recommendations for technical responses and policy support for adaptation. Despite this broad scope and scale of the assessment, the fact that over fifty organizations and community groups were engaged in the technical workshop has ensured that awareness of climate change impacts amongst practitioners, technical specialists and policy makers in the country was raised to a new level. Additionally, the best available science on climate scenarios and the impacts of climate change was combined with information from community experiences of climate change manifested through changes in agricultural production to inform this adaptation planning process. This integrated approach, while broadening the scope of the assessment produced results that were relevant for a wider section of practitioners and policymakers, and have been taken up for testing and implementation by partner organizations in addition to CI.

The results of the current project phase of testing various adaptation recommendations will produce further insights needed to develop a comprehensive adaptation program and process focused on ecosystem and community based approaches in high biodiversity areas of Madagascar. The results and lessons learnt from this project will be integrated into CI's program for adaptation which will work to build community and ecosystem resilience to climate change in Madagascar, provide support to decision makers on adaptation, and inform Ecosystem-based Adaptation (EbA) in other regions of the world.

Further Information

A full report of the assessment is available online and by request from the first author of this chapter. A full list of partners and acknowledgements can be found therein, as well as detailed information on analyses performed, methodology used, and results obtained from the assessment.

Acknowledgements

We wish to thank Dr. Lee Hannah, scientific advisor for the current project and project lead on the vulnerability assessment. We would also like to note that the first project to assess vulnerability and develop preliminary adaptation responses was a joint effort with the World Wildlife Fund (WWF) and funded by the John D. and Catherine T. MacArthur Foundation, in partnership with United States Agency for International Development (USAID) in Madagascar and the Global Climate Change Program of USAID's Bureau of Economic Growth and Trade (EGAT), which led the analyses of livelihood risks. While Conservation International (CI) was the lead on the terrestrial ecosystems' impacts and vulnerability, WWF led the assessment for marine ecosystems. However, all events during the course of the effort were planned and implemented together. Thus, we wish to thank and acknowledge several CI, USAID and WWF staff and consultants for their work on the first project (referred to here as Phase 1). Other partners included the Wildlife Conservation Society (WCS), Missouri Botanical Gardens, the University of California at Berkley, amongst many others.

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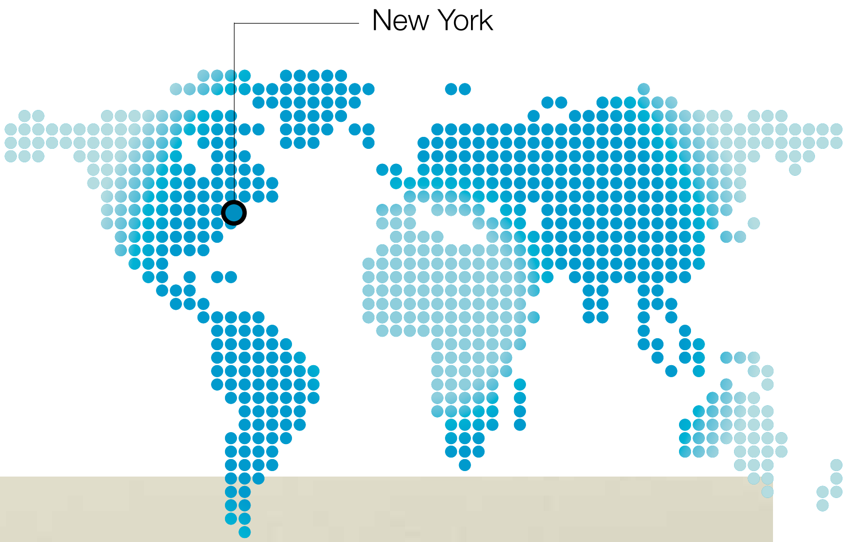
Chapter 6



Adapting to Climate Change

Building Interactive Decision Support to Meet Management Objectives for Coastal Conservation and Hazard Mitigation on Long Island, New York, USA

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The Long Island shores of New York, USA, have highly developed lands in the coastal zone. Much of this private property is only inches above sea level, putting millions of dollars in public and private funds at risk. This also puts coastal wetlands and other ecosystems at risk that provide habitat, natural buffers to storms and other services. Despite a growing awareness global climate change, local decision makers – the primary regulatory authorities on coastal development – still lack the tools to transparently examine different management objectives such as coastal hazards and conservation. Critical information shortfalls limit the options for coastal managers to address climate change-related risks. The costs to human and natural communities are increasing as development continues and natural buffers, such as coastal wetlands and dunes, are lost. Adaptation to coastal hazards has traditionally been undertaken – often unsuccessfully – using shoreline hardening and engineered defences. An alternative approach to built infrastructure, Ecosystem-based Adaptation (EbA), is sorely needed as part of an overall strategy for creating human community resilience in the face of climate change. To address this, the Coastal Resilience project was designed to provide a decision support platform and information to better inform local decision making and the implementation of EbA approaches.

EbA facilitates coastal resilience, the self-organizing ability of a coast to respond in a sustainable manner to morphological, biological and/or socioeconomic pressures. The goal of this project was to design, build and discuss alternative future scenarios that address sea level rise, storm surge, social and ecological vulnerability and conservation priorities. The Nature Conservancy led this effort, working with project partners including the Center for Climate Systems Research (CCSR) at Columbia University and the National Aeronautics and Space Administration's (NASA) Goddard Institute for Space Studies, Association of State Floodplain Managers (ASFPM), the Pace Land Use Law Center, the National Oceanic and Atmospheric Administration's Coastal Services Center (NOAA-CSC), the Department of Geography and Geology at the University of Southern Mississippi (USM) and the Marine Science Institute of the University of California Santa Barbara (UCSB). Through interactive decision support, a web mapping application called the Future Scenarios Mapper allowed local decision makers to examine current ecological, biological, socioeconomic, and management information, alongside coastal inundation scenarios developed from widely accepted climate and hazard models.

The first phase of the Coastal Resilience project, conducted over an 18-month period from January 2008 to July 2009, was guided by the following primary objectives: a) build a spatial database and interactive web mapping application http://www.futurescenarios.org/ that provides decision support for meeting both biodiversity conservation and coastal hazard mitigation objectives, b) construct a website http://www.coastalresilience.org/ that explains the approach, methods, and strategies for EbA to climate change; and c) identify reasonable and viable alternatives that reduce losses and vulnerability of coastal communities for people and ecosystems. At the same time, we conducted an analysis of selected local land use ordinances, regulations, and legal precedent that include specific mention of sea level rise or that incorporate appropriate policy responses that may be used to address the rising seas. Finally, we convened meetings of stakeholders throughout this phase to begin discussing how through interactive decision support important social and ecological characteristics can be compared with sea level rise and storm surge events and visualized within local and state planning processes.

The information presented by the Coastal Resilience Project's web mapping application are intended to advance land use, natural resource management, and emergency response planning when considered and applied according to the needs of local communities on Long Island. We are actively pursuing a five-part approach for designing and implementing EbA strategies on Long Island and in other geographies: 1) amending and passing key legislation; 2) promoting voluntary land acquisition; 3) relocating vulnerable infrastructure and development; 4) engaging in comprehensive, post-storm redevelopment planning; and 5) restoring and protecting natural resources.

Keywords: Climate change, Coastal resilience, Community vulnerability, Conservation, Decision support, Ecosystem-based adaptation, Geographic information systems, Multiple objective planning, Sea level rise

Introduction

Background

Climate change is already driving significant changes to our coasts that will have long term consequences,[1] including rising sea levels and increased storm surge height, intensity and frequency. IPCC (2007) estimates suggest that climate change will lead to increases in sea level from 18 to 59 meters, excluding rapid ice melt; with more repaid ice melt, the increase could be significantly higher (NPCC, in press). Despite a growing awareness of sea level rise (SLR) and coastal storm risks, communities and local decision makers still have only limited access to the full suite of information needed to protect natural and human coastal communities. Critical information shortfalls limit the options for coastal managers to address climate change-related risks through adaptation. Here we present an integrated approach for organizing spatial information in an Internet-based mapping application designed to provide

[1] Climate change here refers to a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer (IPCC, 2007, 2008).

Figure 1. Study area along the southern shores of Long Island, New York, USA. The boundary of the study area is shown in yellow.

interactive decision support among stakeholders concerned about coastal climate issues on Long Island, New York, USA (Fig. 1).

Options do exist for addressing losses and protecting communities through the proactive management of coastal natural resources. In direct response to the need for more comprehensive information to address coastal climate change, an interdisciplinary team from non-government organizations (NGOs), state and federal agencies, and academic institutions formed the Coastal Resilience Long Island project. Project partners include the Center for Climate Systems Research (CCSR) at Columbia University and the National Aeronautics and Space Administration's (NASA) Goddard Institute for Space Studies, the National Oceanic and Atmospheric Administration's Coastal Services Center (NOAA-CSC), the Association of State Floodplain Managers (ASFPM), the Department of Geography and Geology of the University of Southern Mississippi (USM), the Marine Science Institute of the University of California Santa Barbara (UCSB), and Pace University's Land Use Law Center. Through interactive decision support, web mapping applications allow users to examine current ecological, biological, socioeconomic, and management information alongside coastal inundation scenarios developed from widely accepted climate and hazard models.

The gradual nature of sea level rise creates a risk that communities will ignore until it is too late for a thoughtful and well-planned response. Storms are harder to ignore but easy to forget in the calm periods between major events. This case study focuses on climate change impacts on Long Island, its effects on ecological and socioeconomic resources, and how The Nature Conservancy (TNC) and its partners are engaging local communities to develop Ecosystem-based Adaptation (EbA) strategies.

The Issue

Long Island's south shore supports a diverse array of marine and coastal organisms and habitats. The area is home to significant island and fringing salt marshes, with eelgrass beds just offshore. A number of beach-dependent birds come to south shore beaches to breed and feed during spring and summer months including the federal and state listed piping plover, least tern, and roseate tern. In addition, the south shore bays support populations of shellfish and finfish that are important recreational and commercial resources, in addition to being important to overall ecosystem dynamics and water quality.

Sea level rise will continue to change the shores of Long Island in fundamental ways. Globally, climate change contributes to sea level rise in two ways: melting ice caps, glaciers, and ice sheets increase the total amount of seawater; and higher temperatures cause the volume of that seawater to increase through thermal expansion. At a local level, relative sea level rise is affected by land subsidence stemming from ongoing adjustments to the melting ice sheets at the end of the last ice age; other accretion and subsidence forces; and local ocean mass effects. Topographic changes, such as those associated with shoreline development, shoreline protective structures (e.g. bulkheads and sea walls) and impervious surfaces, affect the extent to which relative sea level rise actually impacts particular areas.

Large storm events such as tropical storms (hurricanes) and extratropical storms (nor'easters and other winter storms) have driven the formation and continued development of Long Island's shoreline. During the past 75 years, hurricanes and nor'easters have caused rapid beach erosion, dune displacement, and coastal flooding on Long Island's south shore. The most significant was the Great Hurricane of 1938 (September 21), also known as "The Long Island Express." The storm produced winds that reached over 300 kilometres per hour, generated 5-metre-high breakers, overwashed approximately one half of the island, and created 12 new inlets (Donnelly, Bryant et al., 2001). The "Ash Wednesday" storm of March 6, 1962 was a major nor'easter that resulted in more than 50 washovers. With sea level rise, the baseline sea level on which storm surge operates will be higher, resulting in increased shoreward extent of flooding and severity of impact. For example, if the 1938 hurricane occurred in 2004, it would be imposed upon a sea level nearly 21.3 cm (9 inches) higher than in 1938, thereby having a much more devastating flood effect (Psuty et al., 2005). The interplay of these various factors, and the gaps in our current knowledge, make precise sea level predictions for any given geographic area challenging. While different models yield different estimates virtually all models agree that effects of sea level rise on the region are potentially dramatic.

As of the 2000 US census there were 1.4 million people living in Suffolk County (United States Census Bureau, 2007), which includes part of Long Island's south shore, and a significant percentage of the south shore is heavily developed. Current development places considerable pressure on natural habitats through nutrient loading, toxic run-off, and habitat conversion and degradation. Long Island's coastal communities have a long history of trying to maintain their shoreline using a variety of structural mechanisms, including jetties, groins, and beachfill and construction of bulkheads. This extensive shoreline armouring increases the pressure on natural resources by modifying the sediment budget that supports them. Sea level rise will create a "squeeze" between the sea and these structures, reducing and eventually eliminating space for landward regression of natural features. Accelerating sea level rise will almost certainly increase the demand for shoreline engineering, as people seek to protect their property from erosion and catastrophic loss. As public and private investment in shoreline property continues the cost of coastal hazards increases. Further, human communities are at risk as we lose natural buffers, including salt marshes and dunes that protect the coastlines from storms.

Long Island is certainly not unique in its level of development, and potentially increased frequency and intensity of storm events, and vulnerability to sea level rise. As with much of the US East Coast, sandy beaches and low coastal profiles combine to make these areas attractive for settlement, but also at high risk from rising sea levels and higher storm surges.

The Nature Conservancy and its partners are working with local decision makers – who are the primary regulatory authorities on coastal development – to examine how different management objectives such as coastal hazard mitigation and conservation are related to one another and to visualize alternative scenarios for jointly managing them. Specifically, this project was designed to help stakeholders visualize the impacts of sea level rise and understand how they can make informed decisions about marine and coastal conservation, land protection, and coastal development and to enable local and state decision makers to use the information in their planning, zoning, acquisition, and permitting decisions.

Methodology

Objectives

The first phase of the Coastal Resilience project, conducted over an 18-month period from January 2008 to July 2009, was guided by the following primary objectives:

- Build a spatial database and interactive web mapping application http://www.futurescenarios.org/ that provides decision support for meeting both biodiversity conservation and coastal hazard mitigation objectives;
- Construct a website (http://www.coastalresilience.org) that explains the approach, methods, and strategies for Ecosystem-based Adaptation (EbA) to climate change; and
- Identify reasonable and viable alternatives that reduce losses and vulnerability of coastal communities for people and ecosystems.

Approach

At the same time the partnership team conducted an analysis of selected local land use ordinances, regulations, and legal precedents that include specific mention of SLR or that incorporate appropriate policy responses that may be used to address SLR. Finally, meetings of stakeholders were convened throughout this phase to begin discussing how, through interactive decision support important social and ecological characteristics can be compared with sea level rise and storm surge events and visualized within local and state planning processes.

Bringing together local and state managers and planners on Long Island in three community engagement workshops, stakeholders were asked to vet the information and discuss how online spatial information could facilitate better decision making. Participants explored the project's interactive decision support application, the Future Scenarios Mapper, to help visualize flooding given a range of sea level rise and storm surge scenarios. These current and future flood scenarios were mapped alongside socioeconomic and ecological features. The team frequently tested the utility of the application by discussing with stakeholders and decision makers the concept behind the project and eliciting feedback on the design, rollout, training, and ongoing maintenance of the site. Stakeholders were invited back to subsequent workshops when inundation projections and other data became available to discuss the extent of the projected impact, and what it was hoped would be done with the information.

Vegetation plays an important function in stabilizing sand dunes, as here at the Fire Island National Seashore, Long Island, New York.

The collection and analysis of Geographic Information System (GIS) data was a core component of this project, allowing visualization, exploration, and analysis of multi-layered issues influencing coastal resilience.

Conceptual Framework

The Coastal Resilience decision support platform used the following conceptual framework to allow users to plan and adapt to future changes:

> Assess risks of coastal hazards (storms and SLR) to human and natural communities;
> Visualize potential impacts;
> Provide information that allows decision makers to plan and adapt to minimize losses to human and natural communities; and
> Implement potential Ecosystem-based Adaptation (EbA) strategies in local planning processes.

Data Collection, Analysis and Interpretation

Coastal Flooding and Inundation

The elevation data used for mapping came from a LiDAR-based (Light Detection and Ranging remote sensing) digital elevation model provided by Suffolk County Information Services. These high resolution elevation data were used to map sea level rise and storm surge. Providing scenarios for future SLR on the south shore of Long Island under different Global Circulation Model (GCM) simulations and emission scenarios was done by Columbia University Center for Climate Systems Research which is affiliated with the National Aeronautics and Space Administration's (NASA) Goddard Institute for Space Studies. These projections were developed from the best available scientific information about greenhouse gas emissions (IPCC, 2008) and GCMs run by CCSR. The generation of scenarios including global variables (thermal expansion of the oceans due to global temperature increases and changes in the ice mass (including Greenland, Antarctica, and glaciers), and local variables such as land subsidence and local differences in mean ocean density. Project staff generated model probability distributions of SLR in decadal periods from the 2020s to the 2080s. Projections for the 2020s, 2050s, and 2080s were included as options in the mapping tool, labelled as "conservative," "medium," and "high" sea level rise projections that correspond respectively with IPCC scenarios A1b, A2, and A2 plus ice sheet melting (Fig. 2). The methods used to generate these SLR scenarios are described in NPCC (2010, Appendix A).

Historic tide data and the most current storm surge tidal hydrodynamic data were used to develop flood recurrence intervals over time for high frequency floods such as frequencies of 2, 5, and 10 years; and less frequent storms with recurrence intervals of 40 years and more for the study area. These were also mapped onto the LiDAR elevation data. These were also mapped onto the LiDAR elevation data. Local tide data at the Battery and at Montauk gauge stations on Long Island were used to estimate recurrence periods of high water and surges. For storm surge events the team worked both with CCSR and with NOAA-CSC, utilizing National Hurricane Center's Sea, Lake and Overland Surges from Hurricanes model (SLOSH), which estimates storm surge heights and winds resulting from historical, hypothetical, or predicted hurricanes by taking into account pressure, size, forward speed, track, and winds. From the model's outputs Maximum Envelopes of Water (MEOWs) result from the SLOSH model to portray what could happen when a specific storm makes landfall. MEOW Category 2 and 3 Hurricanes, corresponding to storm surges with estimated 40 and 70 year return periods, respectively, were chosen for the Future Scenario Mapper. Including both high-recurrence interval (i.e. "basement flooding" or semi-annual flooding) and storm-induced flooding (i.e. nor'easters or hurricanes) in the Mapper gave stakeholders an array of realistic flood events both in the near term and future by combining them with SLR projections.

Figure 2. Comparing present-day mean high water (left) at Mastic Beach, Long Island, New York, USA, to an A2 sea level rise scenario as provided by the Intergovernmental Panel on Climate Change (IPCC).

Socioeconomic Vulnerability and Risk

Long Island's shores have some of the most highly developed lands in the coastal zone. Much of this private property is only inches above sea level, and even a moderate sea level rise will result in a significant increase in the likelihood of flooding. More significant rise – or the occurrence of a catastrophic storm – could be very costly in economic terms and potentially put many people in harm's way. We compiled and processed socioeconomic information in order to better evaluate the consequences of SLR and storm surge hazards on human populations and infrastructure. A characterization of at-risk communities provided managers with information to explore opportunities to minimize risk.

The project team used population data from the US Census Bureau (2000) to depict these distributions and to create various census block level indices based on demographic attributes such as age, income, and access to critical facilities such as hospitals. In addition, census block-level demographic data were combined with economic data to forecast the potential economic damage of future SLR and floods based on the present-day economic landscape. Supplemental datasets and analyses were included to further strengthen the baseline data upon which coastal managers might assess risk. These datasets included hardened shoreline structures, land use/ land cover information, and critical facilities locations (i.e. hospitals, fire stations).

Ecological Vulnerability

Among the most productive ecosystems on Earth, coastal wetlands and marshes perform many functions that are highly valued by society, often referred to as ecosystem services (Costanza et al., 1997, 2006 and 2008; Hale et al., 2009). Wetlands protect water quality by filtering land-derived nutrients and contaminants, support coastal food webs, provide valuable wildlife habitat, and protect upland and shoreline areas from flooding and erosion associated with storms. The barrier islands that fringe Long Island's south shore provide protection from storms and storm surge for the human communities along the mainland coast, but they also serve as unique habitats for many species. Fire Island (a barrier island complex) provides critical habitat for several rare and endangered species, and serves as a migratory corridor for birds, sea turtles, and marine mammals. Many species depend on the dynamic nature of barrier island beaches, including beach-nesting species such as the federally- and state-protected piping plover.

The project team selected species, habitat types, and ecological communities – including those discussed above – that are either representative of south shore ecosystems, highly sensitive to human disturbance, considered to be of ecological concern, or are afforded some level of regulatory protection. For this study we collected and analyzed data on the piping plover, barrier island habitats, and particularly coastal wetlands and marshes for their protective and ecosystem services.

Healthy, properly functioning wetlands contribute to shoreline protection and erosion control by mitigating the effects of flooding, particularly during large storm events. Erosion, transport, and deposition of sediment allows for natural evolution of beach and dune features, which naturally protect our coastal communities. In many coastal areas artificial structures have disrupted natural sediment movement, thus reducing the protective capacity of these features. This leaves coastal wetlands and dune ecosystems vulnerable to increased wave attenuation and other physical effects. An Ecosystem-based Adaptation (EbA) strategy, however, would call for the restoration of the natural sediment transport process to allow the shoreline and barrier landforms to respond naturally to sea level rise, restoring its protective capacity and reducing long term erosion rates caused by artificial disruptions in the system.

Results

The Coastal Resilience project was designed to highlight opportunities for promoting Ecosystem-based Adaptation (EbA) on Long Island's shores. The Future Scenarios Mapper illustrates sea level rise and storm surge inundation while it highlights areas of human vulnerability and identifying opportunities for natural protection. At the same time, the web mapping application helped identify strategies for maintaining the health of natural coastal systems so that they might continue to protect human communities into the future.

We conducted a series of socioeconomic and ecological analyses using multiple social, economic and natural resource datasets and developed indices that characterized overall human community vulnerability, estimated potential economic loss from coastal hazards, and provided an illustration of coastal wetlands' potential protective capacity and viability.

Socioeconomic Analyses

The socioeconomic analyses summarized the most likely consequences of SLR and storm surge hazards for human populations, ranking vulnerability on a relative scale for the south shore of Long Island. The project team chose demographic attributes that best represented the socioeconomic vulnerability of Suffolk County, and these attributes were combined to create indices that identified human communities at greatest risk from coastal hazards.

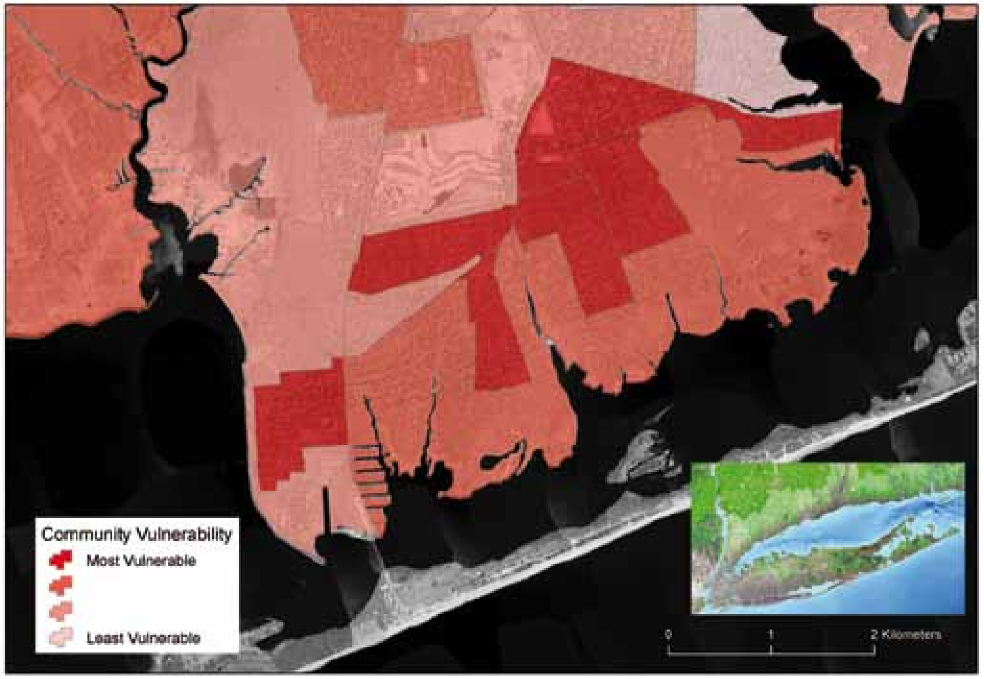
The analyses presented here were based on published risk and vulnerability assessment methodologies, including the Community Vulnerability Assessment Tool (CVAT), the AGSO Cities Project (Granger, 2003), and the Social Vulnerability Index for the United States (Cutter et al., 2003). These methods recommended several variables that characterize social vulnerability, including but not limited to population and population density, housing unit density, median income, households below poverty, those requiring public assistance, those that rent, live on Long Island seasonally, live in mobile homes, and do not have an automobile. These and additional variables were mapped at the census block group scale – the smallest geographical unit for which the census provides detailed demographic data.

A critical infrastructure and facilities index ranked census block groups based on the amount of infrastructure and facilities located within each. Extensive infrastructure related to public safety, communications, utilities, and community facilities increased a block group's vulnerability as communities within and adjacent to it are likely to be highly dependent on the services it provides. Infrastructure and service facilities were counted for each block group, and block groups were then ranked from "most" to "least" vulnerable for inclusion in the index.

An overall community vulnerability index combined the social vulnerability and critical facilities and infrastructure indices to represent the combined vulnerability to flooding of the people, property, and resources in a community. The index was mapped by census block groups in four categories, from "most" to "least" vulnerable (Fig. 3).

Along with these vulnerability indices, sea level rise, storms, and scenarios that combined their effects on economic exposure were

Figure 3. Overall community vulnerability index illustrating the Mastic Beach area, Long Island, New York, USA.



selected to examine economic losses from flooding of infrastructure, including housing, transportation, and commercial structures that are damaged or lost. Economic loss represents the full replacement value of commercial and residential structures. Loss calculations were the result of geographic analysis and display using the Hazards US Multi-Hazards (HAZUS-MH) tool developed by the Federal Emergency Management Agency (FEMA). HAZUS-MH uses GIS software to estimate potential economic losses from earthquakes, hurricanes, and floods.

All of the indices and economic loss calculations can be visualized in the Future Scenarios Mapper by either US census block groups or summarized across towns and villages along the south shore of Long Island.

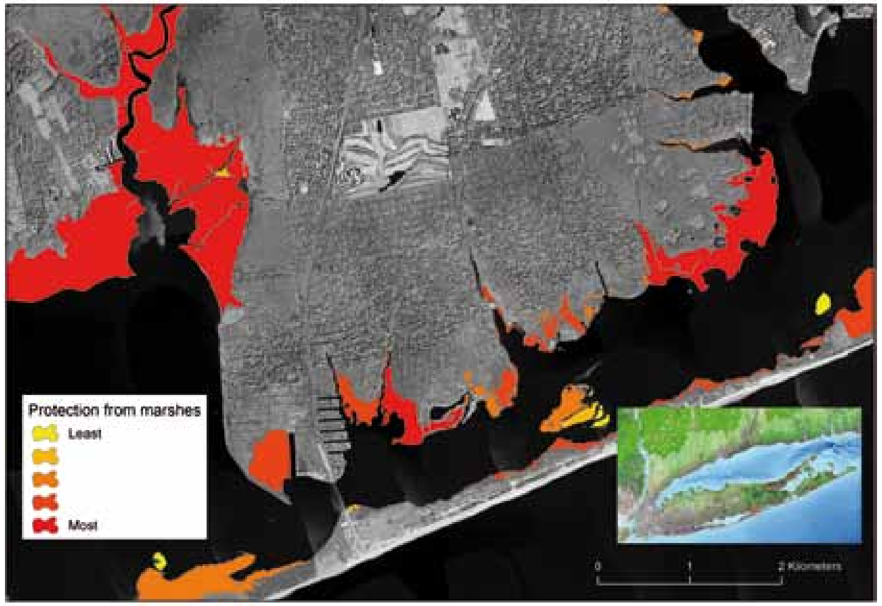
Ecological Analyses

The team conducted a suite of ecological analyses to help estimate the ecological impacts of sea level rise (SLR) and coastal storms on natural resources, with a focus on coastal wetlands. Specifically, relationships between marshes and adjacent lands that either limit or offer space for the potential landward migration of marshes as sea levels rise were examined. In addition, the project team explored the relative potential storm buffering capacities of marshes and their potential to protect coastal communities based on size and proximity to human communities.

