CLIMATE CHANGE VULNERABILITY ASSESSMENT OF THE DISCOVERY COAST AND ABROLHOS SHELF, BRAZIL

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Table of Content

Table of Figures

Executive Summary

The IKI-funded project “Ecosystem-based adaptation in marine, terrestrial and coastal regions as a mean of improving livelihoods and conserving biodiversity in the face of climate change” has been taking place in Brazil, South Africa and the Philippines. Ecosystem-based adaptation entails 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 one of the possible elements of an overall adaptation strategy, ecosystem-based adaptation uses the sustainable management, conservation, and restoration of ecosystems to provide services that enable people to adapt to the impacts of climate change. In order to identify adaptation strategies and interventions in the IKI target, the first step is to conduct a climate change vulnerability assessment, where climate change impacts and vulnerabilities are accessed.

This report describes the results of a climate change vulnerability assessment conducted for the greater Discovery Coast and Abrolhos shelf region, in the Northeast of Brazil. This area includes the Abrolhos shelf and the adjacent terrestrial watersheds of the Mucuri, Doce and Jequitinhonha rivers, and harbours the largest forest remnants within the northern part of the Atlantic Forest biome, as well as the largest and richest coral reefs in the Southern Atlantic. This region supports over 500,000 people and much employment is generated from natural systems, with nearly 20,000 people relying on fisheries and another 80,000 on tourism.

The analysis and recommendations described in this report are the result of a climate change vulnerability assessment process designed with and implemented through consultation with colleagues from Brazilian and international universities, governmental and non-governmental organizations, private companies and members of local communities. Our collaborators helped define research gaps, which were subsequently completed and participated in the expert’s workshop that culminated in this assessment. Collaborators conducted a series of studies to improve the knowledge base of climate change impacts in the region. Due to the uncertainties in the future climatic projections, we worked with two extreme scenarios, one dry and one wet. The results of these studies, together with other relevant science, formed the basis for expert identification of major climate change impacts and adaptation responses during the vulnerability assessment workshop. Those major climate change impacts identified for the Discovery Coast and the Abrolhos shelf are:

1. **Decline in near-shore fisheries** due to the negative impacts of increased ocean temperature and ocean acidification on coral reefs but a potential increase in off-shore fisheries due to the prevalence of winter-like conditions (when a combination of favorable winds and a nutrient-rich water mass creates increased vertical mixing and a burst of primary production). Tens of thousands of people in the study region depend on near-shore fisheries and will be negatively impacted if climate change reduces fish populations.
2. **Increase in sediments delivered to reefs**, especially in their shore-adjacent inner arc of those reefs, as a result of a scenario of high future rainfall. Oceanographic impacts of climate change (increased near-floor orbital velocities) will increase and prolong sediment suspension, which will be intensified by the longer reef submission time caused by sea level rise. The primary first-order impacts of reef sedimentation are coral mortality and an ensuing collapse of fish stocks. Second-order impacts

include degradation of natural beauty, tourism offerings, and fisheries whose stocks depend on reefs and related habitats for a portion of their lifecycles.

3. **Increase the vulnerability of coastal areas to erosion** due to a combination of sea level rise and changes in wave heights and direction due to changes in ocean circulation. Sea level rise will increase the depth of water across the coast of Bahia, potentially flooding many coastal areas and habitats and increasing their vulnerability to erosion, especially during storm events. Changes in erosion patterns and flooding from sea level rise will directly impact local hotels, homes, and restaurants. Infrastructure located on or near the coastline including roads, electrical transmission lines, sewage and water infrastructure, and bridges are subject to damage. This will be exacerbated by the loss of coastal ecosystems (mangroves and *apicum*) that mitigate coastal flooding and erosion.
4. **Increase the feedback among local climate, fire and forest fragmentation**, increasing the frequency of forest fires in the future as a result of a scenario of less rainfall and high temperatures, which would generate new forest edges and more vulnerability to further burns. Climate change may further compound these effects by interfering natural forest regeneration due to the loss of seed dispersers diversity. Climate change will affect the ability to diversify tourism in the region, as well as impacting ecosystem services such as water provision and crop pollination.
5. **Negative impacts on estuaries** due to a freshwater squeeze resulting from an increased salinity on the seaward side, as a result of sea level rise, and a diminished freshwater discharge from upriver. The freshwater squeeze will impact fish stocks, endemic and migratory bird and turtle populations, and marine mammals. Freshwater habitat and biodiversity and fresh water availability for human consumption will be impacted due to the inland penetration of saltwater wedge. Human populations, particularly communities which depend primarily or secondarily on fishing as a source of protein or income will lose employment and income if estuaries are lost to climate change. Reduction and extinction of charismatic animals will greatly diminish the ecotourism appeal and natural beauty of the study area's coastal and marine environments.
6. **Decline in water yield** is expected in some parts of the coast in the study region and in mountainous areas that drain to Porto Seguro, one of the most important cities for tourism in the study region. It is possible that at least 6.8 million people may be at some degree of risk of water scarcity or of decrease in water availability if forested areas located around watersheds or in areas of high fog interception are not properly protected or managed.
7. **Decline in areas suitable for coffee** in the future, with a 53% to 56 % reduction in the future suitable area when compared to the present. The extreme south of Bahia state and the extreme north of the Espírito Santo state, which are the areas with the highest number of coffee plantations at the moment, will no longer be suitable for arabica coffee. Part of one of the most important regions for coffee production worldwide is predicted to no longer be suitable for arabica coffee. As coffee is one of the main agriculture activities in the study region, a large monetary loss (about 400 million dollars per year) is expected with the reduction in suitable areas for coffee as a result of climate change.