Intertidal habitats, including wetlands, require adjacent non-developed space to migrate over time in order to keep pace with rising sea levels; therefore the relationship between marsh distribution and impediments such as roads, land slope, and shoreline hardening was analyzed. A potential marsh viability indicator was calculated by combining the percentage of marsh adjacent to migration impediments, marsh size, and marsh elevation; these results were displayed as a "lower" to "higher" potential viability index.

One of the areas where there are real opportunities for identifying win-win solutions for human and natural communities is in building approaches that combine hazard mitigation and

Figure 4. Potential population protection index for marshes illustrated in the Mastic Beach area, Long Island, New York, USA.



biodiversity conservation in coastal zones to preserve infrastructure while protecting human communities. Coastal wetland ecosystems have the ability to provide protection to these coastal communities. A population protection potential index was calculated as a function of marsh size and proximity to human communities (Fig. 4). Adjacent population was determined by distributing population data from the US Census across Suffolk County parcel data, a process called dasymetric mapping. Housing density values per parcel were used to calculate population density on a sub-census block scale. This index provided a general estimation of a marsh's potential to act as a buffer from flooding and other storm impacts; results were arranged from "less" to "more" protection potential.

Next Steps

The purpose of the Coastal Resilience project is to provide communities – specifically planners and natural resource managers – with easy access to information to assist in coastal planning and management decisions regarding resources at risk from sea level rise and hazards. Coastal Resilience was not designed to promote a specific outcome or agenda; it was hoped that with better information, planners and managers would make decisions that better protected both communities and natural resources. In order to achieve the objective of promoting planning and management of economic, social, and natural resources in the face of climate change, it is essential that planners and managers are aware of the availability of this information and are trained to use it. Consequently, the team designed a three-phase outreach program: the first phase was an expansive overview of the project and objectives described above, the second phase will involve smaller working groups designed for focused, preliminary planning, and the third phase will provide in-depth training tailored for existing, local planning processes.

Following the completion of this first phase of project outreach, we conducted a usability analysis to gauge how workshop participants understood the Future Scenarios Mapper and knew how to use it, and what specific changes would make it more intuitive and applicable to their decision making. The usability test involved working with six workshop participants for an hour each, asking them to complete a series of tasks, and observing what they did. Time to complete each task was measured, and patterns of problems

with the training or the interface were identified. The usability analysis served to identify a number of specific technical changes that could improve the use efficiency of the mapping application. In addition, it helped to identify the issues and concerns that the user community had with the overall approach, and impediments to broader use. The overwhelming sentiment among testers was that the application was approachable and friendly. Testers saw value in the mapping application, but many commented that non-planning/science staff would struggle to understand what to do with the information presented therein. Several worried that it might be used by concerned residents to justify shoreline hardening/revetments, or that companies offering such services could exploit the interactive decision support application as a way to foster business.

In the next stages of the project, the team will focus on providing additional functionality for the Future Scenarios Mapper for identifying ecosystem-based shoreline management strategies, to suggest how communities can move away from structural approaches that could adversely impact natural resources. For example, Fig. 5 is an example of how communities can use the Future Scenarios Mapper to identify Ecosystem-based Adaptation strategies to anticipate to future changes. This graphic shows how the Future Scenarios Mapper can be used to identify vacant parcels for conservation, into which marshes could potentially migrate under future SLR scenarios. Further, we will use the results of the usability analysis to make technical changes to the web interface and the mapping application to facilitate the use of Coastal Resilience in on-the-ground planning.

Community Working Groups

We invited several potential users at the local and state level in New York to a working retreat to discuss their own work on sea level rise and how the information in the Future Scenarios Mapper and Coastal Resilience project could inform these planning efforts. Local participants informed us that for many local decision makers, sea level rise was, at most, an ancillary issue. Many local elected officials do not believe that sea level rise poses a

Figure 5. Using the Future Scenarios Mapper tool to identify vacant parcels (light orange) for the conservation of salt marshes (red and dark orange) in the Mastic Beach area, Long Island, New York, USA.

threat; much less think that it should be a major consideration in planning. The state agency participants have somewhat more flexibility to promote planning for sea level rise, but since most land use planning is accomplished by local governments, state agencies generally need a local partner to engage in sea level rise or coastal hazards projects.

Next, the team conducted an internal exercise to evaluate how local decision makers would respond to recommendations for integrating sea level rise projections into existing planning efforts. In this workshop, participants anticipated the responses of local officials in a role-playing exercise, attempting to identify major planning goals, resources of interest, likely impacts of several SLR and storm scenarios on these resources, and likely response.

Local governments have multiple objectives in shoreline management and planning. First, local governments wish to protect human health, life and property. Second, the towns are interested in protecting natural resources, both for their own sake, and for their value in protecting human health, life, and property. Although some argue that these values are in conflict, in the case of sea level rise planning, in many places this is an inaccurate characterization. Adaptation strategies that aim to enhance the resilience of ecosystems to enable the continued provision of goods and services can be particularly important for vulnerable communities that are often directly dependent upon natural resources. A growing body of evidence suggests that EbA can be a cost-effective strat¬egy across sectors (Campbell et al., 2009). In addition, EbA strategies often address multiple coastal management objectives. An ecosystem-based approach of protecting and restoring "green infrastructure" like healthy coastal wetlands could be a more cost-effective, lower-maintenance means of protecting large coastal areas (Moberg and Ronnback, 2003). In any case, it is generally agreed that natural resources are among the interests that local officials are charged with protecting.

An important principle illustrated by this planning exercise is that doing nothing (sometimes called the no-action alternative) needs to be explicitly considered when weighing alternative strategies for jointly managing community and ecological resources. The no-action alternative is the most likely alternative in places where income levels are too low for sustained private investment in shoreline protection and people are not well connected to political processes that might ensure a government financed project. This alternative would result in no protection for coastal natural resources, and the gradual abandonment of nearshore property, with tax-default parcels reverting to local governments. These governments would then be left with the expensive task of remediating the waste disposal systems on waterfront lots and restoring them. Failure to do so would likely result in a water quality catastrophe when a major storm hits the area. Because this is an undesirable outcome, local officials might be convinced to act.

The next step is to bring together teams of planners and natural resource managers from a subset of town governments to undergo this hypothetical planning exercise for areas within their jurisdictions. The purpose of this workshop will be to ground truth the outcomes of our internal exercise, and to generate interest in the more in-depth planning process described below.

Engagement in Local Planning

The final stage is the development of adaptation plans specific to local communities' needs and priorities. Such plans may be stand-alone sea level rise/coastal hazard adaptation plans, but they are more likely to be components of pre-existing planning processes, like comprehensive plans, wetlands management plans, or other resource management plans. In furtherance of this goal, the team will develop a hands-on process whereby local officials, community leaders, and other key stakeholders integrate hazard and sea level rise risk information into their specific local planning and decision-making activities. Participants will target specific priority hazards and SLR issues and identify locally feasible and sustainable mechanisms for addressing those issues (infrastructure, land use, transportation, community development, and natural resource planning and policy frameworks).

As noted above, the local leaders we have worked with are not always inclined to affirmatively tackle SLR as a stand-alone issue. Accordingly, we are seeking towns that were undergoing pre-existing planning processes, and trying to integrate SLR issues and potential EbA strategies into those processes.

Conclusions and Recommendations

Coastal towns and villages on Long Island are well aware of the threats climate change poses to their communities. They are willing to explore different climate change strategies including Ecosystem-based Adaptation. Although an increasing number of states and local governments are beginning to consider the effects of climate change, only a small number have specifically addressed SLR and its impacts. A leading example of this is found in New York City (NPCC, in press).

The information presented by the Coastal Resilience Project's web mapping application is intended to advance land use, natural resource management, and emergency response planning when considered and applied according to the needs of local communities on Long Island. This information is critical, but actual adaptation to SLR on the ground will require substantial changes in our present shoreline management paradigm. We are actively pursuing a five-part approach for designing and implementing EbA strategies on Long Island and in other geographies:

1. Amending and passing key legislation: Most shoreline management regulations and laws at the federal, state, and local level

Coastal settlements, such as the Long Island Barrier Islands, are particularly vulnerable to sea level rise.

predate the current understanding of the implications of coastal climate change. Amendments that address the realities of SLR at the federal level with respect to the Coastal Zone Management Act, the National Flood Insurance Program, and the various FEMA Hazard Mitigation Programs would increase the ability to both plan for and fund EbA at the regional, state, and local levels. Numerous local and state statutes and ordinances regulating development and natural resource management should be revised to reflect the changing boundaries of the shoreline and adjacent wetlands.

2. Promoting voluntary land acquisition: The passage and/or amendment of progressive adaptation legislation at the federal and state level should provide financial incentives to local governments to enable the voluntary acquisition of coastal property as a means to protect human life and permit natural, sustaining processes to occur in the coastal zone.

3. Relocating vulnerable infrastructure and development: In some cases where risk to human communities is extremely high and/or nature can adapt to rising sea levels by migrating landward, moving vulnerable infrastructure may be necessary.

4. Engaging in comprehensive, post-storm redevelopment planning: Adoption of post-storm redevelopment programs at the local level should be considered as an opportunity to remedy previous land-use decisions that did not address current and longer-term risks and costs attributable to climatic change. The recognition of and need for post-storm redevelopment adaptation strategies should be reinforced and enabled through the federal programs mentioned above.

5. Restoring and protecting natural resources: Central to the advancement of coastal adaptation approaches is the need to invest in restoration and protection of natural resources. Healthy, properly functioning natural shorelines and tidal marshes provide buffers that mitigate storm damage and dampen the impact of tidal surges. A continued and sustained investment in natural resources will provide a return of important ecosystem services and increased nature-based solutions for shoreline protection and erosion control.

In many cases, a successful approach will require the integration of multiple strategies to achieve the desired goals.

The Coastal Resilience project represents a platform for providing information to local communities, but it is also relevant at state and national scales. Building the case for coastal resilience will require local, state, and national integration and coordination, with the premise that what occurs locally can both inform and be informed by state and national policy. By focusing first on local decision makers, we address the needs of stakeholders within their communities while providing a robust framework for identifying place-based ecological, social, and economic relationships and appropriate coastal adaptation solutions. Careful deliberation with regard to the combination of feasible adaptation approaches and the appropriate scales for implementation require greater emphasis at multiple governance scales.

Human and natural communities will need to adapt in order to survive. Mutually beneficial solutions for human and natural communities lie in examining relationships between coastal hazard mitiga¬tion and biodiversity conservation to preserve infrastruc¬ture and livelihoods while protecting nature. Reducing coastal losses to people and nature, and clearly recognizing that decision makers will address people's needs first, the team proposes here that common ground can be reached with ecosystem-based solutions. The well-being of coastal communities is so closely linked to the natural environment that many of the strategies that will protect natural resources in the face of global warming will also enhance the resilience of human communities. At this stage in Ecosystem-based Adaptation, efforts are required to integrate climate science and inundation scenarios with local decision making. This work is just beginning; the present project is one of the first to attempt this integrated approach.

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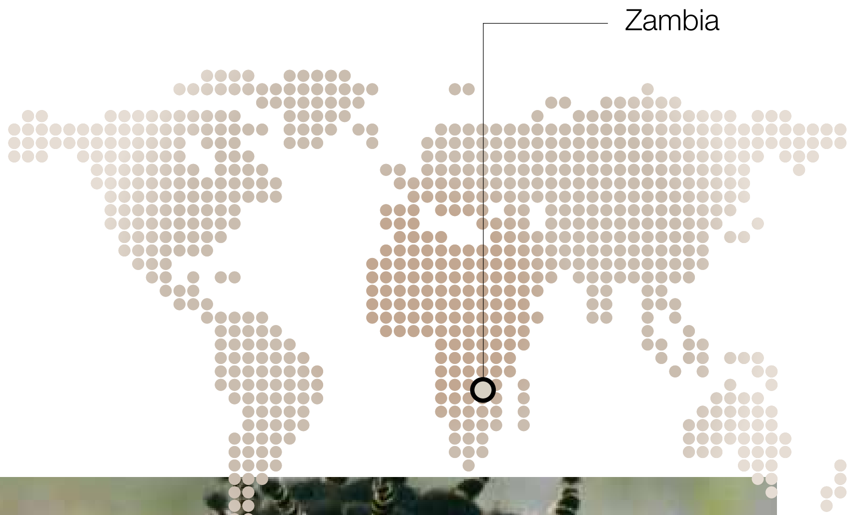

Chapter 7

Climate Change Adaptation Strategies in the Chiawa Community of the Lower Zambezi Game Management Area, Zambia

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Zambia is a vulnerable country to the impacts of climate change, and some regions, such as the Chiawa area are already experiencing direct impacts such as reductions and uneven distribution of rainfall, increasing frequency and intensity of droughts, occasional flooding, increasing temperatures and environmental degradation. Impacts of climate change and variability, and particularly extreme weather events, are already affecting the viability of fishing and farming through reduced water availability for crop production, livestock and domestic use.

The current study was undertaken in the Chiawa area, located in the Lower Zambezi Game Management Area (GMA), which forms a natural buffer between the Lower Zambezi National Park and the open areas that surround it. Research findings provide a clear understanding of the climate hazards affecting communities and how these communities in Chiawa are coping with the impacts of climate change. Through this understanding the community members, policy makers and other stakeholders are better informed to introduce effective measures to reduce vulnerability and enhance the adaptive capacity at the individual, local and national levels in Zambia.

This chapter takes a close look at the many underlying factors causing community vulnerability to climate change and how these interact with the community's variable ability to adapt to current and predicted future climate changes. Recommendations are suggested regarding the strategies needed for the community to adapt to current and projected climate change impacts, and for integrating climate change adaptation approaches into planning and policy processes.

Keywords: Adaptation, Adaptive capacity, Agro-ecological regions, Climate change, Climate sensitivity, Coping strategies, Hazards, Livelihoods, Vulnerability

Introduction

Background

The Chiawa community is one of the communities in Zambia that is already experiencing the adverse effects of climate change. They have limited access to services, are highly dependent on natural resources for their livelihoods and face wildlife-human tensions from the neighbouring Lower Zambezi National Park.

While the Chiawa community has been coping with climate change and variability for years, current

BOX 1. OVERVIEW OF CRISTAL

Introduction:	IUCN, IISD, SEI-US and Intercooperation have developed and tested a project planning and management tool called CRiSTAL (Community-based Risk Screening Tool – Adaptation & Livelihoods). The tool seeks to help project planners and managers to integrate risk reduction and climate change adaptation into community-level projects.
Goal:	To promote the integration of risk reduction and climate change adaptation into community-level projects.
Objectives:	(a) Help users to systematically understand the links between local livelihoods and climate; (b) Enable users to assess a project's impact on community-level adaptive capacity; (c) Assist users in making adjustments to improve a project's impact on adaptive capacity.
Approach:	(a) Draw on environmental impact assessment model; (b) Use the sustainable livelihoods framework to enable users to focus on elements of coping and adaptive capacity at the community level; (c) Offer the tool in multiple formats (e.g. hard-copy, Excel) and in several languages; and (d) Encourage users to adapt the use of CRiSTAL to suit specific needs.
Intended results:	Enhanced local adaptive capacity through a better understanding of: (a) How current climate hazards and climate change affect a project area and local livelihoods; (b) How people cope, looking specifically at the resources needed to cope with climate stress; (c) How project activities affect livelihood resources that are vulnerable to climate risk and/or important to local coping strategies; and (d) How project activities can be adjusted so they enhance adaptive capacity (www.cristal.org).

coping strategies seem inadequate to address the increasing rate of occurrence of droughts, flash floods and extreme heat. It is, therefore, important that communities are supported to urgently improve their coping and adaptation strategies as the rate of climate change and the magnitude of its impacts are increasing.

This study reports the results from a climate change vulnerability assessment undertaken in the Chiawa area located in the Lower Zambezi Game Management Area (GMA), a natural buffer zone between the Lower Zambezi National Park and the open areas beyond. It is situated in Zambia's Agro-ecological region 1, which is most prone to droughts due to average annual rainfall levels of 600 mm coupled with high day and night temperatures. The Chiawa area is drained by the Zambezi and Kafue rivers and their tributaries, making it also prone to flooding.

Objectives

The objectives of the study are to:

- Provide an understanding of the community's vulnerability to climate change and the adaptation strategies being applied by the local community in the Chiawa area;
- Raise community awareness around climate change and its impacts on rural livelihoods;
- Generate information and knowledge, and appropriately package it to influence policy and improve adaptation practice; and
- Test the CRiSTAL tool (Box 1) for assessing climate change vulnerability at field level, and improve it as necessary.

Methodology and Study Area

The climate change vulnerability assessment process involved training of a research team in using vulnerability assessment tools (Box 2), data collection through consultations (with community groups, staff of governmental and non-governmental organizations working in the project sites) and literature review regarding observed climate trends and socio-economic information. Community consultations were conducted with groups of elderly men, elderly women, young women and young men using the community consultations framework (Box 3).

The data collected was analysed using the CRiSTAL programme (www.cristal.org), (Box 1). Analysis served as a platform to design sustainable adaptation measures for the community to cope with both current and future climate change impacts.

BOX 2. TOOLS USED FOR DATA COLLECTION AND ANALYSIS

Historic Time Line and Seasonal Calendar	- To examine key changes affecting the community over the years (incl. social, environmental, political, economical changes) - To examine trends in rainfall and temperature from the community's perspectives - To understand major climate hazards experienced in the community - To record the major impacts of climatic hazards on the livelihoods of the community
CRiSTAL (Community Based Risk Screening Tool – Adaptation and Livelihoods) www.cristaltool.org	- To better understand linkages between livelihoods and climate - To identify which livelihood resources are most vulnerable to climate hazards, and which resources are important for adaptation - To analyze options for improving existing coping strategies
CVCA (Climate Vulnerability and Capacity Analysis) http://www.careclimatechange.org/cvca	- To understand which other factors are causing similar impacts than climate change - To better understand who has control and access to resources and services in the community - To understand what social, political or other factors that may have implications for vulnerability
CEDRA (Climate change and Environment Degradation Risk and Adaptation assessment) mike.wiggins@tearfund.org	- To give consideration to both climatic and environmental hazards which impact on livelihoods and development projects - To ensure a deeper awareness of environmental degradation risks that affect development work are full assessed and an integral part of development planning - To examine what type of environmental degradation affects livelihoods - To analyze how environmental degradation needs to be taken into account in improved coping strategies

BOX 3. COMMUNITY CONSULTATION FRAMEWORK

Climate context (Exposure)	Livelihood context (Sensitivity)	Coping strategies (Adaptive Capacity)
- What climate related events do people remember from the past? - What are the current climatic hazards that affect people's livelihoods? - What are the main impacts of these hazards?	- What are the key livelihood resources that people depend on in terms of natural, physical, financial, human and social or other assets? - What other factors lead to the same impacts on livelihoods as the climate hazards? - Which factors are more influential between climate hazards and the other factors?	- What do people do when climate hazards impact their lives? - How do they cope? - What other than the current coping strategies people know that could be practiced?

The average annual rainfall at Chirundu on the border of Chiawa in the Lower Zambezi GMA is 628 mm. Rainfall usually occurs between November and March with temperatures varying between a low of 6.5°C in July and a high of 40°C in October (Chanda and Tembo, 1993). The area experiences a typical continental tropical climate characterised by three distinctive seasons, namely: a hot rainy season in the months from November to March/April; a cool dry season from April/May to August; and a hot dry season from late August to October. The area receives a mean annual rainfall of about 700 mm in the highlands and around 400 mm or less in the valleys (Hachileka, 1997).

Results

Climate Change Vulnerability and Impacts

Subsistence farming and fishing are the main livelihoods that were assessed in the Chiawa

Table 1. Climate Change Hazards and Impacts on Farming in Chiawa

Climate Hazard	Drought	Floods	Extreme Heat
Impacts	• Crop failure • Water scarcity • Increase in human and livestock diseases • Reduced energy to work • Reduced income	• Crop damage • Damage to infrastructure • Increases in human and livestock diseases • Soil erosion • Disruption of movement	• Crop failure, also in gardens • Water scarcity • Physical fatigue • Increased human diseases

area, with the central villages of Kanyangala and Chiawa representing farming and fishing livelihoods respectively.

Exposure to Climate Change Hazards

Climate change exposure was assessed by addressing three aspects, namely magnitude, character and rate of climate change in the area. The main climatic hazards affecting farming activities in Chiawa are, in order of significance, drought, floods and extreme heat. Table 1 shows the key impacts of these climatic hazards. In turn, the main climatic hazards affecting fishing are, in order of significance, drought, extreme cold and floods. These hazards have a range of impacts on the local fisheries and the fishermen's activities (Table 2).

Sensitivity to Climate Hazards

Community sensitivity to climate change is the degree to which a communities' livelihood is adversely or beneficially affected by climate-related stimuli (CARE, 2009). The communities in Chiawa are mainly practicing rain-fed subsistence crop farming. This makes the farming system very sensitive as the productivity of the farmers depends to a large extent on rainfall patterns. Very dry years led to serious crop failure as the community has no means to irrigate the crops. A number of households in Kanyangala have their fields along river banks where alluvial soils provide fertile ground for crop production. However, during heavy rains the river banks are often flooded due to flash floods, leading to crop damage and loss of crop. This fact makes farming a risky livelihood during both droughts and floods.

The second major livelihood in Chiawa is artisanal fishing. Drought and heat are the most significant climatic hazards affecting fishing activities. Drought was observed to lead to reduced water which affects breeding grounds, as a result from exposure of areas in which fish lay their eggs. Similarly, small fish get exposed as water recedes.

The two most important livelihood strategies in Chiawa, crop farming and fishing, are both affected and increasingly susceptible to climate change hazards with major risks resulting from droughts, extreme heat and flooding. Focus Group Discussions with the community also revealed that livelihood resources important for fishing activities are clearly impacted by climate hazards.

Table 2. Climate Change Hazards and Impacts on Fishing in Chiawa

Climate Hazard	Drought	Extreme Cold	Floods
Impacts	• Reduced fish catch • Reduced fish size • Reduced income • Overfishing • Food scarcity • Water scarcity	• Reduced fish catch • Outbreak of diseases • Damage to horticultural crops and fruit trees	• Crop damage • Damage to houses and toilets • Increase in diseases • Soil erosion

Wetland ecosystems, such as here along the Zambezi River, are particularly important for regulating flooding from excessive rainfall events.

Adaptive Capacity

The adaptive capacity to climate change in Chiawa is very low, due to limited access to resources, lack of know-how and technology, poor services and information, and low institutional capacity.

Some of the key non-climatic causes of vulnerability in Chiawa are endemic poverty, environmental degradation, limited alternative livelihood activities, wildlife crop damage, inadequate technical capacities, poor infrastructure, poor access to markets and weak local institutions. These factors, in combination with climate change effects, undermine the community's capacity to adapt successfully.

Coping Strategies and Adaptation to Climate Change

Coping Strategies

The communities in Chiawa are already undertaking activities to cope with droughts and other climate hazards. An assessment of current local coping strategies, as well as their effectiveness and sustainability, provides an insight into local adaptive capacity. The main coping strategies that farmers in Kanyangala may consider are contour ridging and ploughing across slopes, piece work in commercial farms, collection of wild fruits and tubers and sale of reeds, mats, crafts and grass. Based on the analysis of these coping strategies it can be said that while most of the strategies try to meet community needs during poor harvests, they seem not to be ecologically, socially or financially sustainable in view of long term climate change.

Furthermore, in central Chiawa, the main coping strategies are selling reeds and mats, increasing fishing effort, relief food, digging shallow wells along the Zambezi, food for work, building strong traditional houses, use of traditional medicine for livestock and migrating from the flood areas. It is important to note that not all current local strategies to cope with hazards are efficient or appropriate for long term adaptation while the effectiveness of these strategies also depends on the intensity, duration and frequency of the hazard.

Adaptation to Climate Change

On the basis of coping strategies being undertaken by the community, a number of adaptation options were formulated using the CRiSTAL Tool, which takes into account sustainability in view of projected climate change impacts, as well as using experiences from elsewhere. This was done by analyzing all the coping strategies in terms of sustainability in the face of climate change. The strategies suggested are deemed not to deplete economic assets, nor to have potential to degrade the environment, but rather improve it while enhancing livelihoods of women, men and children in Chiawa.

Adaptation Strategies for Farming

Regarding farming, the following adaptation options are suggested:

a) Provision of farmers with short-term weather forecast data from the National Meteorological Department, tailor-made for farmers, such as 7–10 day forecasts for improved management decisions that will help reduce climatic uncertainties when taking daily farming decisions around choice of crop varieties, timing of farming activities, and general planning. This will help farmers adjust to seasonal changes at the onset and cessation of rainfall by changing their planting dates to make them coincide, for example, with new rainfall patterns.

b) Improved provision of extension services for farming practices through conservation farming with appropriate soil erosion control methods in upland areas, using suitable varieties of drought tolerant or early maturing cereal and legume crops like sorghum, millet, groundnuts and beans, in rotation and intercropping systems. It is recommended that agricultural practices that improve soil fertility such as agro-forestry be promoted, given the declining productivity of the soil.

The sustainable management of river basins requires that all users are involved in decisions relating to water use. Climate change will exacerbate the variability of water availability for all users.

c) Use of minimum and reduced tillage technologies in combination with planting of cover crops and green manure crops should be encouraged as these help in reversing soil erosion and nutrient loss due to climate change.

d) Establishment of tree nursery management systems for indigenous and exotic trees, fruit trees, and multipurpose and agro-forestry trees in areas with secure tenure, while raising awareness and capacity in improved natural resources management.

e) Development of a catchment management plan for the Msanja River in Kanyangala, required for improved water availability for small scale irrigation systems using treadle pumps for winter gardening, integrating conservation farming and agro-forestry.

f) Given the impacts of droughts on water supply for the community, provisional piped drinking water for the community extended from the commercial farm will help the community with domestic water supply, while an irrigation scheme from the Kafue River should ensure irrigated agriculture for the community.

g) Introduce donkey rearing for animal draught power to support conservation farming, since cattle keeping is adversely affected by the tsetse fly given the close proximity of the area to the national park.

h) Establishment of a health post in Kanyangala to promote awareness on hygiene and sanitation, nutrition, family planning, use of mosquito nets, drugs and traditional remedies for treatment of climate change related illnesses, using trained community health workers to assist the community improve its health.

Adaptation Strategies for Fishing

Under the fishing livelihood, the following adaptation options are suggested:

a) Fish Farming: Fishing is a livelihood activity in central Chiawa. In order to promote more sustainable fishing, fish farming should be promoted. This establishment of fish ponds will reduce dependence on natural fishery systems which are largely overfished and degraded due to increasing sedimentation from upstream fields and tourist boat cruises. This requires training in skills as well as start-up capital for fishers, while following environmental and other standards in appropriate locations to ensure minimal cutting of trees and release of effluents into the river system during flooding. Fish farming should be developed on a sustainable basis by providing start-up funds and training, while following environmental and other standards in appropriate locations to ensure the minimum cutting of trees and release of effluents into the river system during flooding. Demonstrations of improved fish processing, including through the use of energy saving stoves is also important, as one of the main causes of overfishing is poor fish processing, resulting in post harvest losses.

b) Community-based Fishery Management: In order to improve fishery management the community should be encouraged to form a Village Fisheries Management Committee to oversee fishing activities and promote sustainable fishing methods and practices.

c) Improved Hygiene and Sanitation: One of the potential impacts of climate change in Chiawa is the reported increase in diseases such as diarrhoea, cholera and malaria which tend to be worsened by poor hygiene and sanitation in fishing camps. Improving hygiene and sanitation in the fishing camps will help minimize disease outbreaks for the community at large, as most fishing camps are located close to villages

d) Community Tree Nursery Together with the Farmers: A community tree nursery will promote improved availability of fuel wood for fish processing using the energy saving stoves. This will help reduce deforestation resulting from fire wood collection near river and lake banks.

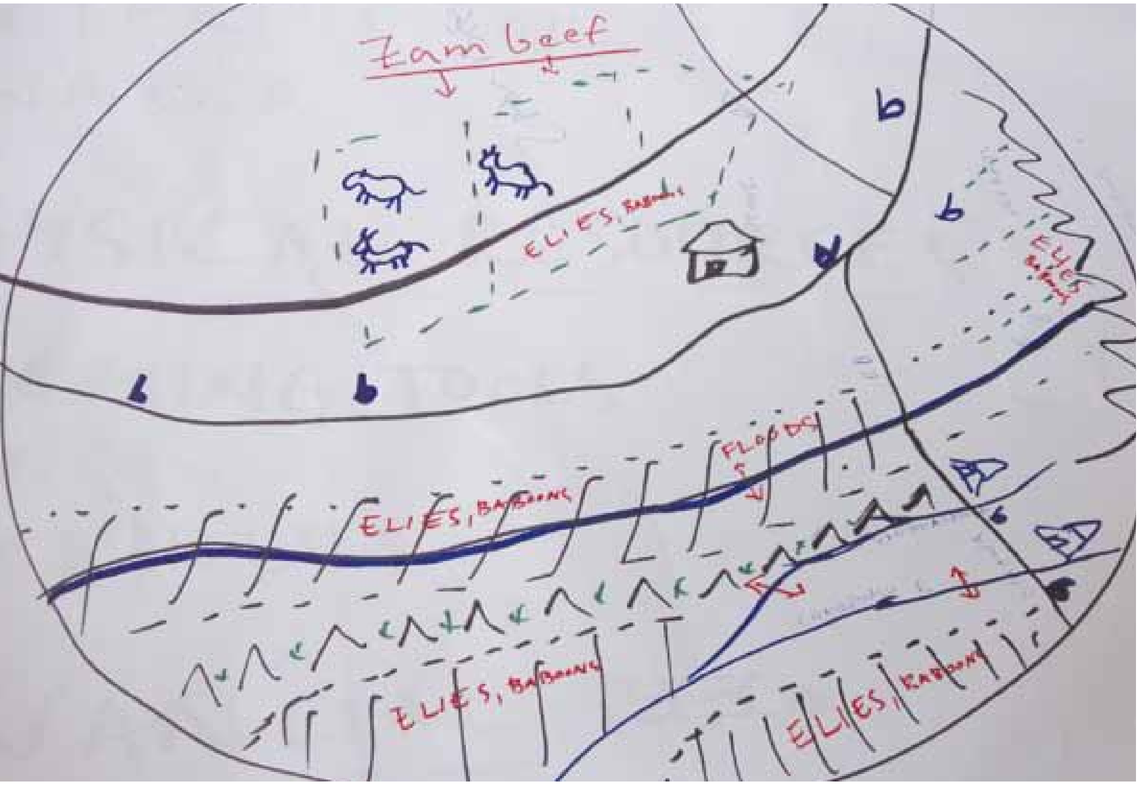
e) <u>Diversification of Income Sources:</u> Fishers should be encouraged to engage in winter gardening to supplement their incomes given the abundance of water from the Zambezi River. In addition, development of small-scale crafts and curios enterprises based on sustainable harvesting of raw materials which would appeal to tourists should be supported and promoted.

Conclusion and Recommendations

The local community in Chiawa depends directly on the services that the various ecosystems in the area provide. However, these ecosystems have been adversely affected by impacts of drought, high temperatures, desertification and flooding. The coping strategies currently applied by the community may be working in the short-term but most of them are not sustainable in the face of climate change and increasing environmental degradation foreseen in the area.

A number of underlying causes of vulnerability, particularly environmental degradation, continue to contribute to the reduction of the capacity of ecosystems to meet the people's needs for food and other products, and to protect them from the impacts of climate change. As such, maintenance of biodiversity and the services that healthy ecosystems may provide to the community will be a triple-A investment, in addition to diversification of livelihoods necessary for building local resilience to the impacts of future climate change.

In order to contribute to the enhancement of climate change resilience in the community of Chiawa, bodies such as the African Wildlife Foundation, the Participatory Ecological Land Use Management group, the Zambia Wildlife Authority (ZAWA), governmental departments (GRZ) and local authorities should integrate current climate variability data, projected climate change impacts, vulnerability and adaptation into development planning and policy processes. Recommendations for mainstreaming climate change adaptation in the region should include the following:



A social and hazard map produced by the Chiawa community during a Participatory Rural Appraisal Vulnerability Assessment meeting.

a) Creating partnerships with weather and climate institutions such as the Meteorology Department for gathering and using accurate climate data;

b) Using traditional knowledge and starting from what people are already doing on the ground when developing adaptation strategies;

c) Integrating adaptation into development plans and policies;

d) Investing in ecosystem health to build community resilience and adaptive capacity to climate change;

e) Improving information and knowledge sharing from pilot climate change adaptation activities;

f) Moving from short-term coping towards long term adaptation so that the underlying causes which affect people exposed to climate change hazards and impacts are addressed in a timely manner; and

g) Diversification of livelihood activities for communities, as people with diverse income sources tend to be more resilient to climate hazards.

It is important to raise community awareness on climate change issues, projections and potential adaptation strategies, so that communities can prepare themselves as much as possible for the upcoming impacts. Adapting to climate change impacts requires awareness raising campaigns focussed towards all stakeholders. Finally, we need to be aware that climate change adaptation processes require a balance between both short-term coping strategies to deal with current climate variability, and long-term adaptation strategies necessary to address future climate change.

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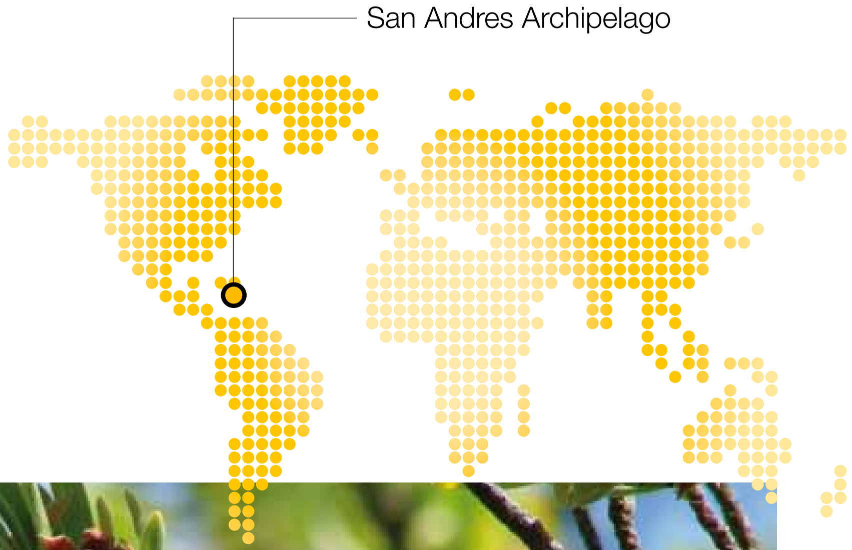
Chapter 8



Ecosystem-based Adaptation in the Seaflower Marine Protected Area, San Andres Archipelago, Colombia

A Community-Based Approach

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The Seaflower Marine Protected Area (MPA) around the San Andres islands is Colombia's first MPA, the largest in the Caribbean, and protects the Caribbean's most extensive open-ocean coral reefs. It covers 65,000 km^2 in the San Andres Archipelago and is managed by the regional representative of Colombia's National Environment System, CORALINA. This entity worked together with local stakeholders on MPA planning, using an ecosystem-based approach to marine management (EBM). A proper balance between conservation and sustainable use is promoted through multiple-use zoning of entire ecosystems and MPA objectives that integrate conservation with local development. Community participation and adaptive, decentralized management – key EBM principles – are emphasized. However, climate change now threatens the ecosystems the MPA was designed to protect, in turn threatening the very survival of the community. Dependence on coastal and marine resources, isolation, poverty, and high population density make the San Andres islands particularly vulnerable to impacts of climate change. Ecosystem-based adaptation (EbA), which relies on recovering and maintaining ecosystem services and the resilience of natural resources rather than on costly engineering solutions, is the most viable way forward. Putting EbA into practice in Seaflower is rooted in achieving the MPA's sustainable development objectives by strengthening adaptive management, implementing multiple-use zoning, ensuring on-going stakeholder involvement, and monitoring MPA effectiveness. Although EbA was not a consideration during planning, the Seaflower MPA's reliance on ecosystem- and community-based approaches effectively laid the groundwork for climate change adaptation. Nonetheless, serious challenges remain; poverty must be alleviated to reduce pressure on fragile resources, local capacity must be built, and adequate financial support must be secured.

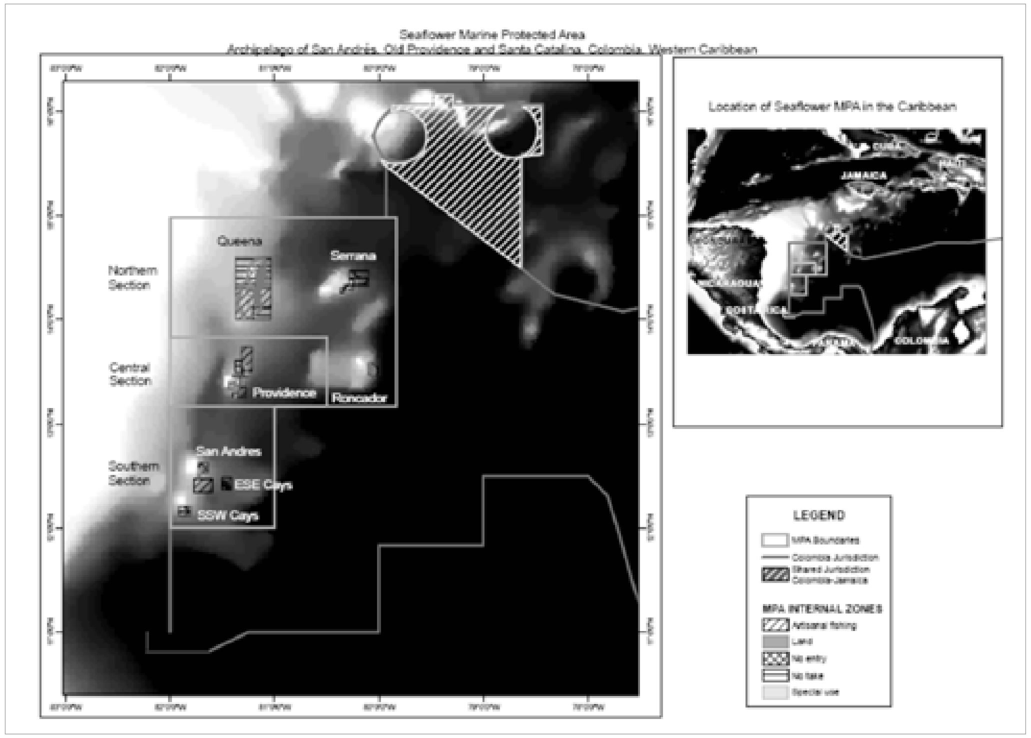
Keywords: Ecosystem-based adaptation, Climate change, Marine protected area, San Andres Archipelago, Seaflower

Introduction

Background

The Seaflower Marine Protected Area (MPA) is Colombia's first MPA and the largest in the wider Caribbean. It covers 65,000 km^2 and is divided into 3 administrative sections: Northern (37,522 km^2), Central (12,716 km^2), and Southern (14,780 km^2) (Fig. 1). This MPA is

Figure 1. Location, boundaries, and sections of the Seaflower Marine Protected Area (MPA), Colombia. Courtesy: A. Mitchell, CORALINA.



part of the larger Seaflower Biosphere Reserve (BR), which encompasses the entire San Andres Archipelago. The CORALINA Corporation for the Sustainable Development of the Archipelago of San Andres, Old Providence and Santa Catalina (OPSC) is the local representative of Colombia's National Environment System (SINA). In the past CORALINA created the Seaflower BR and MPA in collaboration with the community. Now, CORALINA is responsible for the day-to-day management of the BR and all three MPA sections. The marine area of the Old Providence McBean Lagoon National Park, which is managed by the National Natural Parks unit, is part of the Central Section. CORALINA's Old Providence office and the local branch of national parks work closely together in this section. The MPA was first established as a means to protect marine biodiversity and promote sustainable use, but now the Seaflower MPA is seen as an essential tool to combat climate change impacts in the archipelago through the application of ecosystem-based adaptation (EbA) approaches.

The San Andres Archipelago

The San Andres Archipelago contains the largest open-ocean coral reefs in the Caribbean. The location means that, according to the 2004 World Resources Institute's (WRI) Reefs at Risk analysis, the archipelago represents not only one of the most extensive reef areas in the Western Atlantic, but also a particularly complex one due to exposure to currents, wave action, and other physical oceanographic factors (Burke and Maidens 2004). The MPA includes the archipelago's most significant coral reef, mangrove, and sea grass ecosystems (habitats) such as the San Andres barrier reef and coastal waters, southern archipelago atolls (Albuquerque/SSW Cays and Bolivar/ESE Cays), Old Providence and Santa Catalina (OPSC) barrier reef and coastal waters, and significant atolls and banks in the northern archipelago (Quitasueño/Queena, Serrana, and Roncador). Representative examples of coastal and marine ecosystems found in the Caribbean are protected at every site. These ecosystems are valued locally for fisheries, tourism, and shoreline protection, as habitats, and by tradition,

but also are important for national and global conservation. The deep waters between the sites, although mostly unstudied to date, are assumed to be important for maintaining marine food webs and deep sea habitats, flows, connectivity, spawning aggregations, larval dispersal, etc.

The archipelago has a long social and economic history distinct from that of mainland Colombia. Indigenous islanders (now known as *raizales*) descend from European (mainly English) settlers and Africans (slaves and runaway slaves from other islands) who came to the islands in the 17th, 18th, and 19th centuries. Ethnically distinct within the nation, they are English-speaking Protestants. The culture and natural resources are now protected by the new Constitution of 1991 (Art. 310). The islands' remoteness meant that for centuries the community had a high degree of autonomy, controlling their own resources and economy until the latter half of the 20th century. Islanders have pursued a mix of livelihoods; within a single household it was (and still is in traditional households) common to fish and to farm (including raising animals like cattle, pigs, and chickens), hold an outside job, and perhaps go to sea, or own a small business.

In 1953 San Andres was declared a free port. The most significant impact of this designation was the development of a commercial tourism model that targeted mainlanders, attracting them to San Andres to purchase foreign goods. This shifted the economic base from small-scale agriculture and fishing, beginning a process of economic and political marginalization of native islanders. The tourist trade was dominated from its inception by mainlanders. Unintended consequences of the free port seriously affected the *raizal* community. First, it prompted massive migration from the mainland. Then, unable to speak the language, few islanders could get licenses to participate in the free port. Hotels, restaurants, shops, and other development are still mostly owned and staffed by off-islanders. As seamen and boat-builders, islanders had been trading directly with Caribbean countries for centuries. With modernization, after informal trade was abolished, products had to be sold to the mainland at fixed prices. Soon, artisanal fishers had to request permission from naval authorities to go to sea. Losing control over their livelihoods and knowing little about the introduced models of commerce and tourism, native islanders became economically

Table 1. Increase in population density at San Andres Island (1789–2005).

Year	Population size (total number of inhabitants)	Population density (individuals per km^2)
1789	220	8
1793	393	15
1835	644	24
1851	1,275	47
1912	3,124	116
1938	4,261	158
1951	3,705	137
1953: Declaration of Free Port		
1964	14,413	307
1973	20,359	754
1984	31,290	1,159
1993	49,663	1,839
2005	65,627	2,431

marginalized and their quality of life and natural resource base declined.

San Andres Island (SAI) and Old Providence/Santa Catalina (OPSC), with areas of 27 km^2 and 18 km^2, respectively, have an official population of 71,000 (66,000 in SAI and 5,000 in OPSC; DANE, 2007). These figures do not include the "floating" population of tourists, vacation-home owners, and seasonal workers. With a population density of about 2,400 inhabitants per km^2, San Andres is the most densely populated oceanic island in the Americas and one of the most densely populated in the world. Table 1 shows the increase in population size in San Andres over time, with notable increases in the decades following the free-port declaration. The uncontrolled influx of mainland migrants seeking work in the tourism and commercial sections combined with economic incentives that, for nearly 30 years, encouraged continental Colombians to move to San Andres contributed to impoverished social conditions, divisive cultural tensions, and a decline in quality of life of the *raizal* community (Howard and Taylor, in press). In 2000, household surveys revealed that island-wide unemployment and under-employment had reached 53.6 %, while 48 % of households lived on less than US $1 per person per day (Newball, 2000; Van't Hof and Connolly, 2001).

The idea to set up a locally managed MPA emerged during the search for long-term solutions to growing coastal and marine problems. The community agreed with CORALINA that a multiple-use MPA would be a viable tool to reduce human impacts and threats on productive, vulnerable ecosystems and also improve sustainable use (Howard et al., 2003). The archipelago's socioeconomic situation meant that planning had to take cultural and economic realities into account for conservation to be effective. Stakeholders decided that properly designed zoning done collaboratively could serve both conservation objectives and local needs, so the MPA is zoned for management levels ranging from total protection to controlled industrial fishing.

Ecosystem-based Management

The governmental agency CORALINA worked with local stakeholders to design MPA boundaries and zones, and identify management actions using an ecosystem-based approach to marine management. The Convention on Biological Diversity (CBD) defines the ecosystem approach as *"a strategy for the integrated management of land, water, and living resources that promotes conservation and sustainable use in an equitable way"* (COP 5, decision V/6; CBD, 2009a).

The ecosystem approach requires adaptive management to deal with the complex and dynamic nature of ecosystems and the absence of complete knowledge or understanding of their functioning. It recognizes the rights of indigenous peoples or those who have traditionally lived off the resources, considers both cultural and biological diversity, and emphasizes fair and equitable management. The approach is based on 12 inter-linked principles, all of which were considered in planning the Seaflower MPA, but several were prioritized as being especially significant to address the issues hindering marine conservation in the archipelago. Major drivers underlying ecosystem degradation include over-extraction underpinned by poverty and growing food insecurity, and the community's disenfranchisement and lack of ownership of the marine resources that are the basis of their livelihoods, culture, economy, and subsistence. To address the latter, the principle of decentralized management was adopted. Besides being the first MPA in Colombia, the Seaflower is also the first protected area to be declared at the national level but managed locally by the regional autonomous environmental authority; thereby implementing the CBD principle that *"management should be decentralized to the lowest appropriate level"* (CBD, 2009a). Because the archipelago's biophysical, cultural, and economic situations are distinct from that of mainland Colombia, the national government acknowledged that a decentralized approach would improve the efficiency, effectiveness, and equity of any coastal and marine management regime.

Next, the principle of stakeholder participation was emphasized. Not only were stakeholders consulted and involved in every step, they also had decision-making power and came together to get a sense of ownership of the MPA planning process, reaching consensus and signing formal agreements on MPA objectives, zoning, external boundaries, and management structure. This management structure has three participatory advisory committees – the Stakeholder Advisory Committee (SAC), which is composed of marine users such as artisanal fishers, water sports operators, and representatives of the indigenous community; the Inter-Institutional Committee (ICC) which includes other institutions – besides CORALINA – that are involved in coastal or fisheries management, and the International Advisory Board (IAB), which is made up of experts in MPA management from around the world. This collaborative structure ensures stakeholder involvement in implementation and supports adaptive management by facilitating the continuous incorporation of scientific, technical, and indigenous knowledge into management.

Putting in place multiple-use zoning also strengthened the principles of the ecosystem-based approach. Conservation zones encompass adjacent ecosystems, ensuring that ecosystems are managed to conserve structure and functioning. Multiple-use zoning promotes the proper balance between conservation and sustainable use of coastal and marine resources by managing some zones for sustainable use. However, now that the Seaflower MPA is legally in place with objectives, zones, and a management plan and striving to realize its mission to integrate conservation, economic development, and equitable distribution of benefits through implementation of collaborative, ecosystem-based management, a global driver, climate change, threatens the marine environment and, indeed, the very survival of the islands and their communities.

Climate Change Impacts

To understand and accurately predict the effects that climate variability and climate change impacts will have on the marine environment and its living resources – not to mention the spiral effect as changes in oceans feedback into climate change given the synergy between oceans and climate – a great deal of research is needed. The natural variability of ocean environments is substantial and there are many unknowns. However, the Intergovernmental Panel on Climate Change (IPCC) and the Intergovernmental Oceanographic Commission (IOC) predict impacts including sea level rise (SLR), more intense tropical storms, acidification, and physical changes in water temperature, stratification, and currents. All of these would stress coastal and marine ecosystems including coral reefs, mangroves, sea grass beds, and beaches and their associated biodiversity and fisheries resources.

The IPCC Fourth Assessment Report (2007) reported that global sea level is expected to rise between 18 and 59 cm by the end of this century, even without changes in ice flows in Antarctica and Greenland. Local rates of sea level change will depend on global temperature changes and ice melt, as well as on more regional changes in ocean and wind circulation patterns. The Caribbean Community and Common Market's (CARICOM) Climate Change Centre predicts that changes impacting the Caribbean region by 2100 will include a temperature increase of 2 to 4.5 degrees, an increase in sea level of 11 to 77 cm, altered weather patterns, and an increase in hurricane intensity, with significant impacts on tourism, aquifer water, infrastructure, and human settlement, plus ecological impacts such as coastal and marine habitat loss, beach erosion, and destruction of mangroves and coral reefs (CARICOM, 2008). In the last several decades, coral bleaching, pathogens, invasive species, hurricanes, and possibly the warmer water temperatures in some sites have contributed to the rapid decline in the region's live coral cover.

Low-lying islands are especially threatened by climate change. The level of vulnerability depends on a variety of biophysical, sociocultural, and economic factors. Important biophysical factors include the island's remoteness, elevation, size, limited natural resources including fresh water, and susceptibility to hurricanes, tropical storms, and tsunamis. Vulnerability also depends on sociocultural and economic factors like the degree of development and settlement in the low-lying coastal plain, economic dependence on coastal tourism, the importance of subsistence agriculture and fishing to food security, population growth rates, limited financial and technical resources and human capital, and economic and cultural dependence on coastal ecosystems like coral reefs, mangroves, sea grass beds, and beaches (Howard, 2004). Furthermore, a small island's ability to withstand the effects of climate change will depend on its natural adaptive capacity. High levels of anthropogenic stress weaken natural resources and ecosystems, lowering an island's capacity to withstand and adapt to changing conditions.

With little land area or terrestrial resources, the economies and traditional livelihoods of many small islands are dependent on the condition of marine ecosystems. In San Andres, the local economy relies almost entirely on coastal tourism and mangrove and reef-based fisheries. Furthermore, the largest clusters of housing and infrastructure are found in a belt from the coastline to 2 km inland (Faticone, 2008). The unique physical, ecological, and socioeconomic characteristics shared by small islands leave them particularly vulnerable to the adverse effects of climate change. Small island archipelagos with high poverty levels and population densities, such as San Andres, will find adaptation to climate change especially challenging because they are already beset by many problems that will be exacerbated by climate change.

For the San Andres Archipelago, recent models predict a rise in sea level of 40 cm by 2060 (IDEAM). The archipelago has also been identified as having one of the highest water temperatures in the region (NOAA, 2005). Marine organisms will be influenced by resulting changes in temperature, light, and nutrient supply, which is expected to contribute to changes in species abundance, distribution, and composition. Links are poorly understood, but habitat degradation and species loss will unquestionably stress marine ecosystems, affecting health, biodiversity, productivity, and their ability to maintain and ultimately deliver essential ecosystem services. Colombia's national climate change policy calls for implementation of adaptation measures to reduce risk and vulnerability, especially for areas severely threatened by climate change. The archipelago represents a unique oceanic department in Colombia, and its fragile coastal and marine ecosystems, isolated location, poverty, and high population density make it particularly vulnerable to impacts of climate change.


Shoreline vegetation plays a crucial role in protecting coastal communities and reducing shoreline erosion.

Ecosystem-based Adaptation (EbA)

CBD (2009) defines ecosystem-based adaptation (EbA) as *"the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people adapt to the adverse effects of climate change."* As applied to adaptation, the ecosystem approach promotes activities that address both human and biological aspects of the ecosystem where the adaptation activity takes place. EbA aims to preserve and restore ecosystems by using systems that provide natural, cost-effective protection against climate change threats (CBD, 2009b). For example, coastal ecosystems including coral reefs, mangroves, and beaches provide natural protection from storms and flooding. EbA also focuses on conserving biodiversity and the natural resources essential for the survival of coastal communities.

The ecosystem-based approach to adaptation relies on recovering and maintaining ecosystem services and the resilience of natural resources rather than on engineering and costly human-made infrastructure like sea walls, jetties, and levees. The cost of protecting shorelines with "hard" infrastructure like breakwaters and sea walls varies according to the type of protection, size of the structure, design, and availability of construction materials and human capital. However, the cost of infrastructure protection is likely to be more than many island nations and dependencies can afford, especially those in the developing world. Vulnerability studies done for some small islands indicate that the cost of constructed coastal protection would be a significant proportion of their GNP (IPCC, 1996). For example, nearly 20 years ago it was estimated that US$ 550 million and US$ 190 million would be needed to provide initial shoreline protection works in Malta and Cyprus, respectively, to protect against a 20–30 cm rise in sea level (Sestini, 1992). In the Caribbean, the government of Jamaica estimated that protecting the coastline from a sea level rise of one meter would cost up to US$ 426 million, or nearly 20% of its GDP (Sem, no date).

Taking an EbA approach to climate change is the most viable way forward for the San Andres Archipelago for many reasons. The islands are especially vulnerable to climate change impacts, but funding and human capital to build and maintain costly infrastructure are unavailable. Furthermore, the islands are more remote than other islands in the Caribbean, and the land mass is tiny. The remoteness means that there is no easy or cheap access to the resources and physical territory of other places where residents might acquire food or water, dispose of wastes, commute to work, get fuel, and so on. The inhabited islands support a very large population relative to the land mass, giving San Andres the highest population density of any oceanic island in the Americas. As noted earlier, nearly half the inhabitants live below the poverty line; indeed, in 2000, about 32% of households were without a steady income (Newball, 2000). The remoteness, population, and poverty place enormous importance and demands on the coastal and marine ecosystems that support the local economy, livelihoods, and subsistence.

Introducing effective methods to help natural systems and communities adapt to climate change is essential to avoid ecosystem degradation and collapse, loss of biodiversity, and social tragedy. EbA emphasizes cost-effectiveness by strengthening programs and measures that are in place. In San Andres, "natural infrastructures" such as coral reefs and mangroves are already protected and managed in the Seaflower MPA, so at this time it is the best available means to advance EbA in the archipelago. Proper management of the MPA will keep coastal and marine ecosystems and biodiversity healthy and resilient, while allowing the community to better control and cope with impacts of the changing climate. And unlike built adaptation measures, proper management of ecosystems will provide benefits beyond protecting the coast, its many residents and infrastructures from flooding and storms. At a fraction of the cost, EbA will also benefit islanders by sustaining productive fisheries, maintaining beaches and the translucent coastal waters that draw tourists, reducing negative impacts from sedimentation and pollution, and conserving resources essential for the production of food and water.