The main recommendations identified through this vulnerability assessment process are: a) to implement adaptive fisheries management, b) to increase coral reef resilience, c) to strength coastal planning and management, d) to grow the value of forest fragments, e) to implement integrated watershed management for sustainable freshwater supply, and f) to promote shaded coffee practices. The main actions related to each one of those recommendations are described in more details in the report. As part of this grant, two adaptation interventions will be implemented in the region where the assessment was conducted. These adaptation interventions are presented in this report for potential implementation in the municipalities of Porto Seguro and Prado, in Bahia state. One aims to protect coastal infrastructure and improve fisheries in the face of sea level rise and changes in wave dynamics by developing activities that promote more appropriate coastal planning and by protecting offshore coral reefs. The other aims to increase resilience and reduce vulnerability of people, ecosystems and ecosystems services by adding Ecosystem-based adaptation recommendations in a municipal plan of conservation and restoration of the Atlantic Forest.

Resumo

O projeto financiado pelo IKI "adaptação baseada nos ecossistemas em regiões marinhas, terrestres e costeiras como forma de melhorar as condições de vida e conservação da biodiversidade frente às mudanças climáticas" está sendo desenvolvido no Brasil, na África do Sul e nas Filipinas. A adaptação baseada nos ecossistemas é o uso da biodiversidade e serviços ecossistêmicos como parte de uma estratégia para ajudar as pessoas a se adaptarem aos efeitos adversos das mudanças climáticas. A adaptação baseada nos ecossistemas usa a gestão, a conservação e a restauração de ecossistemas a fim de fornecer serviços que permitem às pessoas se adaptarem aos impactos das mudanças climáticas. A fim de identificar as estratégias de adaptação e conduzir intervenções nestes três países, o primeiro passo a ser realizado foi a execução de uma análise de vulnerabilidade às mudanças climáticas, através da qual os impactos das mudanças climáticas e vulnerabilidades foram levantados.

Este relatório descreve os resultados dessa análise de vulnerabilidade às mudanças climáticas realizada para a Costa do Descobrimento e a região de Abrolhos, no Nordeste do Brasil. Esta área inclui a plataforma de Abrolhos e as bacias dos rios Mucuri, Doce e Jequitinhonha, e abriga os maiores remanescentes florestais na parte nordeste do bioma Mata Atlântica e os maiores e mais ricos recifes de corais do Atlântico Sul. Nessa região vivem mais de 500 mil pessoas e a maior parte dos empregos é gerada a partir de sistemas naturais, com cerca de 20 mil pessoas dependendo da pesca e outras 80.000 do turismo.