Methodology

The Importance of Seaflower MPA Zoning

The Seaflower MPA's multiple-use zoning paves the way for ecosystem-based adaptation to climate change in the San Andres Archipelago. To understand why this is so, it is important to examine the zoning process and the relevance of its outcomes to EbA. For the Seaflower MPA to be effective, it had to be owned by the community from the outset. The community-based approach is central to why the MPA can also function as a tool to help the community adapt to climate change impacts. The MPA's zones were designed by the community and authorities using an ecosystem-based approach to assure the protection of ecologically important areas, and hence of biodiversity habitat and ecosystem services. An exceptional feature is the level to which zoning combined best available technical and scientific expertise with indigenous knowledge.

The Seaflower MPA was enacted at the national level in January 2005 by the Ministry of Environment, Housing, and Territorial Development. This declaration legalized the external boundaries delimited in collaboration with stakeholders, and named CORALINA as management agency. The three administrative sections were approved by CORALINA's Board of Directors in June of the same year. Meanwhile stakeholder agreements were reached that defined zoning plans for each administrative section, including detailed maps of key sites. General regulations on the uses and actions permitted in each type of zone were included in these agreements. Regulations are consistent for zone types across sections, except for special use zones where uses and regulations are zone-specific (these are not yet enacted).

Early in the planning process, MPA objectives were developed in collaboration with stakeholders. These objectives, which take an integrated, sustainable development approach, are:

a) Preservation, recovery and long-term maintenance of species, biodiversity, ecosystems, and other natural values including special habitats;

b) Promotion of sound management practices to ensure long-term sustainable use of coastal and marine resources;

c) Equitable distribution of economic and social benefits to enhance local development;

d) Protection of the rights pertaining to historical use; and

e) Education to promote stewardship and community involvement in planning and management.

To achieve these holistic objectives, five types of zones were identified:

a) <u>No-entry,</u> with use restricted to research and monitoring;

b) <u>No-take,</u> allowing a variety of non-extractive uses;

c) <u>Artisanal fishing,</u> for use by traditional fishers only;

d) <u>Special use,</u> for specific uses like shipping lanes, anchorage, ports, and marinas or uses with the potential to generate conflict like heavily used water-sports areas; and

e) <u>General use,</u> where minimal restrictions apply to preserve MPA integrity.

Within the country, the Seaflower MPA is unique in its integrated, sustainable development objectives and enactment of multiple-use zoning to achieve them.

MPA Zoning Methodology

The process to zone the MPA was a five-year collaboration between institutions and resource users. Participatory mapping, consultation, and capacity building involved fishers, dive shops, water sports operators, and other fisheries management and marine authorities. Stakeholders were identified early in the process and organized into focus groups (Baine et al., 2007). Groups worked alone at the beginning and with other groups or in plenary as the process progressed. Ultimately, decisions were made jointly, with the community having input on boundaries and the last word on zoning. Formal agreements were signed with stakeholders, followed by the enactment of the names and boundaries of the three sections, zoning, and general regulations by CORALINA's Board of Directors meant to make these agreements operational.

To gather the information needed to support zoning, the MPA project team used a variety of methods. Desk studies were completed to review and organize what existed and to identify gaps. Since little information was available, a great deal of new information was collected. Research was a major activity during project planning and also during the first two years of MPA planning. Indigenous knowledge about past and present distribution of resources and patterns of use was collected from stakeholders through surveys, semi-structured interviews, and social mapping. Information was gathered from scientists, managers, and communities about risk and vulnerability. Socioeconomic information was collected from primary user groups, and a study examined the value stakeholders gave criteria related to zoning. Baseline data were gathered in field expeditions. A rapid assessment method was used to collect information on coral condition. Benthic habitats and key species were also studied. Project economists simultaneously gathered traditional information on resource distribution, abundance, and use for each site.

Zoning criteria – representativeness, connectivity, inclusion of key habitats, ease of demarcation, likelihood to foster compliance, and potential to effectively meet MPA objectives – were identified by the MPA project team with input from international advisors. The criteria were introduced and explained to the community. Specific zoning objectives were then designed, with input from experts and local stakeholders, to guide the zoning process and ensure that the zoning plan satisfied the criteria and achieved MPA objectives within each of the MPA's three sections; i.e. the concept was to implement different types of zones serving different purposes that, when taken as a package, allow the achievement of seemingly contradictory objectives at a systems level.

The zoning objectives were:

a) <u>Species protection.</u> Provide protection to biodiversity and species of special concern;

b) <u>Habitat protection.</u> Protect representative habitats and those that are critical to the survival of species of special concern and to the maintenance of ecosystem functioning, taking into account habitat connectivity;

c) <u>Recovery.</u> Allow for regeneration of degraded benthic communities and/or overexploited populations of fish and other marine species;

d) <u>Socioeconomic impacts.</u> Minimize adverse socio-economic impacts;

e) <u>Sustainable use.</u> Ensure sustainability of consumptive and non-consumptive uses of the resources;

f) <u>Conflict resolution.</u> Eliminate or minimize incompatible uses and conflicts between users;

g) Equity and tenure. Guarantee equitable distribution of economic and social benefits and protect historical/traditional rights; and

h) Implementation. Consider ease of demarcation for management, compliance, and enforcement.

Each stakeholder group worked together to produce maps showing their preferred allocation of zones based on their knowledge, needs, and use. Since the marine area being looked at was so large, zoning focused on coastal waters or those that included significant ecosystems like off-shore banks, cays, and atolls. First the Southern and Central Sections were zoned simultaneously in San Andres and Old Providence/Santa Catalina by their respective communities. The Northern Section was zoned last. Because the community of both the Southern and Central Sections frequent this area, zoning was done on both islands with the various user groups. Fishers from the Southern and Central Sections were occasionally brought together to discuss and agree on Northern zoning. Stakeholders also identified external boundaries and divisions between sections as part of the process.

CORALINA pulled together the information after each activity – the results of mapping workshops, surveys, interviews, etc. – and entered it into a Geographical Information System (GIS). Information gathered during expeditions was analyzed and systematized, with support from technical partners. GIS maps were then created to illustrate all the information. A technical committee made up of MPA team members overlaid the maps, considered other information gathered during the process, and produced zoning alternatives for each section. The entire MPA team met to evaluate and fine-tune each alternative to ensure that it was faithful to the community's zoning preferences and use patterns and, as a package, satisfied zoning criteria and objectives.

Before alternatives were taken back to the community, they were reviewed by the MPA's International Advisory Board (IAB), who looked primarily at conservation effectiveness. The IAB has an advisory role but is not involved in decision making. Members include marine managers, scientists, and policy experts from around the world who volunteer their time. CORALINA then produced final alternatives for each site that were consistent with expert recommendations and faithful to the participatory process. Finally the alternatives were taken back to the users in plenary. Meetings continued until consensus was reached on final zoning.

Results and Discussion

Zoning Process Outcomes and Their Relevance to EbA

The MPA project's initial goal was to protect a minimum of 2,000 km^2 of significant marine ecosystems within a system of four discrete MPAs (CORALINA, 2000). Ultimately the participatory planning process resulted in a single MPA with three contiguous management sections covering 65,000 km^2 or about 22% of the archipelago's waters. Each of the three sections is zoned for management levels ranging from total conservation to controlled artisanal fishing. In accord with the community's wishes, industrial fishing is allowed only in the Northern Section. The five zone types are found in each section. Their total coverage in the MPA is given in Table 2.

Table 2. Area (km^2) per zone type in the Seaflower Marine Protected Area (MPA), Colombia.

Zone type	Primary purpose	Size
No-entry	Preservation/ conservation	116 km^2
No-take	Conservation	2,214 km^2
Artisanal fishing	Sustainable use	2,015 km^2
Special use	Sustainable use	68 km^2
General use	Buffer area*	60,587 km^2
Total		**65,000 km^2**

* Buffer area: Sustainable uses allowed that are compatible with the protection of conservation zones.

EbA calls for maintaining intact ecosystems to allow biodiversity and people to adjust to changing environmental conditions (Colls et al., 2009). To be viable in the marine area, EbA needs sizeable areas with entire ecosystems under active management. As the Seaflower zoning process progressed, the need to protect large areas of ocean was recognized and addressed. Each of the three sections includes tidal, sub-tidal, and other near-shore waters; off-shore reefs, banks, cays, and atolls; and the open ocean connecting them. Representativeness was a criterion and examples of all coastal and marine habitats and ecosystems found in the San Andres Archipelago are represented. These are coral reefs (atolls, barrier and fringing reefs, coral heads and patches, lagoons, etc.), mangroves, sea grass and algal beds, soft and hard bottoms, beaches, and open ocean (deep sea habitats). Critical areas that are biologically significant are also included; e.g. sea turtle habitat, sea bird colonies, and nurseries. Spawning aggregation sites are being identified and mapped and their zoning status reviewed to ensure adequate protection.

To assure adequate representation of habitats and ecosystems, conservation targets are often used. To protect marine ecosystems and biodiversity these are often 20% or above; for example, Belize has conservation targets of 30% for reefs, 80% for spawning aggregations, and 60% for turtle nesting sites (UNEP-WCMC, 2008). In the case of Seaflower, targets are not defined for the country or region and were not used in zoning. The MPA team looked at recommended targets and those used in other sites but concluded that there was insufficient information to set targets for Seaflower. Another concern was that going into a collaborative process with predetermined targets could be seen by stakeholders as prescriptive and could limit – or be perceived as an attempt to dictate – the community's decisions. Nonetheless, the zoning process produced very high levels of coverage for coral reefs, mangroves, and sea grass and algal beds. Indeed coverage is likely higher than would have been achieved if "top-down" targets had been introduced because targets certainly would not have been set as high as what marine users established through their own volition. Table 3 gives the coverage of key ecosystems included in conservation zones (no-entry and no-take) for each MPA Section, summarized as a percentage of the total ecosystem found in the specific section. For example, 51% of the coral reefs located in the Southern Section are now protected in conservation zones, as are 35% of the corals in the Central Section and 72% of the corals in the Northern Section. Algal beds are also found in all three sections. On the other hand, there have never been mangroves or sea grass beds in the Northern Section.

Table 3. Percentage of main marine ecosystems (habitats) included in conservation zones by Section, Seaflower Marine Protected Area (MPA), Colombia. Further explanation is presented in the main text of this chapter.

Ecosystem	Southern Section	Central Section	Northern Section
Coral reefs	51 %	35 %	72 %
Mangrove forests	100 %	100 %	No mangroves present
Seagrass beds	74 %	48 %	No sea grass beds present
Algal beds	52 %	26 %	81 %

EbA emphasizes the importance of restoring or rehabilitating fragmented or degraded ecosystems and re-establishing critical processes to maintain ecosystem functions (Colls et al., 2009). Seaflower's three sections are contiguous to minimize impacts from fragmentation and "edge effect." In this regard, to be effective EbA requires sound management and protection of interconnected ecosystems. Connectivity, referring to linkages between ecosystems, sites, and processes, was another zoning criterion and was addressed at every site. Each MPA section is linked and ecosystems within each section are connected. Conservation zones include adjacent ecosystems; for example, a section of barrier reef along with its corresponding lagoon, sea grass beds, and mangroves will be protected in a single no-take zone. It should be clarified that there is little scientific understanding of connectivity in the marine environment, so zoning design was based on theory. In the archipelago, aspects relevant to connectivity including larval dispersal, movement of juveniles, and transfer of materials between ecosystems in a single MPA section or between the larger sites of the MPA sections have not been studied.

Ecosystem resilience is critical for EbA and was also considered in zoning. Resilience refers to the ability of a natural system to survive impacts or recover functioning following an outside disturbance, so its importance in an ecosystem-based approach to climate change adaptation is obvious. Multiple coral, benthic, beach, algal and pelagic sites are conserved in every MPA section, while mangroves and sea grass beds are found and protected in two Sections (Southern and Central). Planning took into account replication to improve resilience. Entire ecosystems are protected in every section and conservation zones are sizeable and dispersed to maximize resilience.

EbA is concerned with supporting local communities to adapt and enhance traditional knowledge systems and management practices to changing climatic conditions (Colls et al., 2009). To some extent this is reflected in zoning because stakeholders developed zones based on livelihoods and patterns of traditional use. Considering historical and present use and preferences not only helps meet MPA objectives to improve equity and respect traditional rights, but also is more likely to promote compliance. Likelihood to foster compliance is important to ensure MPA effectiveness and was bolstered by factoring socioeconomic concerns, existing use patterns, and traditional management practices into zoning. Compliance is always important in protected area management, but in sites with weak enforcement and poor funding it must be a priority to ensure effective implementation. Therefore, Seaflower's zoning takes into account existing and traditional use, local knowledge of conservation and management, and community preferences.

EbA also calls for facilitating sustainable use of renewable natural resources under changing climatic conditions. The final criterion was that MPA zoning have the potential to effectively meet the MPA's holistic, sustainable development objectives. To reach objectives that integrate conservation, economic and social development, and equity required that large areas that would be viable for conservation and also that were historically used for fishing and, more recently, for water sports needed to be included. All the islands' coastal waters, the main fisheries and water sports areas, and large connecting areas (buffers) were included to satisfy this criterion. Although EbA was not a consideration at the time objectives were defined and zones were delimited, the results of combining community-based and ecosystem-based approaches to zone Seaflower have strongly positioned the MPA to take an ecosystem-based approach to support climate change adaptation in the archipelago.

The Way Forward

Managing the Seaflower MPA to put EbA to climate change into practice is rooted in effectively achieving the MPA's sustainable development objectives, strengthening adaptive management, ensuring on-going stakeholder involvement, and implementing its multiple-use zoning. Although proper management of the ecosystems and biodiversity protected in the MPA's various zones is the primary tool, diverse methods are needed to truly integrate EbA into management. These include revising monitoring and analysis to improve MPA effectiveness, improving collaborative adaptive management, reducing land-based threats to coastal and marine ecosystems such as pollution and sedimentation, and improving livelihoods and alleviating poverty to reduce pressure on coastal and marine ecosystems. All these methods call for building local capacity through training, community-wide education, and outreach. Indeed, EbA must be mainstreamed into MPA planning, management, monitoring, and evaluation, with knowledge shared and information disseminated to managers, scientists, stakeholders, and the general public through education, outreach, and training.

Actions

Zones must be carefully monitored to ensure that potentially resilient areas are protected. To evaluate effectiveness of zones, biophysical, socioeconomic, and governance effectiveness indicators have been identified in collaboration with stakeholders; however, only a few are being measured to date. Still there is preliminary evidence that conservation zoning is improving the integrity of some habitats and the viability of some species. For example, results of ecosystem monitoring since 2006 reveal that coral condition has remained generally the same, but mangrove coverage has increased throughout the islands. Research and monitoring of several key species found that queen conch *(Strombus gigas)* populations show signs of recovery, as do important stands of elkhorn *(Acropora palmata)* and staghorn corals *(A. cervicornis)* in some sites. These species need to be protected in no-take and no-entry zones to ensure adequate recovery. The populations of a keystone species, long-spined sea urchins *(Diadema antillarum)*, is also recovering following the regional die-off in the 1980s. Such improvements in the condition of ecosystems and species are thought to be the result of effective zoning, adaptive management, compliance, and education, perhaps underpinned by the initial healthy state of the archipelago's ecosystems that helped them withstand and recover from catastrophic regional events including diseases, hurricanes, and bleaching.

Carrying out regular monitoring of ecosystems in different management zones such as no-entry, no-take, and artisanal fishing helps managers and scientists examine ecological changes in MPAs related to levels and types of use. Seaflower has the largest multiple-use zones in the Caribbean, both protected and unprotected from fishing. Putting in place indicators and monitoring protocols targeted to assess specific climate change impacts in each type of zone and ecosystem will provide information that will lead to a better understanding not only of the effects of fishing and effects of climate change on marine ecosystems and biodiversity but, perhaps even more importantly, of the interactions between fishing, non-extractive uses, and climate change in the marine environment. Monitoring protocols are being redesigned using a question-based approach to support management and gather information to help determine how effectively different zones maintain resilience, which will help identify and minimize potential negative impacts of climate change on ecosystems and biodiversity. In particular, to support better implementation of EbA, the revised MPA monitoring program will examine the effectiveness of zoning and management measures within the context of climate change, and will also monitor socioeconomic indicators and strengthen analysis of fisheries data, to determine if climate change is affecting local livelihoods.

Biodiversity conservation is often a co-benefit of managing ecosystems to help people adapt to climate change.

The MPA must be properly managed to maintain the balance between conservation and sustainable use. Seaflower's zones are legally established but, to function properly, zones also need to be clearly demarcated. To this end, each MPA section has been mapped; detailed maps to support research, monitoring, and management have been produced as have simpler maps to educate the wider community. Demarcation buoys now delimit several no-entry, no-take, and special use zones in the coastal waters of the Southern and Central Sections, while some zones are identified by signage on land. However, demarcation is costly to install and maintain, especially in an MPA the size of Seaflower that covers a wide range of sites, ecosystems, and habitats. Education and training is also costly. Marine education with children and broad-based community outreach – covering topics like coral and mangrove conservation, water quality, MPA zoning and objectives, and basics of climate change – are underway, so general awareness is increasing about climate change, coastal and marine ecosystems, and the MPA, but education must be consistent, needs-based, and cumulative so much remains to be done.

To be effective EbA requires adaptive management that is flexible enough to deal with unknowns and the unexpected. Maintaining Seaflower's community-based, collaborative approach to management will ensure that the MPA does not lose momentum, community support, or fail to conserve the marine ecosystems and biodiversity it was designed to protect. Furthermore, the continued effective management and community "ownership" of the MPA will be supported by creating more local jobs in MPA management and building local technical capacity through training in essential functions within the context of EbA such as: adaptive management skills; enforcement, compliance, and research methods; and environmental education, conflict resolution, and outreach techniques.

MPA management is also setting up emergency response programs for ecosystems. Response measures have already included coral reef ecosystem assessment and restoration following Hurricane Beta in 2005, which seriously impacted reefs in Old Providence, and technical analyses of several major groundings on reefs in 2009. However, a structured, formalized emergency response program to prepare for potential acute impacts of climate change such as hurricanes and flooding is needed. Several action plans already support MPA management and directly address anticipated chronic climate change impacts. A water quality action plan is in effect for the coastal waters. Better monitoring of water quality and control of land-based pollutants reduces stress on near-shore ecosystems and should improve resilience, especially of reefs and sea grass beds that are sensitive to sedimentation and excess nutrients generated from sewage, storm water runoff, erosion, and poorly managed agriculture. A management plan for the archipelago's low-lying cays has also been developed that recommends strengthening management and partnerships, broad-based education and training, and using EbA to help combat climate change impacts on these vulnerable environments.

Finally, as mentioned, poverty is a root cause of ecosystem degradation and loss of biodiversity in the archipelago. Climate change impacts will exacerbate poverty – resulting in a downward spiral of poverty and environmental destruction – unless steps are taken as part of EbA to alleviate poverty. To support its EbA measures, management will promote practices compatible with MPA objectives that enhance conservation and provide local economic benefit, including the development of replicable, feasible alternative livelihood projects to diversify the economy, alleviate poverty, and reduce pressure on marine biodiversity and ecosystems. Pilot projects to be examined in partnership with local non-governmental organizations (NGOs) and cooperatives will include seaweed and iguana (lizard) farming with value-added products, marine tourism options led by artisanal fishers, and setting up a community-run mangrove park and nature tourism programs. To maintain and recover coastal and marine ecosystems also means improving the compatibility and practice of existing livelihoods such as fishing, farming and cattle raising, dive tourism and water sports, through examining new technologies, strengthening cooperatives, and promoting sustainable practice. Stakeholder involvement in MPA management can be built with community support programs (e.g. ranger, monitoring, and buoy maintenance support teams), and programs could be supplemented with training in business management, marketing, and other skills related to economic development.

Challenges

In a place like the San Andres Archipelago, EbA is a more feasible and cost-effective approach to climate change adaptation than a "hard" engineering approach. However, proper management of an MPA the size of Seaflower is still costly. Annual operating costs are estimated to vary from US$ 750,000 to 1 million per year. To achieve financial sustainability, CORALINA has applied to the Global Environment Facility (GEF) for funding to help support some of the actions summarized above. An important component of this project would also be for the MPA to become financially self-sustainable. MPA management is looking at implementing a package of flexible and diverse financial mechanisms such as user fees, payment for ecosystem services, a trust fund, and innovative programs of incentive-based conservation. But in a location as poor and troubled as San Andres, ensuring that a sufficient, regular level of financing will be available over the long term will be an on-going challenge.

To successfully implement EbA, gathering and increasing knowledge through targeted research and constant monitoring will be very important. CORALINA does not have the funds, technical capacity, or equipment, including vessels, to mount research expeditions, not only in the far-away open ocean sites but in the coastal waters. For example, the Old Providence barrier reef, on which the people of Providence and Santa Catalina islands depend for their survival, is 32 km long and covers an area of 255 km^2, making it one of the largest reefs in the Atlantic. Studies have identified 40 species of hard coral, 163 species of reef fish from 50 families, 85 known invertebrates, 140 species of sponges, and 23 species of macro-algae in the Central Section alone. Overall, the archipelago contains more than 2,000 km^2 of significant corals, mangroves and sea grass beds. Gathering information technically, and also from the local community, to effectively manage these ecosystems and understand changes that are occurring will be a formidable task.

The communities served by the Seaflower MPA are already confronting impacts that are likely related to climate change and will increase. For example, as in many small islands, the main road in San Andres circles the island along the coast. In some villages this road is crumbling into the sea from erosion as the coastline, currents, and wave patterns shift. Thousands of people live along the coast in these islands, many within several hundred meters of the sea. Displacement and loss of essential infrastructure such as roads, utilities, and water sources are already threatening islanders' well-being. Declining fisheries, invasive species, and loss of corals to disease and bleaching are affecting people's livelihoods and subsistence. Poverty makes them even more vulnerable. And things could become a great deal worse. A recent study revealed projections that climate change could cause major shifts in fisheries from changing currents, higher water temperatures, and other ocean conditions. Studies show that marine fish and invertebrates tend to shift their distributions toward higher latitudes and deeper waters in response to climate change. Resulting changes in food web structure and species distribution could lead to a drop in fisheries catch of up to 40 percent in tropical regions (Cheung et al., 2009). To adapt to climate change impacts will take time, and the clocks on small tropical islands are ticking fast.

What this means for the Seaflower MPA, the San Andres Archipelago, and the wider world of small islands and the people who live on them, is that moving forward with ecosystem-based adaptation is not just a priority, it is a necessity. Because of the urgency and the many unknowns, EbA must take a precautionary approach to ensure recovery and resilience of the marine ecosystems and biodiversity needed for adaptation. As stated in the Rio Declaration (principle 15), "where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." EbA is the most cost-effective measure available at this time and for this approach to work successfully, not only in the Seaflower MPA but in other MPAs around the world, it is necessary to utilize ecosystem- and community-based approaches such as those already employed in Seaflower and go further, anticipating impacts and implementing long-term, holistic strategies that tackle the root causes of marine ecosystem degradation.

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Chapter 9

Fighting to Cope with Climate Change and Drought in the Faguibine System, Northern Mali

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Climate change impacts in West Africa are extensive and profound. This has become evident during the 1970s and 1980s when the Sahel was struck by catastrophic droughts. For instance, the flood dependent ecosystems of the Inner Delta of the Niger River and its Faguibine System in Northern Mali suffered significantly from changes in the climate over the last few decades. In the past, this area was annually much flooded by the Niger River. However, low amounts of annual rainfall that started to occur in the 1970s have caused reduced lake levels and the consequent gradual decline of the Faguibine System. This phenomenon has affected livelihood opportunities in agriculture, livestock production and fisheries, as well as a reduction in waterfowl abundance.

The present study assesses the ways in which the rural population of the Faguibine System have started to address the issue of climate change with its subsequent droughts, reduced river flows and decreased lake levels. Results show that local communities, mainly arabo-berber livestock keepers and sonraï-speaking sedentary farmers, have been forced to abandon their traditional livelihoods over the past decades. Now, adaptation and mitigation actions are being taken to respond to these climate change impacts. The most promising responses seem to be the re-opening of clogged river channels, the stabilization of river banks and sand dunes, the improvement of water management in the Niger River catchment area, and capacity strengthening of communities and institutions in managing natural resources. Fortunately, some successes are already manifesting. For instance, channel clearing in the wetlands has led to flooding of previously dry riverbeds and increased water surface levels of Lake Faguibine, leading to improved food security (e.g. agriculture such as irrigated wheat and rice cultivation, and fisheries). It is hoped that with the implementation of these actions the livelihoods of over 200,000 people in the region will be restored. However, the development and implementation of user agreements among local stakeholders will be a key requirement to achieve long-term success.

Keywords: Adaptation, Agriculture, Climate change impact, Droughts, Flood dependent ecosystems, Mali, Mitigation, Niger River, Sahel

Introduction

Background

Situated in the Sahel region, Mali is one of the largest countries in Africa with 1.24 million km². It is a landlocked country which is amongst the poorest nations on the planet with less than 1,000 US$ per person per year. Main exports are cotton and gold. Mali has a largely rural population of about 12.3 million people. About 1.2 million Malian people are living and working abroad and it is estimated that the remittances of this group contributes over 3% to Gross Domestic Product (GDP). Adult literacy rate is still only 24% and strongly contributes to Mali's low Human Development Index (HDI: 0.38, ranked 173rd out of 177 countries). Women have even less access to education and the Gender Development Index (GDI) stands at 0.371 (ranked 132nd out of 156). Mali is strongly dependent on foreign aid which contributes to nearly 40% of the annual governmental budget (US$ 700 million of a total budget of US $ 1.8 billion).

Climate change has had extensive and profound impacts in West Africa, in particular in the Sahel region which was struck by catastrophic droughts in the 1970s and 1980s. Just 3.8 % of Mali's land is arable, and increased use of natural resources combined with prolonged droughts has nudged the country toward desertification. The Faguibine System is a perfect example of what has happened in this part of the Sahel. Situated some 80 km west of Timbuktu in northern Mali, the Faguibine System (16°45' N, 4°W) is the northernmost depression that can be filled by the annual floods of the Niger River (Fig. 1).

The low average annual amount of rainfall in the area (150 mm) strongly limits the economic options in the drylands surrounding the Faguibine System (FS), mainly to mobile livestock keeping in the short period just after the rains (July-September). However, when flooded, the system provides a range of additional livelihood opportunities in agriculture and fisheries and also provides dry-season grazing for livestock. In addition, transport over water using canoes becomes possible, a considerable improvement in this area which is virtually inaccessible by road. Under such circumstances the system also accommodates hundreds of thousands of waterbirds, mainly overwintering migrants from Europe.

The Faguibine System consists of a complex of five interconnected low-lying fertile plains (or "lakes") of which the spearhead-shaped Lake

Figure 1. Map of the Upper and Middle Niger River and the main current (S = Sélingué; M = Markala) and planned (F = Fomi; T = Taoussa) dams that (will) influence the Lake Faguibine System in Mali.

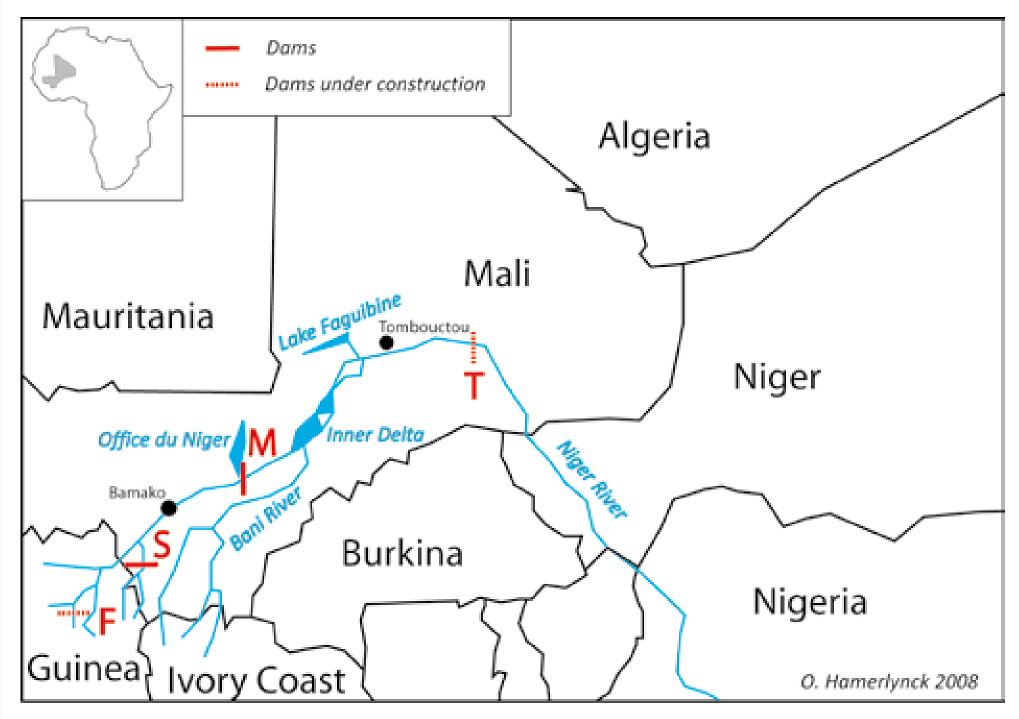
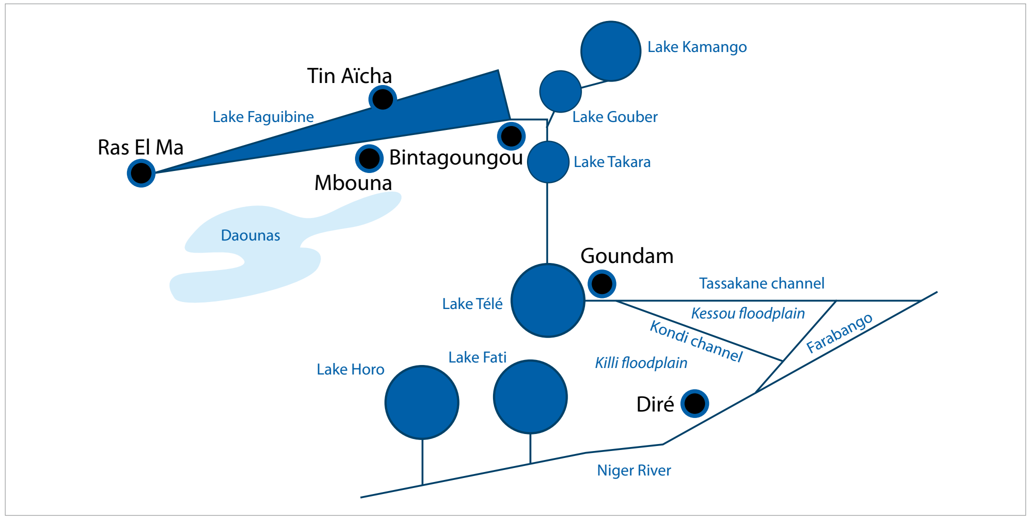


Figure 2. Connecting channels and main depressions that become "lakes" when filled in the Faguibine System downstream from Diré, Mali. The Farabango channel is the western branch of the Niger River that reconnects to the main river downstream of the Tassakane channel.



Faguibine itself is by far the largest (maximum extent 590 km²). The system is connected to the main Niger River by two long (65 and 105 km) and tortuous channels (Kondi and Tassakane) that eventually join and carry the water over another 20 km to the first depression, Lake Télé. In favourable years the water can spill over into the main Lake Faguibine, some 50 km further north. The connecting channels are quite irregular and characterized by series of small thresholds, but from Goundam onwards there is quite a steep slope towards Lake Télé and Lake Takara (Fig. 2).

Lying at the end of a series of basins watered by the Niger River when it floods, Lake Faguibine has experienced widely fluctuating water levels since the turn of the twentieth century, but, at its fullest, has ranked among the largest lakes in West Africa. In 1974, this lake covered roughly 590 km² (230 square miles). By the late 1990s, the traditional livelihoods of fishing, agriculture, and livestock herding became impractical. Even though normal rainfall resumed after 2000, the lake remained nearly dry. Most of the Faguibine System, covering some 3,360 km², is located in the administrative *"cercle*[1]*"* of Goundam which, in 1998, had a population of 131,406 inhabitants and currently some 170,000. Fifteen municipalities are in the Goundam *cercle,* three in neighbouring Diré and one in Timbuktu. Within Mali, the Timbuktu Region is among the poorest with very low human well-being indicators, even in comparison to the rest of Mali.

The Issue

Mali is part of the Sahel region that is affected by armed conflicts and humanitarian crises which have strong linkages to climate change impacts. Such impacts include the gradual decline of Lake Faguibine in Mali since the mid-1970s. Indeed, the Lake Faguibine region in Northern Mali was once a thriving wetland system. Communities developed around the resource, with agricultural and pastoral lifestyles dependent on its flooding regime. However, in the past hundred years the lake has experienced fluctuations of drought, completely drying up in 1914, 1924 and 1944, and remaining at drastically low levels since the 1970s. The shrinking lake has forced more than 200,000 people to abandon their traditional livelihoods, which revolved around agriculture, livestock, forestry and fishery. These drought periods have led to hundreds of human deaths and the loss of millions of livestock. Besides increasing poverty the decline contributes also to

[1] The *"cercle"* is the administrative unit between the *"commune"* (municipality) and the region. There are eight administrative regions in Mali, of which Timbuktu is by far the largest but has the lowest population density (less than two inhabitants/km²).

the loss of biodiversity in the region, such as loss of migratory bird species.

With the collapse of the lake and floodplain ecosystem productivity, the local communities, mainly arabo-berber livestock keepers and sonraï-speaking sedentary farmers, have been forced to abandon their traditional livelihoods. Nomadic groups lost most of their livestock and became sedentary with great dependence to emergency relief programmes. A substantial proportion of the able-bodied sedentary farmers migrated either to the parts of the Faguibine System (FS) that were still flooding or to more southerly areas of Mali, especially to secondary towns and the capital, Bamako. Many of these movements were accompanied by increased competition for resources in the remaining viable space and led to the marginalization of the most vulnerable groups. During the Touareg rebellion (1990 to 1995) the area was almost entirely depopulated as most arabo-berber groups sought refuge in neighbouring countries, mainly Burkina Faso, Mauritania and Niger, while most sedentary farmers were moved to the Inner Delta.

Most of the discharge in the Upper Niger River comes from the high rainfall areas in Guinea, Ivory Coast and southern Mali. The tendency in these areas has been a decline in rainfall that has been reflected by a decline in average discharge of the Niger River. In addition to climate change the other factors that determine the flow in the Niger River are human interventions such as land use change (mainly deforestation for conversion to agriculture but also seasonal burning to revive pasture), increased abstraction for irrigation (in particular by the vast "Office du Niger") and the use of dams for hydropower production. All these factors are affecting the hydrology of the river with a tendency for reducing the height of the flood peak causing the most concern, especially the one caused by the important storage capacity of the planned Fomi dam in Guinea (Zwarts et al., 2005). For the FS the most relevant variables are the height and duration of the flood peak at Diré, just upstream of the system. Effectively, because of the long distances that the water has to flow to reach Lake Faguibine, the force with which it enters the system is a major determinant. That force is mainly determined by the height of the water level at the entry to the Faguibine System.

Actions Taken to Respond to Impacts of Climate Change

The Faguibine System can be restored by: (a) re-opening the clogged river channels; (b) stabilizing river banks and sand dunes; (c) improving the management of water resources in the catchment and the Niger River; and (d) strengthening the capacity of the communities and institutions in the management of their natural resources. Consequently, the livelihoods of over 200,000 people in the region and beyond will be restored. The first condition for the filling of the Faguibine System's lakes is an adequate flow at Goundam, capable of rapidly filling Lake Télé. Water starts entering the Kondi and Tassakane channels when the level in the Niger River reaches 258 m IGN (*sensu* Institut Geographique National) but the flood peak needs to get up to at least 261 m IGN to get a significant flow at Goundam. This can only be achieved if the Kondi and Tassakane channels are well maintained and clear of obstacles. Because of the length (some 170 km along the Tassakane) and the complexity of the connections between Lake Faguibine and the Niger River it takes a series of high flood years to completely fill Lake Faguibine and similarly, once full, it takes several years for it to dry out. These conditions were the driver that led to the actions now taken to respond to the impacts of climate change and drought in the Faguibine region.

The idea of re-flooding the Lake Faguibine System is not new. It was revived each time the lake dried out, at least as early as 1905, and unrecorded interventions on its hydraulic feeding channels have probably been conducted by its users since long (UNEP, 2009). Between 1986 and 1990, the United Nations' Sahelian Office (UNSO) project sought to reconnect the Faguibine System to the Niger River in order to bring back the floods. The project worked to shorten the Kondi channel by the establishment of a new connection to the Farabango and by the cutting of meanders. In addition, sand was removed manually and mechanically from the channels to improve flow. After the forced end of the intervention in 1990 (due to insecurity), the channels were not maintained and wind-blown deposits accumulated to the problems caused by man-made obstacles.

With peace re-established in the area in 1995 the main interventions in the Faguibine System were conducted by the German Gesellschaft fuer Technische Zusammenarbeit's (GTZ) Mali-Nord Programme in collaboration with the European Union (EU) and the World Food Programme (WFP). The emergency phase (1995–1999) concentrated on support to the return of the refugees, the reconstruction of social infrastructures in all parts of the FS, and the introduction of irrigated agriculture along the Niger River. Downstream stakeholders also revived the concept of re-flooding the FS, and its municipalities, established in 1999 partially due to the instability of the region, embarked on a renewed rehabilitation effort primarily using its own means. From 2000 to 2005, GTZ and the German Kreditanstalt für Wiederaufbau (KfW) invested in finalizing infrastructure and expanding the work on irrigation and controlled flooding in an area much wider than the FS.

Initial studies were funded in 2002, a regional forum discussed the development options in April 2004, and the "Office pour la Mise en Valeur du système Faguibine" (OMVF) was created in January 2006. With government funding, OMVF has initiated a vast programme of deepening the connecting channels, the removal of man-made obstacles in the system, the stabilization of dunes and river banks, reforestation, etc. Since 2002 there has been cooperation between the various villages of the FS to manually remove the sand. OMVF now coordinates this activity. At the request of the Mali Government, the United Nations Environment Programme (UNEP) proposed to contribute to the rehabilitation and sustainable management of the Lake Faguibine System for improved human well-being. Its project focuses on strengthening civil society groups and engaging people from all sectors of society in the restoration of the Lake Faguibine ecosystem. Lack of resources, though, has pushed groups into violent competition for resources. The UNEP program aims to bridge those gaps by including all the local communities in conservation education and mitigation. As the ecosystem is restored, it is hoped conflicts will diminish, as there will be greater cooperation among competing groups. At the same time, the partner environment is expected to be strong enough to support everyone.

Wetlands in drylands are especially important ecosystems to support people in the face of climate change. Well-managed wetlands can provide for people and biodiversity.

The mitigation efforts focus on clearing waterways to allow the rivers and streams to flow and fill the Faguibine System. Siltation has played a large role in the destruction, so a crucial component of restoration is digging out riverbeds and streams. Additionally, dunes and riverbanks are being stabilized and reforestation is promoted to ensure a sustainable and lasting impact. Plant life strengthens the riverbanks and dunes to prevent collapse and blockages. Man-made obstacles and dead animals also dam the river flow and are being removed. Entire communities are involved in the project's labour. While men rebuild riverbanks, women plant trees.

Results

Some positive results have already been achieved with these different interventions. For example in 1990, an excess of 100 M m^3 reached Lake Faguibine despite the low flood (260.95 m IGN at Diré). This volume was similar to the one that reached the lake in 1988 at a higher flood level (261.44 m IGN at Diré). This difference was attributed to the impact of the channel clearing and deepening by the UNSO project. On the other hand infiltration was underestimated and seems to be much more important than expected after a series of dry years. In summary, the UNSO project, by shortening (5 km), deepening and clearing the Kondi channel (and to a lesser extent the Tassakane), led to more water in Lake Faguibine than before the intervention, for any given flood level in the Niger River.

The Mali-Nord Programme has had a positive impact on rural income, contributed to reducing poverty and improved food security (Dillon, 2007, 2008). For the Faguibine System, this programme has lifted some of the pressures on the Kondi and Tassakane channels by providing alternative livelihoods that can use the water from those channels by pumping to supply fields at their edges. In that sense, it has created an opportunity to revive the channel rehabilitation programme with a reduced risk of the resource-adjacent communities blocking the channels for agriculture, dry season bourgou (Echinochloa stagnina pasture) cultivation and fisheries.

The main results achieved so far by OMVF itself and with the support of UNEP have been very substantial. There is now an earlier entry date for the water that comes from the Farabango channel and flows into the Faguibine System through the Kondi and Tassakane channels. This has improved transport over water and has allowed an earlier start of the agricultural season, in particular regarding irrigated wheat and rice cultivation in the Killi and Kessou floodplains. The refilling of the lakes has improved access to water for local communities and livestock by shortening the period during which the channels and the lakes (mainly Télé and Faguibine) are dry, and by enabling the existence of *bourgou*. This increase in flood duration and flooded surface area in the lakes have also improved groundwater recharge through infiltration in the sandy soils. It has also improved fisheries. Indeed, when the Faguibine System is flooded it provides an important fishery, estimated at about 5,000 tons annually. The return of water into the Faguibine System led to the return of hundreds of families out of the diaspora and the expansion of recession agriculture positively affected food security. However, the Faguibine System restoration is only just beginning and lot of works remain to be done to sustain these first and positive results.

Conclusions and Recommendations

In spite of a major expansion of irrigated agriculture in Mali, the flood dependent ecosystems of the Inner Delta and the Faguibine System continue to provide easy-access and low capital input livelihoods for over a million people often in vulnerable categories, as well as being a haven for biodiversity in particular for migratory waterbirds. Representing at least 10% of GDP, the productivity of these systems is increasingly threatened by climate change and human interventions (upstream hydropower dams increased abstraction for irrigation including

agrofuel development in the Office du Niger). While there remains a significant amount of work to be done, there have already been tangible results. Water is flowing through previously dry riverbeds and people are able again to begin agricultural and pastoral activities to feed themselves and support their families. As the environment stabilizes, people will be able to diminish their reliance on humanitarian aid and resume social and economic development. The Lake Faguibine region is a good example of climate change mitigation through effective partnerships from a local to a global level. Ecosystem restoration is time and cost intensive. Substantial resources and a long term commitment are needed to successfully rehabilitate Lake Faguibine.

The main challenge after the clearing and deepening (carefully removing windblown sediment without affecting the impermeable layer) and bank stabilization is therefore the work related to the system's maintenance and the development and implementation of agreements with local users in order to ensure they won't become engaged in activities that may jeopardize the flow.

Finally, reducing the influx of wind-blown sediments is of crucial importance and permits reduction of channel maintenance costs. Interventions protecting or restoring vegetation cover in the dune fields that are the source of these sediments are therefore necessary. This will also contribute to restoration of dryland ecosystem service delivery, e.g. regarding firewood, traditional medicine, wildlife and pasture.

Improved water management is often the most important adaptive response to the impacts of climate change.

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Chapter 10

Climate Change and Ecosystems

Impacts and Ecosystem-based Adaptation in the Antarctic and Southern Ocean

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Adaptation is a relatively new concept in the management of the Antarctic region. There is little understanding of the concept among decision makers representing the Parties to the Antarctic Treaty and to the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). The Antarctic and Southern Ocean Coalition (ASOC), which occupies the only NGO observer seat within the Antarctic Treaty System (ATS), has been the lead advocate for climate change adaptation in Antarctica. It has been working to bring examples of adaptation strategies from other parts of the world and develop prototype adaptation strategies that could initiate discussions in the Antarctic context. To date, management of non-native species is the most developed of adaptation strategies discussed within the ATS. A range of biosecurity measures, risk assessments and practical guidelines are now being discussed, although there is no systematic implementation. Discussions have also begun on how to adapt the Antarctic protected area system to ensure it has the ability to respond to changes in distributions and characteristics of values for protection. The first Marine Protected Area (MPA) was designated in 2009, with proposals for additional MPA(s) pending. Nevertheless, adaptation remains only one of many drivers behind the push for MPAs. The ATS is a consensus-focused body. Changes and decisions take place slowly. However, considering how fast some areas are warming and the ongoing trend of increasing human activity, it is important that climate change adaptation actions are developed and implemented quickly in order to help increase the resilience of Antarctica's ecosystems.

Keywords: Antarctic, Antarctic protected area system, Antarctic Treaty System, Climate adaptation strategies, Convention on the Conservation of Antarctic Marine Living Resources, Marine Protected Areas, Non-native species, Southern Ocean

Introduction

The present study addresses the case of the Antarctic Treaty Area (ATA) on the Antarctic continent and Southern Ocean which are governed by the Antarctic Treaty System (ATS). The ATA is defined as the area of land and sea that is located south of 60° latitude south. The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR), which is part of the ATS, has a boundary that extends further north towards the Antarctic Convergence which goes as far as 48° south, at certain places.

Whatever definition of 'biodiversity' is adopted, Antarctic terrestrial biodiversity is low (Convey et al., in prep.). At the level of species diversity, 'richness' is low, while at higher taxonomic levels many groups are missing. In terms of ecosystem functions or services, many are poorly or not represented (Convey, 2007b), and those that are present possess low levels of redundancy (i.e. other taxa performing similar functions).

The terrestrial fauna is made up of invertebrates, predominantly microarthropods with only two 'higher' insect species present (Block, 1984), and plant communities are largely cryptogamic (e.g. mosses, liverworts and lichens) (Ochyra et al., 2009; Øvstedal and Smith, 2001), with only two higher plants present on the Antarctic continent. A greater, though still limited diversity of higher plants and invertebrates is present on the sub-Antarctic islands (Convey, 2007a), although native terrestrial vertebrates are still absent on most islands, the exceptions being a single species of insectivorous passerine bird, two ducks and two sheathbills, each restricted to a single or at most two islands.

Importantly, baseline survey data and up-to-date taxonomic treatments for most groups of biota remain very patchy, with existing published information heavily skewed towards research areas of specific interest to certain national operators or individual specialists, both on the continent itself and the surrounding sub-Antarctic islands (e.g. Chown and Convey, 2007; Peat et al., 2007; Convey, in press). Overall, microbiota are the least known, while some recent studies suggest intriguingly that they may be considerably more diverse than previously thought (e.g. Cowan et al., 2002; Pearce et al., 2009). In fact, some of the simplest terrestrial ecosystems on the planet are found in this region (e.g. Convey and McInnes, 2005; Hogg et al., 2006).

Regarding marine ecosystem, and in accordance with a temperature-related gradient, the biodiversity of the Southern Ocean is relatively small, but biomass is huge. This overall pattern is related to the cold, nutrient-rich waters that circulate around the Antarctic continent as part of the largest ocean current on Earth, the Antarctic Circumpolar Current (ACC). Waters south of the Southern Boundary of the Antarctic Circumpolar Current (SBACC) are especially productive owing to extensive upwelling of nutrient-rich water, particularly along the continental margin, despite the fact that much of these waters are in darkness for a major portion of the year owing to the seasonal day-night cycle and the extensive sea ice that covers them during winter-spring. On the other hand, waters south of the SBACC are in continual sunlight for several months per year. Waters south of the Antarctic Polar Front (APF, Antarctic Convergence), are the destination for numerous whales and seabirds, which forage there during summer but calf in warm waters or breed on islands at sub-Antarctic or temperate latitudes. Populations nowhere else in the planet's oceans can compare with their numbers in the Southern Ocean. Also, a unique assemblage of seals, including the most abundant species in the world, frequents the pack ice region. The bird fauna associated with the pack ice is unique as well. The fish fauna is dominated by one unique family, the Nototheniidae, which diverged from the cosmopolitan fish fauna when Gondwanaland disintegrated and populations radiated to fill dozens of 'vacant' niches. Finally, owing to the variously deep shelves of the Antarctic and due to the isostatic depression of the land from the mass of the ice sheet, the richest benthic fauna is spatially constrained to a limit of shallow water, in turn regularly perturbed by ice berg scour. In turn, the invertebrate fauna of mid-waters is dominated by several copepod and Euphausiids species, including Antarctic krill, which assumes the role of the anchovy or sardine in temperate, upwelling-rich waters. In some southern areas, pteropods are especially abundant. Due to the cold waters, and the boundary formed by the APF, other than the many upper trophic level species that migrate to forage during summer, much of the Southern Ocean's marine fauna is restricted to this region.

Methods

Vulnerability Analysis

In 2009, the Scientific Committee on Antarctic Research (SCAR) produced a review on Antarctic Climate Change and the Environment (known as ACCE), which summarizes our current

knowledge on the state of Antarctica's climate and its relation with the global climate system (Turner et al., 2009). To date, it is the most comprehensive document on the subject and very useful as input to any vulnerability analysis.

In summary, the ACCE Report concluded that (Turner et al., 2009):

> For the last 30 years, effects of the ozone hole have worked in opposition to potential effects of global warming, resulting in little change in surface temperature across the bulk of the continent. In addition, the cooling of the stratosphere (due to the ozone hole) and the warming of mid-latitudes has resulted in the acceleration of the circumpolar winds. That in turn has caused alteration of the placement of the polar jet. The main result of the latter is intense warming in the southwest Atlantic sector, where the jet dips much farther south than formerly, and especially warming of the western/windward side of the Antarctic Peninsula. The increasing temperature is several times higher than the average rate of global warming, what makes the Antarctic Peninsula one of the world's regions that is warming up most rapidly. The vast majority of the Antarctic, however, remains relatively unchanged.

> The Southern Ocean is warming: the ecosystem will change. Antarctic Circumpolar Deep Water has warmed slightly due to warming in the mid-latitudes where these waters are formed. Antarctic Surface Water, except in the SW Atlantic region, has not warmed much due to its cooling during the Antarctic winter. The cold waters are problematic as atmospheric CO_2 concentrations rise; cold waters dissolve more of the CO_2, with progressive ocean acidification as a result. Ecological key species (such as planktonic snails [pteropods] and benthic invertebrates) are expected to be disproportionately and negatively affected. Climate envelope models indicate that if water temperature continues to rise, the range width of many Antarctic species will significantly decrease, as the continent itself represents a boundary to southern habitat expansion. Increased sea water temperature may open the door to immigration of a variety of alien species that are superior to local species in competition and may replace the native Antarctic species. The arrival of crabs, for instance, would severely impact the current benthic ecosystem.

> Net sea ice extent has changed little around the Antarctic over the last 30 years as a result of the ozone hole and mid-latitude warming. While sea ice extent across the Arctic Ocean has decreased markedly over recent decades, around the Antarctic it has increased by perhaps 10% since 1980. The little change is the result of significant growth in extent in the Ross Sea region to counter the large decrease in the Bellingshausen Sea region (west of the Antarctic Peninsula). These changes are due to acceleration of circumpolar winds and alteration of the polar jet, with effects on local atmospheric circulation. Due to the loss of sea ice west of the Peninsula, changes in algal growth are seen along with a shift from large to smaller species. As a consequence, stocks of krill (the shrimp-like

Nassauvia magellanica is native to South America, and recently established in Antarctica. A warmer climate increases the risk of non-native species establishing in Antarctica.

key species in the food web in that region) have declined significantly. The distribution of Adélie penguins has also changed, with many populations on the northern Antarctic Peninsula disappearing due to a reduced period of sea-ice, whereas in the Ross Sea and East Antarctica populations are generally stable or increasing. The consequences of historical harvesting reduce our ability to understand the impacts of climate change, particularly on fish, seals and whales. It is highly possible that some whale species may not be able to recovery from whaling if the krill population remains at a low level or decreases further.

> There has been rapid expansion of plant communities across the Antarctic Peninsula. Along with higher temperatures, the Antarctic Peninsula has experienced a marked switch from snowfall to rain during the summer, as well as a retreat of ice fields. These linked changes have led to rapid expansion of plant communities and the colonization of newly available land by plants and animals. In regions on land where there is greater availability of liquid water and higher temperatures, plant, animal and microbial communities will expand. Humans have inadvertently introduced alien organisms, including grasses, flies and bacteria.

> Assuming a doubling of greenhouse gas (GHG) concentrations over this century, Antarctica is expected to warm by around 3ºC. At the same time, sea ice extent around the continent is predicted to decrease by a third.

More specifically, between now and 2100 all marine ecosystem components closely related to the sea ice will show significant changes in their ecological performance in response to changes in sea ice extent. A recent modelling study indicates that significant sea ice change will continue to show greater and greater effects well before 2100, i.e. when Earth's atmosphere reaches 2°C above industrial levels, projected to occur following current trends during 2025–2052 (Ainley et al., 2010). This includes further substantial sea ice loss off the western Antarctic Peninsula, and continued growth in the southwest Pacific sector.

The changing seasonal break-up of sea ice is one of the greatest impacts on biodiversity in both the Arctic and Antarctic.

Climate change is expected to have impacts on both the habitats and food webs of Antarctic biodiversity.

In areas with an originally large Antarctic krill population, a sea-ice related species, size of the population is likely to stabilize at a lower level where sea ice disappears. In those areas all main krill consumers will experience serious food limitations over the long term. The mink whale will lose 5–30% of its ice-associated habitat, while for blue, humpback, and fin whales a compression of foraging habitat in the highly productive zone south of the ACC southern boundary is projected. The ice-obligate emperor and Adélie penguins, as well as crab-eater, Weddell, leopard and Ross seals will likely become extinct locally due to changes in both habitat and food web dynamics. Species of any systematic group with a sufficient initial population size and circumpolar distribution are expected to survive at least in the Pacific sector south of Australia and New Zealand, where according to predictions the sea ice is likely to remain relatively stable (Turner et al., 2009, pp. 384–385), and actually continue to grow in the next few decades (Ainley et al., 2010).

Regarding terrestrial ecosystems, the frequency of freeze-thaw events and occurrence of minimum temperatures are predicted to increase under climate change. The tolerance limits of arthropods and continental bryophytes could readily be exceeded, although lower lethal temperatures show substantial capacity for both phenotypic plasticity and evolutionary change. Increasing aridity is likely on the continent in the long term. Local reduction in water availability in terrestrial habitats can lead to desiccation stress and subsequent changes in ecosystem structure. High amongst future scenarios is the likelihood of invasion by more competitive non-native species, as warmer temperatures and increased human visitation combine to make it easier for non-native species to colonize and establish themselves (Turner et al., 2009,

An ice arch at Norsel Point, Anvers Island, just before it collapses.

pp. 355–356). Cumulative effects not yet well understood include climate change (e.g. changes in precipitation and temperature), the higher probability that non-native species establish themselves, and the increased human disturbance through increased visitation (e.g. trampling) – all issues that deserve further study.