A análise e as recomendações descritas neste relatório são o resultado de um processo de avaliação de vulnerabilidade projetado e executado por meio de consultas com pessquisadores de universidades brasileiras e internacionais, e colaboradores de organizações governamentais e não-governamentais, empresas privadas e membros das comunidades locais. esses parceiros nos ajudaram a definir lacunas no conhecimento, as quais foram posteriormente completadas, e participaram do *workshop* onde a informação foi revisada, os impactos das mudanças climáticas foram identificados e as recomendações e repostas de adaptação foram sugeridas. Nossos colaboradores realizaram uma série de estudos para melhorar a base de conhecimento sobre os impactos das mudanças climáticas na região. Devido à incerteza das projeções futuras, trabalhamos com dois cenários extremos, um seco e um chuvoso. Os resultados destes estudos, juntamente com outros estudos relevantes disponíveis para a região, formaram a base para a identificação dos principais impactos das mudanças climáticas e as respostas de adaptação. Os principais impactos das mudanças climáticas identificados para a Costa do Descobrimento e a região de Abrolhos são os seguintes:

1. **Declínio da pesca costeira**, devido aos impactos negativos do aumento da temperatura dos oceanos e a acidificação nos recifes de coral, mas um potencial aumento na pesca *off-shore* devido à prevalência de condições típicas de inverno (quando uma combinação de ventos favoráveis e uma massa de água rica em nutrientes disponibilizada pelo aumento na mistura vertical , gerando uma grande produção primária). Dezenas de milhares de pessoas na região de estudo dependem da pesca *costeira* e serão negativamente impactadas se as mudanças climáticas reduzirem as populações de peixes nessa região.
2. **Aumento de sedimentos que aportam nos recifes**, especialmente no arco interno dos recifes, como resultado de um cenário futuro com mais precipitação. Impactos oceanográficos das mudanças

climáticas, como o aumento das velocidades orbitais do fundo, poderão aumentar e prolongar a suspensão de sedimentos. Esse efeito vai ser intensificado pelo maior tempo de submersão dos recifes causado pelo aumento do nível do mar. Os impactos primários da sedimentação sobre os recifes são a mortalidade dos corais e um consequente colapso nos estoques pesqueiros. Outros impactos incluem degradação da beleza natural, turismo e pesca, já que muitas espécies dependem dos recifes e habitats relacionados durante pelo menos uma parte de seus ciclos de vida.

3. **Aumento da vulnerabilidade das zonas costeiras à erosão** devido a uma combinação do aumento no nível do mar e mudanças na altura e direção das ondas, decorrentes das mudanças na circulação oceânica. O aumento do nível do mar pode potencialmente inundar muitas áreas costeiras e habitats, aumentando a vulnerabilidade da costa à erosão, especialmente durante tempestades. Mudanças nos padrões de erosão e inundações decorrentes do aumento no nível do mar irão impactar diretamente hotéis, casas e restaurantes. A infra-estrutura localizada na costa ou próxima a costa como estradas, linhas de transmissão de energia elétrica e pontes, estará sujeita a danos. Esses impactos provavelmente serão agravados pela perda de ecossistemas costeiros (como manguezais e apicum) já que estes são importantes agentes na mitigação de inundações costeiras e erosão.
4. **Aumento da retroalimentação entre clima local, o fogo e a fragmentação florestal**, aumentando a frequência dos incêndios florestais no futuro, como resultado de um cenário mais seco e quente, o que geraria uma maior área de borda nos fragmentos florestais e uma maior vulnerabilidade a novas queimadas. As alterações climáticas podem agravar ainda mais esses efeitos, interferindo na regeneração da floresta natural, devido à perda da diversidade dos dispersores de sementes. As mudanças climáticas afetarão a capacidade de diversificação do turismo na região, bem como impactarão os serviços ecossistêmicos, como a provisão de água doce e a polinização de cultivos agrícolas.
5. **Impactos negativos sobre estuários** devido a um aumento da entrada de água salgada e a uma diminuição da descarga de água doce nesses sistemas como resultado do aumento do nível do mar e de um possível cenário climático futuro mais seco. Esse processo afetará peixes, aves endêmicas e migratórias e populações de tartarugas e mamíferos marinhos. A penetração de água salgada afetará os ambientes de água doce, a biodiversidade e a disponibilidade de água doce para o consumo humano. As populações humanas, principalmente as comunidades que dependem primariamente ou secundariamente da pesca como fonte de proteína ou renda poderão ser muito afetadas pelo processo das mudanças climáticas. Uma possível redução e extinção de animais carismáticos reduzirão o apelo turístico e a beleza natural dos ambientes costeiros e marinhos da região de estudo.
6. **Declínio na disponibilidade de água** está prevista em algumas partes da costa da região de estudo e áreas mais altas que drenam Porto Seguro, uma das cidades mais importantes para o turismo na região de estudo. É possível que, pelo menos, 6,8 milhões de pessoas possam sofrer escassez de água se florestas localizadas em torno de bacias hidrográficas ou em áreas de alta interceptação de neblina não sejam devidamente protegidas ou gerenciadas.
7. **Diminuição das áreas apropriadas para o plantio do café** no futuro, com uma redução de 53% a 56% em área quando comparadas com as áreas destinadas ao cultivo de café atualmente. O extremo sul do estado da Bahia e o extremo norte do estado do Espírito Santo, que são os locais com o maior número de plantações de café no momento, poderão não apresentar condições climáticas apropriadas para o plantio do café arábica. Como o café é uma das principais atividades

agrícolas na região de estudo, uma grande perda monetária (cerca de 400 milhões de dólares por ano) poderá acontecer se houver uma redução das áreas adequadas para o café como esperado, resultante das mudanças climáticas.

As principais recomendações identificadas através deste processo de análise de vulnerabilidade são: a) implementar um manejo de pesca, b) aumentar a resiliência dos recife de corais, c) fortalecer o planejamento e gestão costeira, d) valorizar os fragmentos florestais, e) implementar um manejo das bacias hidrográficas para manter a disponibilidade de água na região, e f) promover práticas de plantio de café sombreado. As principais ações relacionadas a cada uma dessas recomendações são descritas em mais detalhes no relatório. Através desse projeto, duas intervenções de adaptação serão implementadas na região de estudo. Estas intervenções de adaptação são apresentados neste relatório para potencial implementação nos municípios de Porto Seguro e Prado, no estado da Bahia. Um dessas intervenções visa proteger a infra-estrutura costeira e melhorar a pesca na região frente aos possíveis impactos das mudanças climáticas, através do desenvolvimento de atividades que promoverão um planejamento costeiro mais apropriado, e através da proteção dos recifes de corais. A outra intervenção visa aumentar a resiliência e reduzir a vulnerabilidade das pessoas, dos ecossistemas e dos serviços ecossistêmicos, através da inserção de recomendações de adaptação baseada nos ecossistemas no plano municipal de conservação e restauração da Mata Atlântica em Porto Seguro.

I. Introduction

This report describes the results of a climate change vulnerability assessment conducted for the greater Discovery Coast and Abrolhos shelf region of Northeast Brazil. This is a joint assessment of marine and terrestrial systems, which allows understanding of interactions and linkages between the marine and terrestrial realms. The study region is defined as the Abrolhos shelf and the adjacent terrestrial watersheds of the Mucuri, Doce and Jequitinhonha rivers (Figure 1). This region encompasses some of the most threatened tropical forests in the world in direct juxtaposition to a rich and unusual coral reef, covering an area of 32,000 km^2 of terrestrial ecosystems and nearly 46,000 km^2 of marine habitats. The project area harbours the largest forest remnants within the northern part of the Atlantic Forest biome, as well as the largest and richest coral reefs in the Southern Atlantic in the Abrolhos Seascape. This region supports over 500,000 people and much employment is generated from natural systems, with nearly 20,000 people relying on fisheries and another 80,000 on tourism.

The analysis and recommendations described in this report are the result of a vulnerability assessment process designed with and implemented through consultation with colleagues from Brazilian and international universities, governmental and non-governmental organizations, private companies and members of the local communities. Our collaborators helped define gap-filling research to be done as part of the assessment and participated in the expert's workshop that culminated the assessment process. Collaborators conducted a series of analyses to improve the knowledge base of climate change impacts in the region. These studies addressed the impacts of climate change on: a) plant species distributions, b) vertebrate species distributions, c) water and sediment yield, d) crop suitability, e) marine primary productivity, f) the stability of the coastal regions, and g) socioeconomic conditions. Downscaled climatologies for the region and climate change maps were assembled to support the analysis. Detailed reports on those aspects are presented at the end of this document. The results of these analyses, together with other relevant science, formed the basis for expert identification of major climate change impacts and adaptation responses during the vulnerability assessment workshop (the workshop is described in Section III). The result of the research and the expert guidance in the workshop are storylines describing the key processes in the study area that will likely be impacted by climate change and recommendations for priority Ecosystem-based Adaptation (EbA) actions to respond to these impacts.