Results

Actions Taken to Respond to the Impacts of Climate Change

Adaptation is a relatively new concept in the management of the Antarctic region. There is little understanding of the concept among managers and decision makers representing the Parties to the Antarctic Treaty and to the CCAMLR. The Antarctic and Southern Ocean Coalition (ASOC), which brings together thirty environmental non-governmental organizations (NGOs) interested in Antarctica's future and occupies the only NGO observer seat within the ATS, has been and remains the lead advocate for the case of climate change adaptation in Antarctica.

ASOC has been working, within and outside the ATS, to:

> Highlight the need for adaptation strategies for conserving Antarctic ecosystems;
> Bring examples of adaptation strategies from other parts of the world to Antarctica;
> Introduce basic concepts of adaptation;
> Develop prototype adaptation strategies that could initiate thinking and guide discussions;
> Advocate for the development and implementation of adaptation strategies; and
> Advocate for strengthening existing and developing new management practices that may contribute to successful adaptation.

Specifically, ASOC has been advocating for possible adaptation options for Southern Ocean marine ecosystems (ASOC, 2010a; and see ASOC, 2010c, 2010d and 2010e for further detail), including:

> Establishing a representative network of marine protected areas (MPAs) to serve as scientific reference areas, for example to help understand how to manage activities in the face of climate change impacts, and to provide areas to increase the resilience of the Antarctic marine ecosystem to climate change or other impacts;
> Identifying and protecting areas most likely to maintain stable sea ice, especially the Ross Sea, in the Pacific sector of the Southern Ocean, which is seen as perhaps the last oceanic area on the planet where sea ice will be present year round;
> Putting into place adaptive management systems which are able to incorporate uncertainty and to respond to new information, for example through the expansion and improvement of CCAMLR's Ecosystem Monitoring Program (CEMP); and
> Considering further spatial management measures on krill harvesting to compensate for the compression and reduction of high-krill areas in the Southern Ocean.

Similarly, possible adaptation options for Antarctic terrestrial ecosystems (ASOC, 2010a) include:

> Implementing appropriate biosecurity measures across different spatial scales and applied to different biological groups;
> Considering restrictions on human visitation and direct disturbance to reduce the number of different concurrent stresses; and
> More holistic and strategic designations of a network of protected areas that can protect representative ecosystems and values of Antarctica.

Although discussions of climate adaptation strategies in the Antarctic context are still in its early days, progress has been made the past two years. The subject of climate change was officially put on the agenda of the Committee for Environmental Protection (CEP) at the Antarctic Treaty Consultative Meeting (ATCM) in 2008, and was acknowledged officially by CCAMLR in 2007 when the Commission asked the Scientific Committee for information on the subject.

An Antarctic Treaty Meeting of Experts (ATME) on climate change was held in April 2010. This meeting produced thirty recommendations which covered issues of mitigation, adaptation and monitoring. It is expected that these recommendations will form the basis of future decisions on the management of Antarctica within the context of climate change. Shortly after that meeting, at the ATCM in May 2010, the Antarctic Treaty parties agreed to make climate change a major topic in future treaty meetings.

Furthermore, discussions on non-native species in Antarctica have been ongoing for at least five years and hence have become the most developed of climate adaptation strategies discussed in the Antarctic context. A range of biosecurity measures, risk assessments and practical guidelines are now being discussed (e.g. Government of France, 2010), although there is no systematic implementation as yet.

Outside the discussion of non-native species, discussions have begun on how to adapt the Antarctic protected area system to ensure it becomes dynamic and flexible, and develops the ability to respond to changes in distributions and characteristics of values for protection (Government of the United Kingdom, 2010). With respect to the marine context, the first Marine Protected Area (MPA) in the Southern Ocean was designated in 2009 around the South Orkneys (CCAMLR, 2009). Proposals are also on the table to protect part or all of the Ross Sea – an area with little human impact that is expected to maintain stable in terms of sea ice cover – in one or several MPAs (Government of Italy, 2010; ASOC, 2010b; and see ASOC, 2010c, 2010d and 2010e for further detail). While MPAs can contribute towards climate change adaptation, adaptation has thus far been only one of many drivers behind the push for MPAs in the Southern Ocean. Finally, CCAMLR will consider the recommendations from the ATME at its meeting in October-November 2010 in Hobart, Australia. Fortunately, there is no doubt that climate change is now a major issue on this meeting's agenda.

Conclusions

Although discussion of climate adaptation strategies in the Antarctic context is still in its early days, they are starting to move forward seriously. Adaptation-focused scientific investigations as well as practical strategies still need to be developed, though. They should then be followed by an implementation stage. Once implemented, the effectiveness of the strategies will have to be assessed through monitoring and evaluation efforts, of which the results should then feed back into an adaptive management system.

The ATS is a consensus-focused body. Changes and decisions take place slowly. However, considering how fast some areas in the region are warming up and looking at the ongoing trend of increasing human activity in the region, it is important that climate change adaptation actions are developed and implemented quickly in order to help increase the resilience of Antarctica's marine and terrestrial ecosystems before irreversible losses of its unique ecosystems take place.

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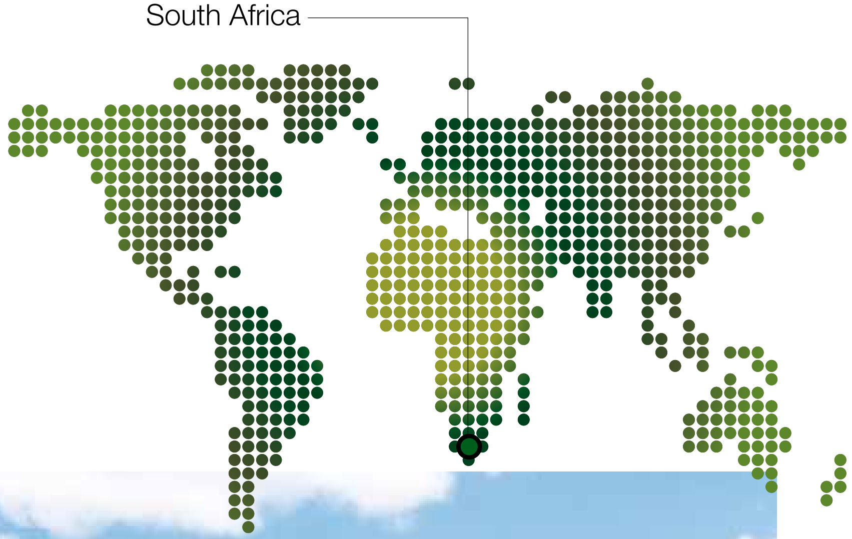

Chapter 11

Cultivating the ‘PRESENCE’ Learning Network to Restore Living Landscapes

Adapting to Climate Change in the Baviaanskloof Catchment, South Africa

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‘PRESENCE’ is a collaborative learning network in the Eastern Cape, South Africa, and stands for ‘Participatory Restoration of Ecosystem Services and Natural Capital’. It aims at guiding ecosystem management and restoration of ‘living landscapes’ in the Eastern Cape region. In this part of the country, the Baviaanskloof Mega Reserve (BMR) is located: a unique natural area which contains seven of the eight biomes found in South Africa. As a convergence point for three regional biodiversity hotspots, a section of the BMR was formally listed as a UNESCO World Heritage Site in 2004. However, over a number of decades, areas across the BMR have been subject to severe ecological degradation. This is largely a result of stock overgrazing, large-scale crop irrigation and human-induced modifications of the hydro-morphological system. Such activities have led to (river bank) erosion, a lowering of the groundwater table and a decline of water supply to the downstream nature reserve and Kouga Dam. This decline of natural capital and derived ecosystem services is causing greater socio-economic constraints upon the area and its people. In response, the South-North multi-stakeholder PRESENCE learning network was initiated to address these issues in an integrated manner. The current chapter provides a brief overview of PRESENCE’s approach and its achievements in guiding restoration actions meant to build resilience to climate change in Baviaanskloof, South Africa.

Keywords: Catchment, Ecosystem services, Learning network, Natural capital, Participatory, PRESENCE, Restoration

Introduction

The collaborative learning network ‘PRESENCE’ – Participatory Restoration of Ecosystem Services and Natural Capital – attempts to guide and mainstream the integrated restoration of ‘living landscapes’. Its main aim is to work toward creating landscapes in which agriculture, nature conservation and tourism can sustainably co-exist whilst at the same time anticipated effects of climate change are mitigates.

During the last three years, PRESENCE has been applying and refining an integrated ecosystem (services) approach in Baviaanskloof (“valley of baboons”) in South Africa’s Eastern Cape region. The process applied a trans-disciplinary approach in understanding area properties (e.g. hydro/ecological processes, stakeholder willingness, and institutional capacity), perceptions and values of ecosystem/landscape services, and strategic options for making knowledge operational for action.

Specific mitigation and adaptation strategies that PRESENCE proposed for putting knowledge into action include: a continued investment in stakeholder engagement; 'reforestation' with native vegetation to enhance CO_2 sequestration and microclimates; recovery of former wetlands meant to increase the base flow and serve as a buffer for extreme weather events; and design effective communication and education strategies for implementing an incentives scheme for ecosystem management (e.g. payment for environmental services, PES). Collectively, such actions should continue to build social-ecological resilience to the anticipated effects of climatic change.

Study Area and Methodology

Physical Setting, Historic Context and Modern Change

Baviaanskloof is a 75 km long valley, of varying width and depth that lies between the parallel east west running Baviaanskloof and Kouga mountain ranges in the western region of South Africa's Eastern Cape Province (Boshoff, 2005). The eastern-most point of the valley is some 95 km north-west of the coastal city of Port Elizabeth, and its most southerly point is 50 km from the Indian Ocean (23°35' E to 24°25' E, and 33°30'S to 33°45' S). The case study area is shown in Fig. 1. The Baviaanskloof valley forms an integral part of the constantly evolving Baviaanskloof Mega Reserve (BMR): a cluster of state-owned protected areas within a network of private and communal lands comprising an area of over 600,000 ha (Boshoff, 2005). Landowners voluntary choose to be a part of the BMR concept and, in doing so, are required to align their land-uses and management practices with biodiversity conservation (Boshoff, 2005).

The specific pilot case study area is focused on the western part of Baviaanskloof (Fig. 1). This area consists of a mix of large, privately-owned farmlands, conservation zones and communal lands. The private and communal lands can essentially be considered as 'islands' that are landlocked within the surrounding formal protected area, the Baviaanskloof Nature Reserve. The communal lands are occupied by coloured communities: Sewefontein is an emerging community farming trust; Zaaimanshoek is a community situated on church-owned land; and Coleskyplaas is a small community comprised largely of former farm dwellers and now situated within the protected area. Together, these communities comprise over 70% of the western Baviaanskloof community and mostly consist of aged pensioners, farm workers and extended families largely dependent on government pensions and disability grants (Crane, 2006). The remaining 30% of the valley's approximately 1,000 inhabitants are largely a mix of white Afrikaans farmers and families, lifestyle farmers, tourism operators, civil servants and a small community of 'alternative lifestyles'. Rich cultural heritage also exists as prehistoric and historic artifacts and sites including cave paintings.

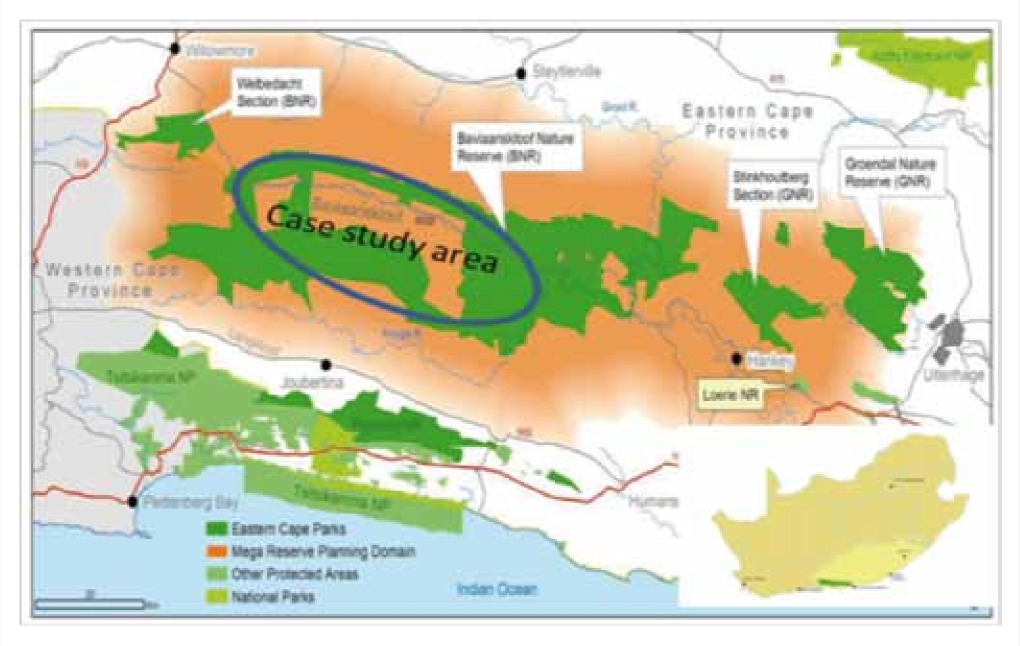


Figure 1. Study area showing the western sector of Baviaanskloof, South Africa.

The study area is located within the Baviaanskloof municipality, one of the poorest of the nine municipalities in the Cacadu District Municipality in the Eastern Cape Province (Baviaanskloof Municipal Councillor, pers. comm.). It is of astonishing ecological and social importance. With a long history, it possesses a highly rich natural and cultural heritage. However, during the last century, the area has witnessed considerable changes in the natural, economic and political landscape. These converging influences, along with questionable agricultural subsidies and extension policies, have collectively contributed to a loss of ecological integrity and severe ecosystem degradation. The area is facing a steadily declining agricultural productivity and increased economic hardship. These trends are now being starkly brought into view with current and impending climactic changes. Erratic and declining rainfall is further undermining the resilience of the social-ecological systems in Baviaanskloof.

Since a natural recovery of these 'degraded' ecosystems is quite unlikely over the short to mid-term, an active landscape restoration programme has been initiated in an effort to mitigate the anticipated impacts of climate change. One of the many restoration actions planned or underway is reforestation through planting of spekboom *(Portulacaria afra)* on degraded landscapes. This is currently happening in Baviaanskloof and follows the assertions that *spekboom,* a pioneer tree species, provides a suitable micro-climate that allows other species to prosper, thus catalyzing the process landscape restoration, and serving as a means to sequester carbon.

Center of Biodiversity Hotspots

The Baviaanskloof Mega Reserve (BMR) is a conservation planning domain consisting of a complex of various land-uses and tenures without a fixed boundary. The broader area, of which the western Baviaanskloof is a critical component, is recognized for its exceptional natural beauty and its spectacular landscapes. It contains a highly diverse flora and fauna, a product of the BMR being located at the convergence of three biodiversity hotspots: the Cape Floristic Region, the Succulent Karoo and the Maputaland-Pondoland-Albany hotspot (R. Cowling, pers. comm.). Seven of South Africa's eight biomes can be found within the BMR: *fynbos,* subtropical thicket, *nama-karoo,* succulent *karoo,* grassland, savannah and forest (Boshoff, 2005; Crane, 2006). The *fynbos* biome is found on the poor soils of the mountains, the subtropical thicket biome on the more fertile soils in fire-protected valleys, the *nama* and succulent *karoo* biomes on the semi-arid flats to the north and west, the grassland biome on the planed, gravelly surfaces in the foothills, the savannah biome on alluvial soils in the bottomlands, and the forest biome mainly in the sheltered, moist ravines. This exceptional diversity, unique in South Africa, is largely a product of the impressive physical and climatic variation in this 'transition' area (Boshoff, 2005). From a geological and topographical perspective, the Baviaanskloof is nothing short of spectacular. Geological formations – and the associated river basins of the present-day Baviaanskloof, Kouga and Gamtoos rivers – can be dated back to the breakup of the ancient continent of Gondwanaland (Boshoff, 2005). These formations have remained relatively stable since that time and this is an additional contributing factor to the remarkable levels of biodiversity and endemism.

**BOX 1.
LIST OF CRITICAL ECOSYSTEM FUNCTIONS AND SERVICES PROVIDED BY EASTERN CAPE BIOMES THAT ARE PARTICULARLY RELEVANT TO PRESENCE**

Provisioning:	- Supply of material for horticultural activities - Resource harvesting (medicinal plants, fuelwood, timber) - Supports commercial and subsistence pastoralism
Cultural:	- Wildlife-based tourism, hunting and re-creation - Cultural and spiritual activities (biocultural diversity) - Contribution to economic diversification
Regulating:	- Erosion and sedimentation control - Climate regulation (provision of clean air) - Sustaining water quality (purification)
Supporting:	- Provision of habitat (biodiversity) - Maintenance of nutrient, carbon and water cycles - Soil formation and retention

Based on: STEP, 2006; De Groot et al., 2006; Wiersum and Shackleton, 2005; Milton et al., 2003; and MA, 2005.

More than 1,000 plant species have been recorded so far and it is expected there are more than 2,500 species in the whole BMR (Boshoff, 2005). This includes at least 52 IUCN Red List species. These natural riches are now formally valued and recognized, since the Baviaanskloof Nature Reserve was listed in 2004 as a UNESCO World Heritage Site.

Land Use History

The largest portion of the land in the BMR complex is demarcated as Nature Reserve (65%). The area comprises 231,386 ha (May, 2006). Agriculture and small settlements claim another 35% of the area. Farming from the early European immigrants is understood to have commenced in the Baviaanskloof at the start of the late 1700s. Various farming practices were evident, including livestock production, vegetable seed production and pasture. The booming periods of mohair in the 1970s resulted in increased stocking of Angora goats and this is believed to have denuded the hillside vegetation considerably through overgrazing.

The current cultivation of alfalfa, maize, onion seed, carrot, pumpkin and citrus (approximately 800 ha) requires irrigation, principally from groundwater through abstraction from the Baviaans River channel, water from springs upstream of farmlands into small dams, stressing the catchment's hydrological regime. Since the early 1990s, the number of farmers and the area of cultivated land have reduced. This is partly due to implications of stricter labour legislation (the cessation of farming subsidies significantly increased costs for this remote area and caused a steady decline in the regional economy). However, apart from socio-economic pressures, a general decline in agricultural productivity directly and indirectly contributed to severe degradation of the soil, vegetation and water resources. Due to these socio-economic pressures and the loss of 'natural capital', (commercial) agriculture is no longer a given in ensuring long-term socio-economic security or refraining the region's growing unemployment. Nature-based tourism, game ranching and predator-friendly farming are increasingly recognized as attractive opportunities to support economic growth through value-added products and services. Possibilities are also being explored for carbon farming and reforestation of degraded farm landscapes by planting *spekboom* trees. This approach serves both the improvement of vegetation cover for water retention purposes (which will then be the argument to develop a system of 'Payment for Watershed Services', PWS), and carbon sequestration, meant to mitigate climate change impacts in the area.

Problem Identification

Degradation of landscapes through the over-exploitation of natural resources results in the loss of biodiversity, ecological integrity and ecosystem functions. This ultimately affects the well-being of people who depend directly and indirectly upon these functions and the benefits derived from them (i.e. ecosystem services); this is the case in Baviaanskloof. The situation in the western Baviaanskloof is typical of

trends experienced throughout South Africa's biologically diverse biomes where ecological pressure is resulting in a loss of human well-being. Large areas have been severely impacted through human activity – intense grazing pressure, water mismanagement and the overharvesting (that is, unsustainable use) of natural resources (Milton et al., 2003; Mills et al., 2005).

Despite the dependence on key ecosystem services provided (Box 1), activities have led to: a transformation of natural resources necessary for the fulfilment of local communities requirements (Cocks and Wiersum, 2003); a deterioration of the aesthetic appeal of the landscape for tourism development; a decline in soil quality (Mills and Fey, 2004); the loss of biomass and carbon (Mills and Cowling, 2006; Mills et al., 2005); and an overall decline in natural capital due to decreased diversity (Lechmere-Oertel et al., 2005). Privately-owned land enveloped within a protected area of global significance can present a number of challenges to reserve managers, farmers and institutions alike. Both the protected area and land owners are highly vulnerable to conflict with the other in terms of 'management' practices, e.g. water usage, waste management, soil erosion, alien invasive vegetation, predator poaching and fire risk (Crane, 2006).

The implications of such a scenario are clearly apparent in the Baviaanskloof where impaired ecosystem functioning and modified hydrological systems are eroding natural capital and livelihood security. In response, the PRESENCE network was formed to synergize earlier efforts largely initiated by the South African Government's national 'Working for Water and Woodlands' poverty relief initiatives to investigate options for restoring the valuable subtropical thicket biome to meet both socio-economic needs and ecological objectives.

Water Resources and Uses

As a water catchment, the Baviaanskloof plays a critical role in supporting rural livelihoods, the regional agricultural sector and meeting growing urban water demand (Boshoff, 2005). Over the past two decades, the role of the Baviaanskloof in provisioning water and other essential ecosystem services has received greater attention (Crane, 2006; Van der Burg, 2008).

Although rainfall in this area is low and erratic (average annual rainfall is around 300 mm), the Baviaanskloof still supplies 35–40 million m^3 of water to the Kouga Dam which, with waters from the adjacent Kouga catchment, is the lifeblood of intensive citrus production in the Gamtoos valley downstream, as well augmenting water supply for the water stressed Nelson Mandela Metro Municipality (for the city of Port Elizabeth). In more recent years, the valley has experienced increased irregularities in precipitation, with an increase in summer rainfall and extreme rainfall events and a decrease in winter precipitation (Jansen, 2008a). Local records indicate that dry periods with very little rainfall are quite common in the region, with droughts occurring periodically, followed by a major flood event (Jansen, 2008a).

Farmers of the Baviaanskloof adhered to earlier Government incentives and agricultural extension advice and, over the past decades, have taken measures to canalize water from the main river in order to control the flooding on agricultural lands. This has typically involved the construction of weirs in and across river channels and tributaries, in order to canalize the water and prevent overflow to surrounding areas and subsequent crop damage (De Paoli, 2008). Additional protection measures in the past have also included digging channels from the side tributaries to the river to divert water away from the low lying areas where crops have been planted (Jansen, 2008a).

While these measures have been successful in protecting crops and valuable pasture land, these barriers and channels have further exacerbated the ecological degradation (such as wetlands degradation and erosion). The associated consequences of this land and water mismanagement have already become apparent and stand to deteriorate further with rising water demands, resource pressures, economic downturn as well as the growing threat of global climate change. Recent observations made during

Figure 2. Cause-effect cycle of vegetation loss and water security in influencing ecosystem resilience (based on Jansen, 2008).

a stakeholder field trip in 2008 indicate that seasonal wetlands once occurred throughout the valley and have now disappeared. This has partly resulted because water whelms, dams and pits were constructed in order to collect the water from the subsurface, ensuring water availability in the dry periods. Such modifications may have improved perceived security to unexpected and acute weather events (i.e. primarily flash flooding). However, collectively, these modifications may have had the cumulative effect of increased land and human vulnerability to more chronic and long-term climatic changes such as prolonged droughts (Janssen, 2008a).

Vegetation

The significant loss of vegetation cover in the valley has been established as the primary cause for a cycle of cause-effect chain events which exacerbate ecological degradation. This cycle is depicted simplistically in Fig. 2 as a way of illustrating linkages between vegetation losses and water regulation. Naturally, there are numerous other complex and anthropogenic factors involved which can affect ecosystem resilience and water security and, in effect, what is depicted here as unchanging cycle, in fact becomes a downward spiral where reactive human actions such as increased water extraction and more intensive grazing further undermine ecosystem resilience.

Although major flooding events play a natural role in the system, the vulnerable, erosion-prone banks and slopes can no longer withstand water movement at such velocities, which further channelize the water bodies. Not only does the fast flowing water increase erosion problems, but the deep channelization prevents water from naturally flowing, dispersing over the floodplain and allowing valuable silt deposition (which aids soil quality and productivity) across the 'veld'. As a result, silt accumulates further downstream – or in Kouga Dam – where it can become a costly removal process.

Downstream Implications

The cumulative effect of hydrological modification and vegetation loss have imbued the Baviaanskloof with what could be colloquially referred to as 'catchment diarrhoea' – whatever comes in one end passes through and straight back out the other end. Rainfall and aquifer flows rapidly pass through or runoff the system and are no longer held / absorbed in wetlands or soils to nourish the catchment over the longer term.

The cost of the degradation upstream in the valley has far reaching consequences, and is felt by both residents of the Baviaanskloof as well as residents downstream of the Baviaanskloof Nature Reserve in the Gamtoos Valley and beyond to the Port Elizabeth metropolitan area. For example, current strict water restrictions downstream are leading to substantial losses in productivity and profitability in the Gamtoos Valley. Heavier aquifer extraction upstream is simultaneously reducing the ecological base flow for the Nature Reserve Area. The lack of buffering for extreme weather events (e.g. flashes flooding, dam overflows) can similarly cause localized flooding and severe crop damage/ losses. Increased siltation from upstream erosion affects both the storage capacity of Kouga Dam and a sharp increase in water treatment costs (Van der Burg, 2008). It is evident that downstream implications are both varied and widespread with socio-economic and ecological ramifications.

Actions Taken to Respond

The South African Government's Department of Water Affairs and Forestry and South African National Biodiversity Institute (SANBI) continues to expand programmes such as Working for Water/Woodlands/Wetlands to address environmental degradation and implement solutions for restoring the region's valuable and globally significant biomes and hotspots to meet both socio-economic demands and ecological objectives.

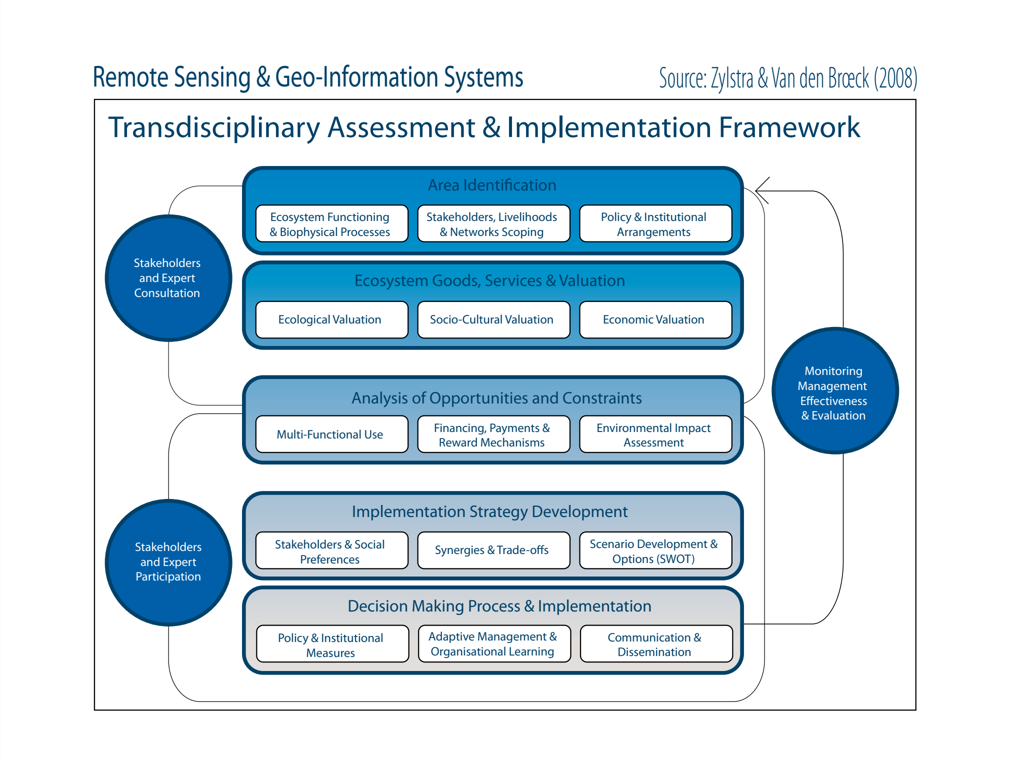
During the 2006 Subtropical Thicket Restoration Programme (STRP) Annual Review Meeting, it was decided that, in order to achieve these ambitious aims, additional institutional and academic capacity and research was required to improve best management practice by building restoration knowledge and effectively communicating and disseminating new insights. Mainstreaming the improved understanding of ecosystem processes and human dependence on related natural resources will provide a solid platform for restoring and building resilience in natural (reinstating biodiversity) and social systems (securing regional livelihoods).