This report presents an overview of the region, the summary of the climate change vulnerability assessment workshop, the storylines describing impacts of climate change in certain processes and potential Ecosystem-based adaptation recommendations, and the description of priority interventions for climate change adaptation in the region. Ecosystem-based adaptation is the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change. As one of the possible elements of an overall adaptation strategy, ecosystem-based adaptation uses the sustainable management, conservation, and restoration of ecosystems to provide services that enable people to adapt to the impacts of climate change.

II. General Overview of Region

The study region encompasses the area that can generally be referred to as the greater Discovery Coast and Abrolhos Shelf. The precise boundaries of the study area are defined by the extent of the Abrolhos Shelf and adjacent watersheds, an area quite a bit larger than the formal Discovery Coast, in that it extends to north of Espírito Santo state and inland to parts of Minas Gerais. Here we review the socio-economic and biological conditions in the study area, the climate and seasonal variability, the major services provided by the terrestrial and marine ecosystems, and the dominant mechanisms of marine and terrestrial connectivity.

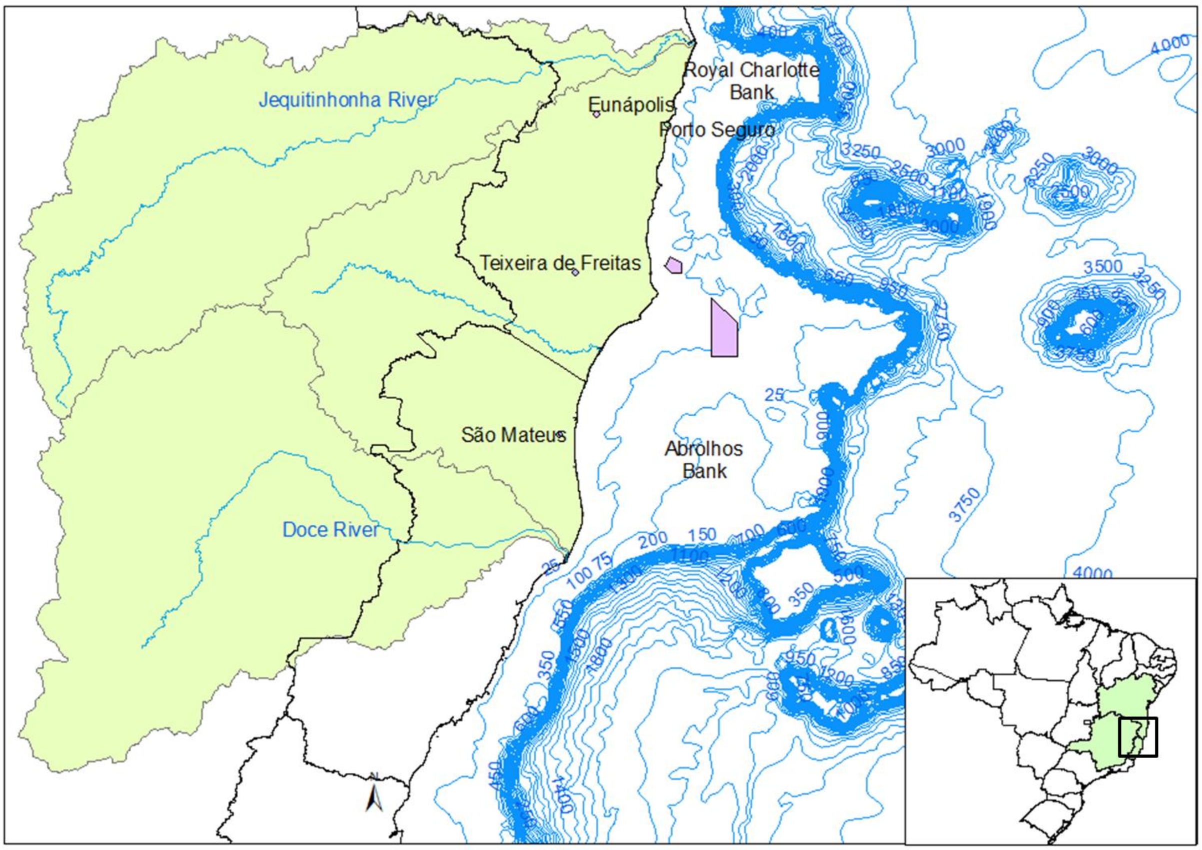


Figure 1. Study area, including the three watersheds and the Abrolhos shelf (Prepared by Renata Pereira, Conservation International Brazil)

1. Socio economic conditions

The study area is economically very heterogeneous. Per capita income is 70% of the average per capita income of Brazil. On the other hand, the region is experiencing faster economic growth rates than the country during the last decade. It encompasses 365 municipalities in three states: Bahia, Minas Gerais and Espírito Santo. The municipalities have a total population of 6.2 million people, with 73% living in urban areas. The level of urbanization and the growth rate of the population in the region are below the national average.