In this context, PRESENCE was subsequently put forward as a collaborative effort to identify opportunities for 'up-scaling' restoration through national and international research collaboration; and, for example, in creating opportunities for South African and other nation's students and researchers to undertake their research in this field. In early 2007, PRESENCE – as a seed phase proposal – was prepared by the EarthCollective network and jointly financed through Wageningen University and Research Centre's (WUR) Interdisciplinary Research and Education Fund (INREF), the South African Department of Water Affairs and Forestry (DWAF) and Rhodes University. The main focus of the seed phase "Planting PRESENCE" was to provide a thorough basis for understanding the key knowledge gaps that exist in our current understanding of ecosystem restoration and which needed to be addressed through focused transdisciplinary research in order to catalyze and upscale potential mitigation measures.

The three main actions taken during the seed phase include: (a) a multi-stakeholder workshop; (b) the development of a guiding framework; and (c) the development of a learning network. This was taken with the view that the restoration of degraded landscapes is crucial in stabilizing ecosystem functions, thus providing ecosystem resilience against climate change.

An initial step was a multi-stakeholder workshop held in 2007, themed 'Planting PRESENCE: The Seed Phase Workshop'. The objectives of

Figure 3. PRESENCE in the Baviaanskloof approach: TAIF Framework.



this workshop were three fold. Firstly, it aimed at getting a better grip on the current status of research, implementation and stakeholder perspectives: was everyone on the same page? Secondly, the workshop provided the platform for science, management and government actors already active for a long-time, with various aspects of regional restoration, to collectively synergise and pinpoint the research priorities and capacities needed to guide broad-scale mainstreaming and implementation of restoration. Attendees to the workshop came from various institutes and disciplines and brainstormed and discussed around key topics. Outcomes of these discussions were formulated as research questions in order to guide and establish priorities for long-term restoration. And thirdly, the workshop aimed to stimulate North-South interdisciplinary research partnerships intended to support participatory approaches and build capacity for addressing the critical scientific questions identified during the workshop, hence underpinning ecosystem restoration.

During the workshop, a Transdisciplinary Assessment and Implementation Framework (TAIF, see Fig. 3) was developed and refined to include research themes. Frameworks can be either highly useful or terribly tiresome in terms of trying to capture a complex 'reality'. They may enlighten the research context in terms of providing a clear understanding of how all the pieces fit together, or they may become a source of confusion that leads project partners into a downward spiral of discussion! Obviously, the objective at this point was to arrive at a conceptual framework that has practical meaning and relevance for all involved.

The TAIF intended to provide a 'conceptual space' for stakeholders to determine what research, actions and contributions are required to effect restoration, and has been employed over the last three years. The TAIF was intended to support strategic analysis, planning and negotiation to aid effective transdisciplinary research and stakeholder communication. Whilst it is represented as a step-by-step linear and hierarchical framework, it was recognized that in reality many elements of the framework will need to be considered simultaneously whereby flexibility and adaptability would be critical. The TAIF was formulated based on various integrated assessment approaches currently used in the fields of integrated ecosystem management and conservation planning. Specifically, the TAIF drew upon frameworks and models such as those of Cowling et al. (2008), De Groot and Stuip (2005), Shepherd's Ecosystem Approach (2004), Zylstra and Verschuuren (2005), Zylstra (In press), and the Millennium Ecosystem Assessment (MA, 2005).

One of the main realizations of the initial workshop was that adaptive management and multi-stakeholder learning processes will be crucial in order to succeed with the mainstreaming of restoration. To be able to facilitate these processes, PRESENCE was further developed from a research program towards a learning network to guide ecosystem management and restoration of 'living landscapes'. In this sense, PRESENCE set itself the aim of becoming an adaptive and well-structured learning network which serves as a solid platform to support and mainstream existing – and catalyze new – programmes for restoring 'living landscapes' (ecosystem services and natural and social capital) across the Baviaanskloof Mega Reserve and beyond. The network acknowledged that it needs to be adaptive and 'strategically opportunistic' (R. Cowling, pers. comm.) in order to respond to stakeholder preferences, implementer's needs and constraints, improved scientific understanding and institutional learning.

The PRESENCE network has sought to guide the socio-ecological restoration of 'living landscapes' with an initial focus on the Baviaanskloof Mega Reserve. In an ambitious vision, the network strives to adopt a holistic approach that sustains and restores healthy ecosystems, economic viability, social values, biocultural diversity and institutional feasibility whilst utilising stakeholder participation to empower pro-restoration behaviour. It is envisaged that this will build ecosystem resilience to buffer rural livelihoods against the effects of climate change.

A crucial component of a learning network is the establishment of a 'process enabler'. In 2009, Living Lands was established as a South African foundation to function as secretariat to the PRESENCE network with the main activities of:

a) Integrating diverse elements of PRESENCE research programs;

b) Linking restoration programs (new and existing) under PRESENCE;

c) Coordinating on-ground (student) research activities;

d) Involving interested universities and research institutions to collaborate and form mutually beneficial partnerships;

e) Ensuring open and continuous dialogue between stakeholders;

f) Communicating and disseminating new information and knowledge;

g) Stimulating 'South-North' collaboration to create new learning opportunities and building skills and expertise;

h) Interfacing to help bridge research-implementation gaps;

i) Catalyzing new ideas, opportunities and networks; and

j) Building bridges for trust and relationships.

The PRESENCE network is now being successfully piloted as a collaborative effort across the Baviaanskloof Mega Reserve in developing an integrated catchment restoration programme termed "PRESENCE in the Baviaanskloof". The programme has been applying and refining an integrated ecosystem (services) approach which investigates how restoration and conservation of ecologically degraded and threatened biomes can help secure ecosystem services and natural capital, and improve local livelihoods into the future.

Results

The main achievement to date has been the creation of the PRESENCE network, and in subsequently keeping this multi-stakeholder learning network open, active and engaged. Much effort has been put into stakeholder engagement since a learning network is run by people and not only by a theoretical framework approach such as TAIF. However, the theoretical framework is the underlying strategy and therefore the core strength of the PRESENCE learning network.

Preliminary results indicate that a change of mindset is underway within the Baviaanskloof where stakeholders are open to new ideas and alternatives for land management, and are willing to work together to investigate if landscape restoration can contribute to livelihoods. The key challenge to date has been to reassure stakeholders that the research and applied approaches taken are related to real options and a sincere desire to practically address both ecological and socio-economic issues. In other words, something tangible should come out of the research. In this sense, flexibility and adaptability in framing the research needs and building social capital (trust and goodwill) has been a pre-requisite for ensuring that the case study remains targeted toward stakeholder needs and additionally backed by the longer term vision of restoring ecosystem services and natural capital.

Within the PRESENCE network, the South African Government's Department of Water Affairs (with their 'Working for Water/Woodlands' programmes) and the Dutch Government's Water for Food and Ecosystems programme have become the primary funders of the network's activities. Significant investments have been made by key partners such as Wageningen University and Research Centre (WUR) (e.g. its Ecosystem and Landscape Services Programme, SELS), Scientific and Industrial Research (CSIR), Rhodes University, Restoration Research Group and Stellenbosch University. Crucial in-kind support has been delivered through Eastern Cape Parks and the Gamtoos Irrigation Board. The Baviaanskloof Farmer's Union has been provided ongoing support in facilitating stakeholder workshops, field trips and updates.

Currently, the PRESENCE partners are involved in the collaborative development of:

a) Integrated restoration plan: An integrated restoration plan is currently been developed to ensure that the investments made toward restoration will achieve optimal outcomes and lead to increased ecosystem resilience. Throughout the development of this restoration plan, variables like soil erosion risk, dispersal of exotic and invasive plants, social-economical issues, landscape corridors, willingness of landowners, effects of climate change among others, are being taken into account;

b) Restoration implementation: The restoration implementation effort is being achieved through the adoption of measures by various PRESENCE network partners. As determined in late 2008, restoration measures will focus on different locations of the catchment: tributary streams and related floodplains; natural vegetation on adjacent hill slopes and the main Baviaans river channel (De Paoli, 2008). This includes: removal of man-made berms ('keerwalle') in tributaries; removal of these berms in the main channel; removal of man-made channels to the main river channel bed of the Baviaanskloof River; construction of weirs in river beds/tributaries; re-planting of slopes with indigenous plants, mainly *spekboom,* to reduce erosion, enhance infiltration and sequester carbon; possible other measures to rehabilitate natural flows; clearing of alien invasive plants; and restoration of wetlands. It is anticipated that such measures will catalyze a process necessary for restoring ecosystems and hydrological functioning;

c) Operational monitoring system: The main objectives of the monitoring plan aim at: assessing (cost-) effectiveness of measures; adapting measures if unwanted impacts are reported; generating information for up-scaling of proposed restoration measures; evaluating impacts on biodiversity and the resilience of ecosystem services; monitoring the effects of climate change; and generating information for the application of restoration measures in other catchment areas where similar problems occur;

d) Stakeholder consultation: Ensuring the participation, engagement and acceptance of the local stakeholders is crucial for the long-term sustainability of the project. Interviews, field trips, meetings and workshops are planned for stakeholder consultation activities;

e) Research: The outcomes of the preliminary research has contributed to: gaining a better understanding of the underlying dynamics behind various biophysical and social processes in relation to restoration in the Baviaanskloof; developing ways to improve local livelihoods; exploring possibilities for implementing and institutionalizing 'Payments for Ecosystem Services' (PES); and, most importantly, creating awareness among partners and primary stakeholders such as farmers and other kinds of land-owners. The research conducted thus far has laid the basis for further developing sustainable restoration in the face of climate change in the Baviaanskloof. Further analyses will be done regarding the opportunities and constrains for optimizing the use of ecosystem services, incentives schemes for sustainable farming and restoration (e.g. PES), and tourism, among others;

f) Capacity building and awareness raising: Capacity building is used to effectively engage local residents, Eastern Cape Parks, municipalities and other stakeholders in the restoration activities by establishing a participatory programme and transferring co-management responsibilities to stakeholders to ensure the ongoing sustainability of the restoration initiative. Activities related to skills development will not only boost employment opportunities but also increase knowledge, understanding and appreciation of key ecosystem services and a range of related ecological, socio-economic and socio-cultural issues. Activities that are envisaged will include courses, workshops, field trips (participatory mapping), economic opportunities/employment and other social events;

g) Web-based portal: A web based portal has been developed in order to provide the network with an accessible communication platform. The portal is composed of various interactive tools including: online discussion forums; downloadable documents and reports; and an interactive online map which facilitates stakeholder participation in identifying, describing and visualizing perceived priorities for landscape restoration;

h) Learning Village: The Learning Village is a critical core component of the PRESENCE network (in the Baviaanskloof) and is currently in the process of extending itself to other conservation and educational initiatives. The establishment of physical facilities in the valley will bring researchers, implementers, managers and local communities closer together, creating a dynamic transdisciplinary environment. The ultimate intention of the Learning Village is to create and support: national and international universities and research centres to collaborate in research teams; build South-North collaboration to increase knowledge, expertise and technology; transfer the acquired knowledge and experience to managers and implementers of restoration and conservation programs; build local capacity that employs and implements the acquired knowledge, expertise and technology; offer community-based education and awareness activities linked to nature restoration; and, finally, monitor and evaluate the success of the initiative. The PRESENCE Learning Village includes the Working for Woodlands Nursery (currently being expanded to become a cultural botanical garden to educate and showcase regional biodiversity); and education and training buildings and accommodation for visiting researchers, implementers, stakeholders and students.

Discussion

The TAIF as a theoretical framework for guiding research and implementation has proven to be a very useful mechanism to keep the PRESENCE network focused. Through its multi-disciplinary focus, it has created a space and platform for involving a range of stakeholders across a range of issues. As mentioned, both scientific researchers and implementers were involved. Their involvement required an integration of bottom up and top down approaches. In other words, science is connected to applied science which in return is linked to implementers and so on. These small differences between stakeholder groups make communication easier, since there are always stakeholders involved that speak multiple "languages", what would create a level of comfort that would facilitate open communication. Secondly, TAIF made the creation of a larger network possible and so brought in a huge amount of knowledge. The combination of this chain of stakeholders and their knowledge ensured that short term successes and results were made. In conclusion, one could say that these short term successes, the effort in stakeholder engagement and the smooth communication between different stakeholder groups are the result of the successful and ongoing implementation of the PRESENCE network, with TAIF as a strategic framework.

Conclusions and Recommendations

There are many lessons to be learned from applying PRESENCE in the Baviaanskloof and its aim of 'mainstreaming' landscape restoration as an effective climate mitigation strategy. Key recommendations lie in openly acknowledging and endeavouring the importance of:

Climate change can compound the degradation brought about from stock over-grazing. Active managment of landscapes is an essential element of ecosystem restoration.

a) Diverse stakeholder perceptions: The ways that nature and ecosystem services are viewed (i.e. the ways in which they value the benefits obtained from their natural environment);

b) Perceived stakeholder priorities: What may be deemed a priority to researchers and implementers may not necessary be shared by other (local) stakeholders. This includes being aware of making false assumptions of what we think stakeholders might think or want;

c) Local, regional and national contexts: This would include history, conflicts and resolutions, organisational networks, stakeholder relationships, institutional priorities and what has (and has not) worked in the past (for both conservation and restoration purposes);

d) Social behaviours: Determine what can be – and what needs to be – reinforced or changed in order to safeguard existing biodiversity and promote restoration;

e) Views and dependence on the ecosystem: The socio-economic and cultural links between people, species and landscape priority areas and the utilisation of 'resources';

f) Realistic timeframes: In planning, researching, consulting, implementing and monitoring.

g) Action-oriented research: Activities must be seen by stakeholders as making a positive and immediate contribution to their needs and challenges currently faced;

h) Ecosystem dynamics: It is necessary to know to what extent restoration is ecologically possible – which areas can be reforested, what rate of survivorship can be expected and what ecosystem services will be restored (e.g. the amount of carbon that can be fixed);

i) Outreach and extension: Communication with stakeholders should be regular, informal and inclusive. Delivery of intermediate feedback, even if 'results' are not necessarily final or provide 'ground-breaking' new insights. Stakeholders should feel that they are an important part of the entire process (from the beginning);

j) Facilitation, integration and 'enabling': A dedicated role should be in place for an individual/organisation to build bridges (and become the 'glue') between science, implementation and stakeholders in order to coordinate overarching aims, guide activities and network between partners to ensure everyone is 'on the same page'. This often overlooked role should also assist with 'fixing' market and institutional 'failures' at the local and regional level;

k) Relationships built on trust, openness and shared benefit: Delicate and sensitive relationships exist, so one must learn the art of negotiation and 'smoothing out';

l) Social marketing and communication: Values and behaviour are embedded in the social context and this insight is vital for creating effective 'intervention' strategies;

m) Building local capacity: Experience, knowledge and social learning during the process are only truly valuable if it remains 'in-house'. Expertise must be available in the future to contribute, facilitate and deliver local insight to similar processes;

n) Realistic promises and expectations: It is critical that project aims and potential outcomes/benefits are not over-estimated when engaging stakeholders;

o) Realistic options and alternatives: 'Solutions' should seek to be obtainable, location specific approaches in line with the historic, cultural and political realities;

p) Synchronistic events and processes: In being strategically opportunistic, it is essential to recognize, capitalise on, and seek to cultivate those serendipitous moments where things come together in a remarkable and usually unplanned-moment way. See Biggs (2008) for a detailed example of synchronistic processes acting for mutual benefit in a South African context;

q) Vision, determination and 'can do' ethic: With limited resources, it is imperative to be opportunistic, look for linkages, and remain positive that aims can be realised. It should be stressed that the simple listing of these lessons learned does not imply that the PRESENCE network has adhered to all of them! However, the programme understands what is needed and, in being aware of them, they become a clear guide for orienting ongoing activities.

Experiences within PRESENCE to date have shown that the programme can only succeed if it is stakeholder inclusive and adaptive: responsive to stakeholder preferences; responsive to implementer's needs and constraints; and responsive to improved scientific understanding and local perceptions of ecosystem functioning and climate change. Relationships between all these groups must be founded on mutual respect and understanding. Such virtues will build long-term trust and form effective working relationships between partners, so ambitious objectives can be achieved into the future.

Many lessons have already been learned and, in many ways, PRESENCE has engaged in a 'learning by doing' process. Importantly, the case study has aimed to illustrate that, scientific researchers, implementation managers and local stakeholders can make both good bedfellows and measurable progress in achieving shared objectives together. However, it was essential to put in place effective coordinating and networking structures which ensure communication and transparency. Finally, the approach must be embedded in a social context; the best science in the world cannot succeed if the motives and players in the game are not first understood.

In recalling a guiding theme of the Ecosystem Approach, we must remind ourselves of the following statement from Shepherd (2004) when endeavouring to achieve restoration objectives: *"It is important to understand that knowledge will inevitably be incomplete at the beginning but that it will grow over time if harmonious working methods are set in place from the start"*; and that: *"The Ecosystem Approach demands realism: often we must settle for what is possible, not what is theoretically ideal"* (Shepherd, 2004).

This understanding has guided PRESENCE in the Baviaanskloof and its ambitions toward enacting landscape restoration as a critical strategy for climate change adaptation and mitigation. Given the size of the task that lies ahead and the resources available, it is essential that any mitigation strategy is seen, first and foremost, as a social process which must ultimately aspire toward shared learning. This provides a basis for improved transdisciplinary understanding of landscape-scale issues and ensures that subsequent biophysical research and implementation strategies can be embedded within an 'enabling environment'. Results and improved knowledge then informs decision making and bolsters an ongoing consensus-building processes amongst stakeholder groups. Given the external variables, the socio-political landscape, the economic situation, breaks in funding cycles and, of course, nature's increasingly unpredictable patterns, this is by no means a 'sure-fire' strategy. But experience dictates that in order to effectively mitigate any external pressure, such as climate change, one must first seek to build resilience across the entire social-ecological system.

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Chapter 12

Championing Climate Change Adaptation at the Community Level by Using an Ecosystem Approach

An Example from Greater Sudbury in Ontario, Canada

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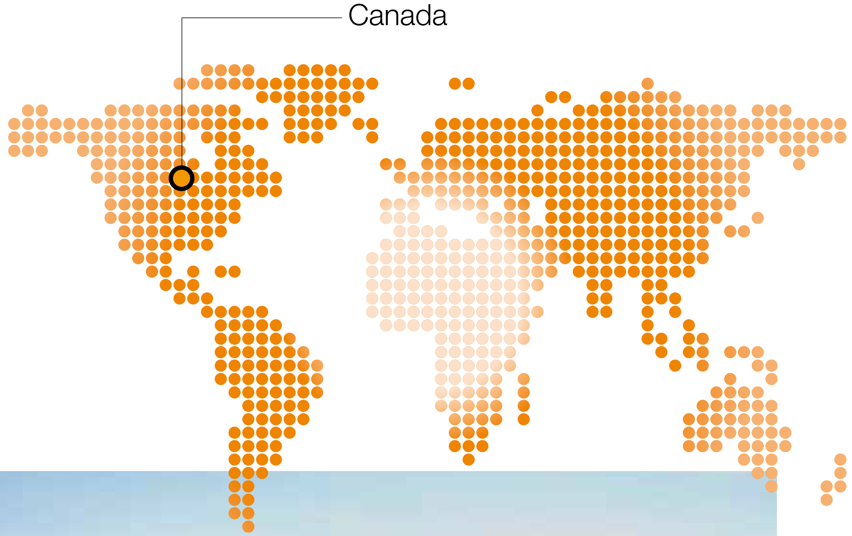


Resource-based communities, especially those in northern or rural regions of Canada, such as Greater Sudbury, will face unique challenges due to the impacts of climate change. Reliant on natural resources to support economic activities, these communities are highly sensitive to changes in the environment. With a changing climate, the City of Greater Sudbury can expect warmer summers and winters, with more frequent and severe extreme events, including floods and storms. Changes in seasonal precipitation are uncertain; however, the city is likely to see an increase in precipitation as rainfall. Various sectors of the community will be impacted, including the natural environment, its infrastructure, industries such as tourism and agriculture, and its drinking water. We can expect a decrease in water quality with more algal blooms and lower lake levels, impacts that may be worsened by increased development on waterfront properties. Following a Case Study on Climate Change Vulnerabilities and Potential Adaptations conducted during 2005–2007, a position paper approved in March 2009 by the Nickel District Conservation Authority (NDCA) served as a basis for the "Sudbury Consortium on Climate Change".

Through NDCA, the consortium was created and approved by the municipal council in November 2009 to assess the potential impacts of climate change on municipal infrastructure and water resources and to determine what adaptation strategies would be needed to address these impacts in the City of Greater Sudbury and its watershed. The consortium brings together the various partners who have a stake in ensuring the City of Greater Sudbury ecosystem can adapt successfully to changes. The consortium is communicating on a regular basis with the general public to educate and inform them, so they know what is happening and that it is a problem, tied in with specific actions they could take. In addition, the consortium has moved to compile recent climate/weather data to update information and understand how the area/planet has changed in the past fifty years and what the projections are for this area. Information and data are currently being assembles into a geographic information system (GIS) database and will be available to the various partners. In addition, at the level of the City of Greater Sudbury, there is a new study available that determines and adds to the GIS the locations of the most vulnerable populations and vulnerable infrastructure, in order to be able to improve response time in case of extreme events. Already, the City of Greater Sudbury has moved into actions with the maintenance of the programs to burry all electrical and phone wires in case of ice storm. While the Consortium is relatively new, strategies are taking shape and a charter is being developed to enhance public participation.

Keywords: Adaptation, Climate change, Community-based management, Consensus building, Consortium development, Extreme events, Interdisciplinary approach, Resource-based community, Water

Introduction

Communities that mainly rely on extracting natural resources for their economy are highly susceptible to influence by climatic and environmental conditions, in addition to market fluctuations. Communities with their major industry being in the exploitation of non-renewable resources, such as copper, nickel, diamonds, gold, etc., may especially be at the mercy of climatic and environmental conditions. This is particularly true as these industries directly rely on continuous supply of electric power and water, both being impacted by climate change. Such communities are found in most countries and are usually medium-sized, with most of their citizens being employed directly or indirectly by the industry. In Canada, these communities are mainly located in northern or rural regions. Greater Sudbury is a typical resource-based medium size community that acknowledges it will face unique challenges due to the impacts of climate change. This case study summarizes the work that was initiated in Greater Sudbury to first better understand the potential impacts of the current climate scenarios, then identify the vulnerabilities in the population, and finally, through the development of a consortium, explore the various adaptation strategies that can be implemented in the region to help the community become more resilient to the expected changes.

Figure 1. Map of Greater Sudbury, Canada, and its surrounding (Courtesy: Growth & Development Department, City of Greater Sudbury, Ontario, Canada).

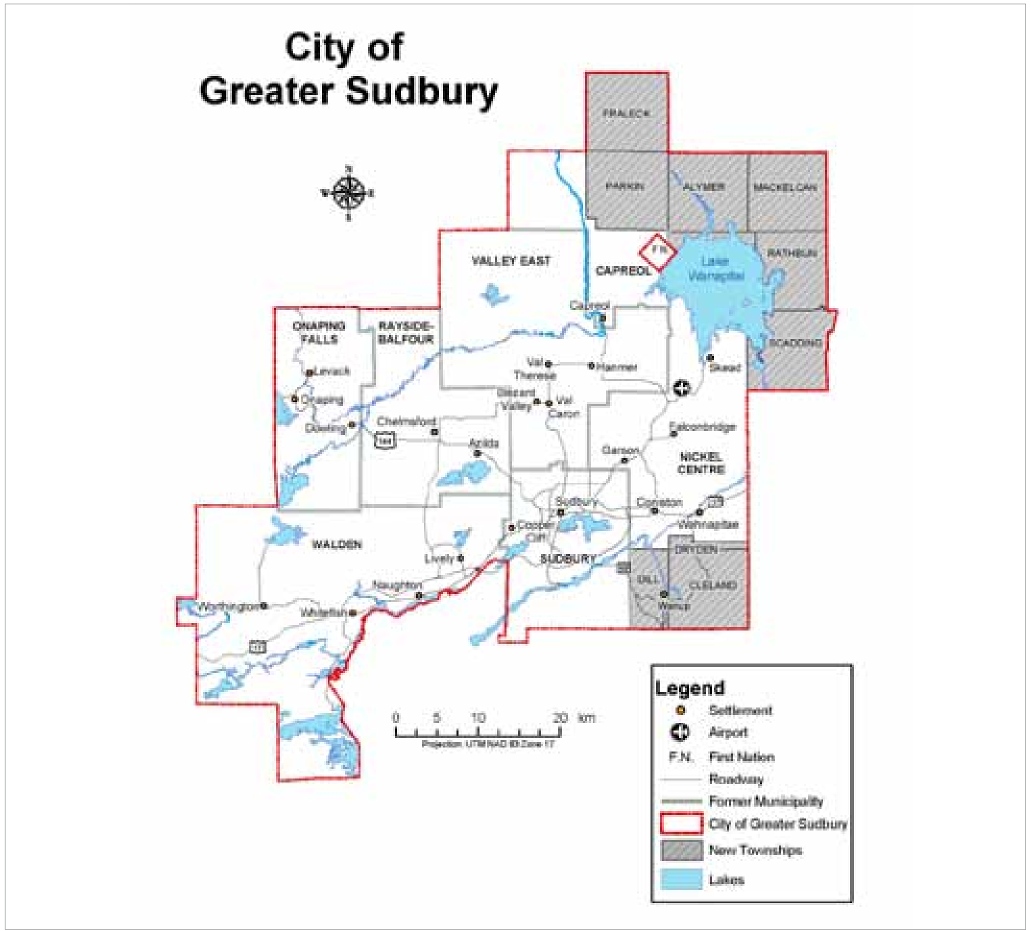
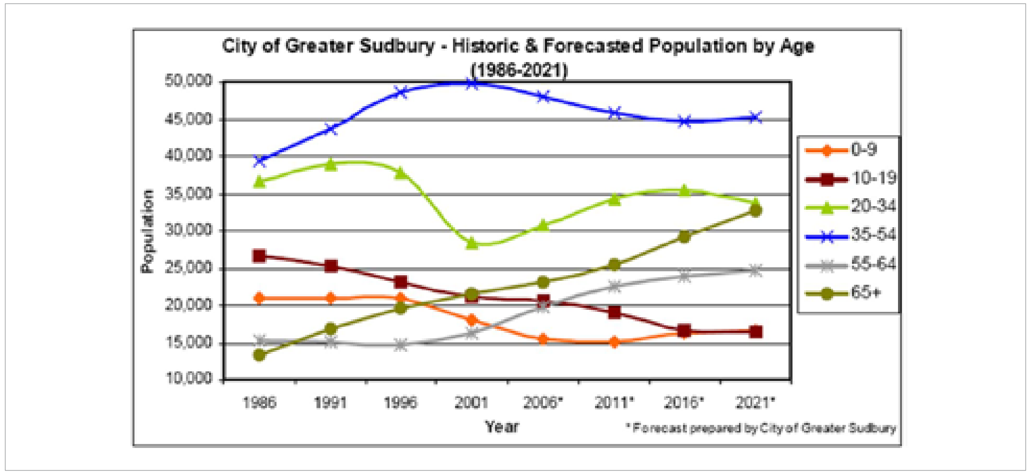


Figure 2. Changes in age composition in the population of Great Sudbury, Canada, between 1986 and 2001, as well as the projected changes between 2001 and 2021 (Source: City of Greater Sudbury, 2006).



terms of human health issues and vulnerabilities to climate change.

Study Area: The City of Greater Sudbury

The City of Greater Sudbury is the second largest municipality in Canada in terms of territory (Fig. 1). It is located in northern Ontario and is home to approximately 158,000 people (Statistics Canada, 2006). The community is considered multicultural and bilingual, with a significant presence of various ethnic groups. The Francophone community represents 28% of the population and 4.8% are of Aboriginal origin. Like many other rural and northern communities in Canada, the population of Greater Sudbury is aging (Fig. 2). This information is highly important to consider in terms of human health issues and vulnerabilities to climate change.

The main industry is mining of nickel, copper and other precious metals, the region being one of the largest deposits of these metals in North America. The mining industry was established in the late 1800s and has since continued to expand its operation in the region. However, such large industrial activity has not come without environmental cost.

Greater Sudbury is well aware of its environment and the need to protect it. Over the past thirty years, the community has developed strong partnerships between stakeholders, decision makers, post-secondary institutions, industry, and others, to deal with environmental challenges. As the impacts of mining on the environment became clear, the community decided to act. With changes in regulations for gas emissions, the mining companies were able to greatly reduce their emissions, thereby reducing the level of pollution in the immediate area. Through community efforts, land reclamation/revegetation programs were initiated that led to what is now a greener environment. The re-greening of Sudbury is an internationally renowned success (Fig. 3). The case study on climate change has been able to build on these strong partnerships in the community.

Figure 3. Photos illustrating the re-greening of a subdivision of the City of Greater Sudbury, Canada, between 1978 (left) and 2001 (right) (Courtesy: City of Greater Sudbury).

Methodology

The Beginning of this Endeavour: Impacts and Vulnerabilities

Between 2005–2007, with the support of a grant from Natural Resources Canada and matching funds from various partner organizations, a study was initiated to identify the climate vulnerabilities in the community of Greater Sudbury. This project brought together 26 different partners from the City of Greater Sudbury. Since it is clear that climate change is going to impact on various spheres of our lives, the study intended to integrate various aspects – from protection of natural ecosystems to public infrastructure and human health. Therefore, the project was interdisciplinary in its approach and involved the participation of researchers and groups in various fields of socio-cultural, economic and biophysical sciences. The case study acknowledged that there is a need to:

a) Acknowledge shared responsibilities for taking action;

b) Build understanding between stakeholders in a community; and

c) Develop public participation in ecosystem management and integrated decision making and planning (Vasseur, 2007, p. 3).

The objectives, designed with the participation of the stakeholders, were to respond to the following:

a) Establishing risk assessment-based, climate vulnerability profiles across the sectors of the Greater Sudbury community for existing and future climate scenarios;

b) Estimating the socio-economic consequences of the climate vulnerability profiles;

c) Determining what information and communication strategies are most effective in enhancing the adaptive capacity and sustainability of the community; and

d) Identifying and triggering adaptive responses (among the existing ones) and actions in the community, including the integration of adaptive strategies into Greater Sudbury's Official Plan and emergency preparedness planning (Vasseur, 2007, p. 5).

The methodology was based on issues raised by Mendis et al. (2003) and was designed to *"link traditional climate change research and assessment to community stakeholders and community attributes such as stability and well-being"* (Vasseur, 2007, p. 6). The project included acquisition of data from current climate change scenarios (with the collaboration of Environment Canada based out of Toronto), interviews and focus groups to identify vulnerabilities, and identification of the priority needs and targeted groups. These steps were combined with various data analyses and stakeholder round-table discussions. For example, the results from the scenarios' projections for the period of 2010–2039 suggested:

a) A two degree Celsius increase in mean summer temperatures and a one degree Celsius increase in winter temperatures;

b) A slight (1%) precipitation increase (on annual basis), with uncertain changes in seasonal distribution of precipitation, and more precipitation falling as rain and less as snow (snowfall season going from October-May [baseline 1961–1990] to November-April [projection 2020]);

c) More frequent and intense extreme events (e.g. droughts and heavy precipitation); and

d) Shorter winter and longer summer seasons with close to twice as many hot days (days with > 25°C) and 4–6 times as many days > 30°C, compared to baseline 1961–1990 data (Vasseur, 2007, p. 15; and see for further detail: www.nickeldistrict.ca).

With a changing climate, warmer summers and winters are expected, with more frequent and severe extreme weather events, including floods and storms. Changes in seasonal precipitation are uncertain; however, the city is likely to see an increase in precipitation as rainfall and freezing rain. Further interviews and focus groups allowed the project to identify specific sectors of the community that will be impacted, including the natural environment, public infrastructure, industries such as tourism and agriculture, and drinking water. The projections suggested that a decrease in water quality was also expected with more algal blooms and lower lake levels, impacts that may be worsened by increased development on waterfront properties.

Defining Next Steps

Following the report of the Case Study on Climate Change Vulnerabilities and Potential Adaptations (2005–2007), Sudbury's Nickel District Conservation Authority (NDCA) became interested in sustaining efforts regarding climate change by continuing to build on the first phase of the case study. This work had become of greater importance with the establishment of The Greater Sudbury Source Protection Authority, where climate change surfaced as a major issue of the city's water management.

In the fall of 2008, NDCA decided on the preparation of a position paper, which was approved in March 2009. In this paper, the NDCA and the City of Greater Sudbury acknowledged the work needed in order to succeed in adapting to climate change and maintaining sustainability of the community: *"Water supplies are limited and climate change (especially the projected extremes in weather) will mostly likely increase pressures on water quality and quantity; we will need to work with all residents to implement actions and activities that will protect our resources; through these actions, we can make the watershed more resilient to face the changes; and short, medium and long term planning and programming priorities of the NDCA and the City of Greater Sudbury will be essential in achieving these goals"* (Vasseur and McMillan, 2009, p. 15).

The action items were approved as follows (Vasseur and McMillan, 2009, p. 16–18):

a) <u>Initiate a Sudbury Consortium on Climate Change:</u> The NDCA has an opportunity to continue to act as a broker to bring together the various partners who have a stake in ensuring the City of Greater Sudbury is able to adapt to climate change impacts. (…);

b) <u>Protection of Lakes:</u> As invasive species become a greater threat to water quality with warmer summers and continuous movements of boats between water bodies, the NDCA and the City, in collaboration with research groups such as the ValeInco Living with Lakes Centre, should maintain a long term monitoring program and define over time the need for restrictions for water use and restoration approaches to ensure long term enjoyment of our lakes. (…);

c) <u>Enhancement of Flood Warning System:</u> As extreme weather events that include a freeze-rain-thaw sequence in the winter become more frequent, there will be a need to ensure that the current NDCA warning system be supported and enhanced in areas more prone to flooding. (…);

d) <u>Public Infrastructure Upgrades:</u> With extreme changes in temperatures, especially in the winters, it is expected that a greater number of water pipes (main and secondary ones) [or roads] will break due to freeze-thaw exposure [and a medium to long term action plan must be defined]. (…);

e) <u>Improved Modelling:</u> The need for data gathering and modelling remains important to better predict what changes are expected at the watershed level and understand the consequences of climate change. The recent analyses were done using various models, some being less adequate for the region. There is a need for downscaling (i.e. information at the local scale) and for completing biophysical modelling (e.g. digital elevation modelling, DEM) for the watershed in order to integrate the scenarios, the potential impacts on the watershed and where actions must be initiated first in order to protect the water supply and municipal infrastructure for all watershed residents. Through continuous collaboration between the different partners in the community, as well as external organizations such as Environment Canada and the Ontario Ministry of Environment, data can be gathered over the next few years, depending on funding and other logistic support;

f) <u>Protect Municipal Drinking Water:</u> Work to integrate climate change into the Drinking Water Source Protection (DWSP) project is vitally important. This is especially important in areas where the population is continuously growing, such as in the Valley, or in areas where most water supply relies on one or two wells. (…);

g) <u>Prevent Water-borne Diseases and Contamination:</u> With warmer summers and extreme rainfall events, toxic chemicals can be released into the water system or lakes and can lead to the proliferation of pests, such as mosquitoes which can carry diseases such as the West Nile virus. It remains important that the Sudbury District Health Unit, with the City of Greater Sudbury, maintains the surveillance program and continues to implement a wide and efficient warning system to alert the community of any type of potential danger. (…); and

h) <u>Public Education:</u> Education remains essential for all residents of the watershed to better understand the vital role that lakes and the water supply play in their lives and the need for their protection, especially in the face of climate change. To do this, all partners must continue to enhance education in schools and outreach programs to the general public.

Results and Actions

Since the spring of 2009, the NDCA with its partners, mainly the City of Greater Sudbury and researchers, have continued putting the building blocks towards effecting the actions of the position paper. One of the first priorities underlined in the position paper and spearheaded by NDCA was the establishment of a consortium that would include partners such as: Laurentian University, Greater Sudbury Development Corporation, Sudbury and District Health Unit, Cooperative Freshwater Ecology Unit, Northern Ontario School or Medicine, MIRARCO, Government of Canada, Government of Ontario, Science North, ValeInco, Xstrata Nickel, Greater Sudbury Utilities, EarthTech, Golder and Associates, Cambrian College, Collège Boréal, Greater Sudbury Chamber of Commerce, and EarthCare. The first step was taken in June 2009, when the NDCA met with the staff of the City of Greater Sudbury to discuss the idea of the consortium (action #1) and further actions that could be taken in relation to the position paper. From this meeting and others, the "Sudbury Consortium on Climate Change Adaptations" was officially endorsed by the municipal council in November 2009. Subsequently it was endorsed by the City of Greater Sudbury's Healthy Community Cabinet, as a Healthy Community and United Nations Regional Centre of Expertise on Education for Sustainable Development initiative.

Its mandate is to continue assessing the potential impacts of climate change on industry, people, municipal infrastructure, and water resources and to determine what adaptation strategies will be needed to address these impacts in the City of Greater Sudbury and its watersheds. The consortium brings together the various partners who have a stake in ensuring the City of Greater Sudbury ecosystem can adapt to a changing climate. The consortium was established based on the format of the United Nations Regional Centre of Expertise on Education for Sustainable Development Sudbury. Indeed, in 2005, Greater Sudbury applied and received the formal nomination of a Regional Centre of Expertise under the United Nations University's (UNU) Institute of Advanced Studies. The Regional Centre acts as a network working on issues of sustainable development with formal, non-formal and informal elements of actions and communication with partners and the community. The consortium wants to communicate on a regular basis with the general public to educate and inform people on the issues, problems and adaptation solutions to a changed climate. The consortium is using the principles reported by Vasseur et al. (2007) which cover adaptation strategies that can help reduce, remove, accommodate, or avoid risks or vulnerabilities due to climate change. The Consortium is led by a small executive group and Managing Partners, the multi-sectoral representatives of the community. While the consortium is relatively new, strategies are taking shape using a process for action ('identify, initiate and integrate'). Already, a charter/covenant is being developed for sign-on, to enhance public participation and increase awareness. Decision making is based on consensus. The Consortium reports, through the NDCA, to the Council of the City of Greater Sudbury, the Healthy Community Cabinet and the general public. Many of the activities that are related to the consortium and the position paper are described in the next paragraphs (Fig. 4).

Regarding lake protection, the NDCA's strong collaboration with the ValeInco Living with Lakes Centre at Laurentian University allows for the possibility to continue monitoring the lakes. Researchers report on a regular basis to various authorities who help keep the public and community organizations informed and secure. In this case, the principles of avoidance or reduction of the risks of contamination are applied.

Figure 4. Photo of the managing partners at the March 30, 2010 workshop. Front Row (from left to right): L Vasseur, J. Landry-Altmann, S. May, J. Hamr, I. Kaletka and C. Orlando-Mathur. Second Row: R. Arbour-Gagnon, E. McMillan, I. Vetoretti, V. Morrow, D. Talbot-Lariviere and D. Robinson. Third Row: S. Monet, B. Hawkins, B. Rogers, I. Filion and P. Sajatovic.

Flooding and public infrastructure have been discussed mainly with the City and Public Works Department. From the June 2009 workshop, the Emergency Measures Department has moved to compile updated information showing how flooding would affect the region. The information and data have been integrated into a GIS database, with data and mapping provided by the NDCA, and will be available to the various partners. In addition, with the City, the system is used to locate the most vulnerable populations and infrastructure in order to improve response time in case of extreme weather events. The City of Greater Sudbury has already taken action with the maintenance of programs to bury all electrical and phone wires, an action which has proven to be effective protection in case of ice storms. From the work of the Junction Creek Safety Committee (created after the drowning of a child during an extreme flooding event), efforts are maintained to develop a more integrated warning system that would use the 'reduce principle' of adaptation in case of such events. Another adaptation was the fast track construction of the Box Culvert Access facility (which is dedicated to the child) to have better access to the creek which runs under the downtown core of Sudbury and where emergency services had few or no possible access in the past.

Additional public infrastructure work is currently being examined with medium and long term planning for the replacement and strengthening of the water system. This will involve renewal of the pipes in the next 5 to 15 years in order to ensure adequate distribution and reduce water loss and leakage due to damage. The City also understands that it will have to re-examine the existing wastewater infrastructure to ensure that it will handle extremes and protect the natural ecosystem. Similar work is also occurring for the road system.

Municipal drinking water is an important issue for Greater Sudbury and has been reported as a priority for most stakeholders during the previous case study (Vasseur et al., 2007). Through the Drinking Water Source Protection Assessment Report, serving as the basis for the Source Protection Plan to be tabled in 2012, the NDCA, Greater Sudbury Source Protection Authority (GSSPA) and Greater Sudbury Source Protection Committee (GSSPC) have started to include climate change issues into the management structure of the plan. The main goal of this integration was the protection of current and potential, future municipal drinking water sources for the community. Currently, Greater Sudbury relies on 22 groundwater wells and three main surface water bodies (Lake Ramsey, Vermilion River and Wanapetei River) for most of its water. However, with population growth and urban development, especially around Lake Ramsey, there is a concern that warmer temperatures in the summer will lead to limitation in water quantity, particularly with respect to algal bloom and coliform contamination (the lake being used for boating, swimming and host of many waterfowl).

This action to protect water quality is linked with the action item on diseases and contamination in the position paper. The Sudbury District Health Unit has a program, implemented through their new strategic action plan, tying into these action items. Under the mandate of the Health Unit, they have been targeted by the provincial government in 2009 to be the regional lead on climate change related health issues, such as safety of the elderly, monitoring of the West Nile virus, water borne diseases, contamination, etc. This mandate is very comprehensive and will be in part supported by the other consortium partners. In this case, the consortium is helping with linkages and supports the work of the Health Unit.

Public education is also an important action item in the protection of our water resources. The NDCA, the City of Greater Sudbury, Sudbury District Health Unit (SDHU) and other partners continue to support the Water Festival and continue to employ exhibits and other workshops in the region to explain the science and impacts of climate change and outline the actions currently being taken by the community to adapt to these challenges. Over the next 2–4 years, training of city staff and employees of different industries should be encouraged to help support greater awareness and action towards adaptation to a changing climate. In addition, the SDHU and other partners continue supporting the Children's Water Festival, an event targeting the schools and their education on water issues including the impacts of climate change. The event also outlines the actions taken by some members of the community to adapt to water changes due to climate change.

As education was felt to be very important, it has been not only integrated into the previous actions, but has also been targeted as a separate action in the position paper. There are many education organizations that have become involved over the past few years in this field. It is worth noting the role of the four school boards of Greater Sudbury. One of the municipal councillors is involved through the Junction Creek Safety Committee and the Rainbow School Board in the development of new educative materials on climate change, early warning systems for extreme events (mainly flooding) and adaptations for elementary school students. They added emphasis on safety for situations in fast flowing rivers and creeks, instead of the usual lake safety material, to ensure better preparation of the children in the region where creeks are as predominant as lakes.

Finally, it is important to note that over the next 2–4 years the NDCA, with the collaboration of the City of Greater Sudbury, will encourage city staff and employees of different industries to be trained to help support greater awareness and action towards adaptation to a changing climate.

Conclusions and Recommendations

While the project was initiated only recently, because of the past history of the community and its desire to work together for the betterment of the community, it has been possible to start engaging various actors in the process of designing adaptation strategies for the region. This was achieved despite the scepticism that exists in the community regarding climate change. As a first step in this engagement, the Managing Partners of the Consortium and others are engaged in completing a climate adaptation actions matrix. The matrix includes identifying the risks, the anticipated rate of occurrence, the estimated costs associated with the risks, and adaptation actions to mitigate and manage the identified risks. The matrix is currently in the process of becoming populated.

Regions such as Greater Sudbury have experienced (until now) milder impacts of climate change and few major catastrophes, compared to coastal regions where sea level rise, erosion and storm surges have already impacted to the point of understanding the need to adapt to changes. Combined with challenges due to the current economic situation, the consortium is aware that it will take more time and more convincing before the general public will rally to this cause. In the meantime, the city and several local organizations are moving forward in order to have the capacity when needed to implement strategies and thus help their citizens adapt at the right time to climate changes.

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Chapter 13

Conclusions and Recommendations

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The case studies presented and discussed in this publication cover a wide range of communities and ecosystems with different biophysical and socioeconomic conditions and varying degrees of transformation and vulnerability to climate change. Cases come from around the world and address communities living in or depending on ecosystems such as the tropical highlands of South America, the wetlands in the African Sahel, urban settlements in Canada, coral reefs in the Caribbean, and cold systems in Antarctica, among others.

This overview of case studies is an attempt to contribute to the knowledge linking the management of ecosystems for biodiversity and ecosystem services, and societal adaptation to climate change.

The main conclusions and recommendations that result from an analysis of the case studies presented in this publication are:

1. **Climate change adaptation is still in its early stages:** Although there are many approaches used, there remains considerable scope to further develop a clear conceptual framework and set of guidelines necessary to understand and measure vulnerability, and develop feasible adaptation strategies needed to address climate change successfully.

2. **Adaptation science is very complex:** Ecosystem-based Adaptation (EbA) recognizes that social and ecological aspects have to be analyzed and addressed in an integrated manner, as adaptation is seen as the ability to live with change and build resilience. There is also a need for information and guidelines in the field, for developing strategies and measuring resilience of socio-ecological systems. This is the main challenge for the near future.

3. **Ecosystem-based Adaptation (EbA) to climate change is strengthened by using the principles of the Ecosystem Approach:** The twelve principles of the Ecosystem Approach proposed initially in the context of the UN Convention on Biological Diversity, serve as a useful framework for assessing both climate change impacts on socio-ecological systems as well as the systems' vulnerability, and proposing actions for adaptation.

4. **Ecosystem-based Adaptation (EbA) should pay attention to the relevant cultural aspects of adaptation:** Humans and their culture are an integral part of most if not all ecosystems. Therefore, the design and implementation of adaptation measures should include not only technical aspects, but also the transformation of the sociocultural patterns that link them to the environment.

5. **Vulnerability assessments of ecosystem services are an important element of understanding comprehensively the impact of climate change and propose adaptation actions:** Some case studies present vulnerability analyses in relation to ecosystem services provided to society. Such a scheme is very useful, but more

work is needed, particularly in developing appropriate tools for assessing vulnerability and proposing adaptation measures that both deal with ecological and social requirements.

6. **Ecosystem-based Adaptation (EbA) recognizes that the loss of biodiversity directly influences ecological functions that support human life:** Nevertheless, the living and non-living components of ecosystems and the links among them that are responsible for specific ecosystem functions and services, are in many cases still not yet well known and understood. In this regard, it is important to stress that to maintain ecosystem functions and keep the associated biodiversity, it is key to conduct vulnerability analyses, and design adaptation measures that take into account uncertainty.

7. **Uncertainty is one of the main constraints of Ecosystem-based Adaptation (EbA):** Due to a lack of information on the impacts of climate variability and climate change on people and biodiversity, and due to our limited knowledge of socio-ecological dynamics, there are high levels of uncertainty regarding future projections and system responses. Such constraints could limit all adaptation responses, including the intended impact of any EbA interventions.

8. **As with all interventions, a monitoring strategy is essential for Ecosystem-based Adaptation (EbA):** Due to the aforementioned uncertainty the design of adaptation measures must include a monitoring strategy that provides information about the effectiveness of EbA. Comprehensive monitoring strategies also may provide a means for learning and offers the possibility to adapt planned actions to changing conditions. Monitoring is a long term process and may be very costly. However, it has to be part of an adaptation strategy to make that strategy effective in the long term. So far, only a few cases presented in this publication already included or discussed the topic of monitoring, since the concept is relatively new.

9. **Ecosystem-based Adaptation (EbA) has to address the negative, cumulative effects of past interventions on natural ecosystems:** Negative impacts on ecosystems that result from human intervention or extreme events, such as the desiccation of wetlands, the breakup of connecting channels among water bodies or the canalization of rivers, among others, will increase those systems' vulnerability to climate change. Hence, such negative impacts will require the reconstruction of a "natural or green infrastructure" – such as offered by ecosystems – as a main response to reduce that kind of vulnerability.

10. **Ecosystem-based Adaptation (EbA) is associated with disaster risk reduction:** In many cases the effects of climate variability and climate change are associated with extreme events that increase the frequency of factors that disrupt the integrity of ecosystems and the welfare of local communities. The interface between these two components are the ecosystem services they provide, especially those that contribute to mitigating potential impacts such as floods, landslides, avalanches, etc.

11. **Ecological restoration with participation of local communities is a relevant adaptation measure within the scope of Ecosystem-based Adaptation (EbA):** The restoration of ecosystem structure and function can be a key element of EbA. Most case studies in this publication refer to the importance of land cover restoration in supporting the continued supply of ecosystem services. Nevertheless, additional relevant social and ecological indicators have to be defined and measured, in order to be able to evaluate the effectiveness of restoration in reducing vulnerability to climate change and variability. Such an approach would include actions that help reduce adverse effects of climate change impacts, e.g. by planting species that respond successfully to changes in humidity and temperature, help decrease the risk of wildfires, contribute to the recovery of water sources, stimulate pollination services, and increase connectivity among ecosystems, among others. Restoration activities should be promoted through participatory community agreements established at local levels.

12. **Ecosystem-based Adaptation (EbA) should be integrated into broader adaptation strategies:** The case studies demonstrate the use of two different, often separate approaches: a top-down and a bottom-up approach. It is recommended, however, that both EbA approaches are applied as appropriate in different contexts, and in a complementary manner to ensure better integration. The top-down approach often starts with a vulnerability analysis done by a government and/or established institutions, with the aim to develop concrete actions locally to address climate change and enhance ecosystem resilience. On the other hand, the bottom-up approach is often led by local people, rural communities and civil society groups aware of climate change affecting their lands. They may develop conceptual frameworks and guidelines as well as strategic adaptation plans that eventually are elevated to regional and global levels. To ensure that the top-down and bottom-up approaches become more effective, they should be integrated using existing (mid-level) institutions as vehicles. Also, they should take into account the development of new mechanisms that enable the establishment of agreements around the so-called "global commons".

13. **Social participation is an essential structural basis on which Ecosystem-based Adaptation (EbA) is built:** The dissemination of knowledge on global climate change and its impact on ecosystems and human communities enriches social processes and agreements between relevant sectors and stakeholders to address climate change issues. Such processes are essential to the success of EbA approaches and in the near future will require complementary financial and economic assessments of adaptation strategies.

14. **Community networking is the key to effective Ecosystem-based Adaptation (EbA):** Most case studies emphasize the importance of developing a social framework that allows the permanent interaction among all kinds of actors and stakeholders, as well as local communities. In this regard, the development of appropriate institutions at local, regional and national level is vital to the success of EbA in a social context. Initiatives discussed in this publication include the establishment and consolidation of networks of relevant stakeholders and the development of local community agreements that focus at management of natural resources (e.g. water), ecosystem restoration and conflict resolution.

15. **Institutional and governance networks are key elements that enhance the adaptive capacity of an ecosystem beyond mere natural resource availability:** Networks at institutional levels that take into account different degrees of governance are essential vehicles that facilitate the development and implementation of effective EbA measures. They help overcome socioeconomic and political barriers that impede adaptation processes and therefore should be taken into account when strategies are designed and subsequently implemented. Such institutional development processes allow the introduction of climate change adaptation measures in land use plans, disaster risk reduction plans, and (inter) sector policies at different governance levels

16. **Economic considerations need to be taken into account to ensure the appropriate implementation of Ecosystem-based Adaptation (EbA) approaches:** As some case studies in this publication have stressed, there are important economic issues that relate to EbA approaches. Many

EbA interventions can provide long-term returns on investment that might exceed the benefits of other adaptive solutions and "business as usual" options. Adaptation actions that do take into consideration an ecosystem's biodiversity, its ecological processes and the services it generates, will have a positive effect on the system itself and provide benefits to mankind in such a way that both the issue of climate change is addressed and fundamental ecosystem functions necessary to ensure community survival and human health are maintained. Nevertheless, financial studies of adaptation measures have to be made, as none of the case studies include such an analysis.

17. **Ecosystem-based Adaptation (EbA) has its limitations:** There is considerable uncertainty about many aspects of EbA. For instance, little is known about the thresholds of EbA implementation in positively affecting the levels of a system's vulnerability to climate variability and change. None of the case studies presented in this publication directly addresses this point by, for instance, using existing information to define the limitations of EbA. However, adaptation to climate change is very much a process of "learning by doing" that needs to be enhanced by monitoring systems and a permanent feedback mechanism that allows for adaptive management and would ensure that reliable information about the vulnerability, resilience, and adaptive capacity of socio-ecological systems is incorporated into the EbA process.

18. **Ecosystem-based Adaptation (EbA) can have co-benefits for poverty alleviation:** Adaptation to climate change is fundamental to reduce poverty, sanitarian risks, hunger and thirst. More than 2 billion people live under climate change threats for their livelihoods, and it is expected that their numbers will rise by another billion in the near future. In order to quantify the contribution of EBA to achieving the UN Millennium Development Goals (MDGs) such as poverty reduction and environmental sustainability, the impact of EbA interventions on these issues should be measured clearly. Indicators and metrics to measure the impacts of ecosystem-based adaptation interventions on poverty, hunger, etc. need to be further developed.

19. **Capacity building requirements to implement Ecosystem-based Adaptation (EbA) need to be defined:** One of the critical limitations for implementing EbA in many countries is a lack of institutional capacity and related capacity development plans. A special effort is required to raise awareness of capacity building needs, and to better resource and implement capacity developments.

20. **Conservation strategies are fundamental for developing and implementing practical Ecosystem-based Adaptation (EbA) solutions:** As many studies have demonstrated, conservation strategies should be considered an integral part of the Ecosystem-based Adaptation practice. It has been suggested that the design of integrated, comprehensive and ecologically resilient conservation networks at the appropriate scales could play a key role in implementing adaptation solutions to maintain and restore biodiversity and associated ecosystem services.

21. **Ecosystem-based Adaptation actions should be taken in different types of ecosystems vulnerable to climate change all over the world:** As the case studies in this publication have shown; not only small islands and coastal areas are experiencing climate change problems. A lot of other ecosystems like wetlands and high mountains are facing climate variability and change. This global phenomenon requires comprehensive studies now and calls for quick action at national levels to develop strategies that focus both at mitigation and Ecosystem-based Adaptation, rooting in thorough assessments of biodiversity, analysis of vulnerability levels, socio-economic monitoring, and cooperative networks.

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