The Mucuri basin, which encompasses the coastal areas, has the most productive eucalyptus plantations in the world (Figure 2). This region also has one of the most important tourist destinations of the country, especially around Porto Seguro. Fisheries are an important economic activity for all coastal municipalities. Most industries, with emphasis on metallurgy, are concentrated in the upper area of the Rio Doce Basin with several factories along the Vitória-Minas Railway. The Doce River has important paper factories and eucalyptus forests around Ipatinga, which is the most important industrial pole of the whole region, and one of the world`s most important coffee landscapes around Manhuaçu. The Jequitinhonha Basin has the least dynamic economic activity among the three basins as this region has not developed industrial activities or complex urban economies.

a) Land Use and Land Cover

Deforestation of the Atlantic Forest has begun in the sixteenth century, driven by cycles of different economic activities: timber, sugar cane, cattle, gold and coffee. Historically, the expansion of the agricultural frontier through occupation of forested areas has been a way to accommodate the growing population (Young, 2005). Deforestation was promoted by public policies, particularly in the 1960s and 1970s, which encouraged the establishment of economic activities in the area, such as cattle ranching, and by the establishment of the highway BR-101 in early 1970s. The eucalyptus monoculture cultivation began in the 1960s in the Espírito Santo State and in the 1980s in Bahia State, and the eucalyptus areas currently exceeds 450,000 ha in the extreme south of Bahia. In addition to eucalyptus plantations and native forest (Figure 2), other land uses include pasture lands, and coffee, sugar cane, cassava, beans, corn and cocoa plantations (Figure 3).

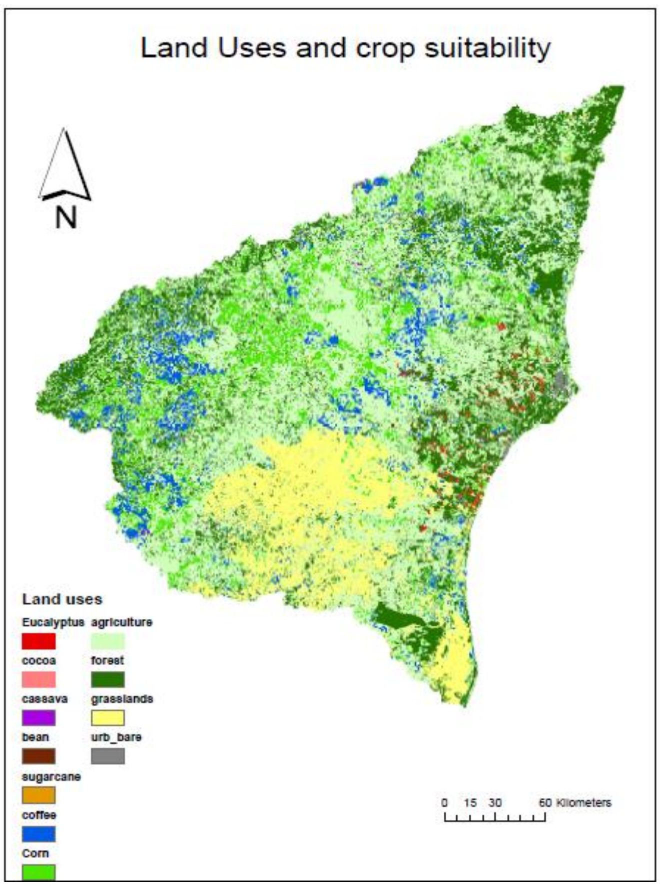


Figure 2. Detailed classification of land cover including the six main crops in the area. Agriculture cover includes both rain-fed, irrigation and mosaic agriculture; forest cover includes all forest areas including primary and secondary forest; grasslands cover contemplates herbaceous vegetation according to MODIS VCF; and bare soil cover consists of areas of no vegetation or very few sparse vegetation. The six crops were defined based on the IBGE data of commercial crops per municipality (Prepared by Leonardo Saenz, Conservation International).

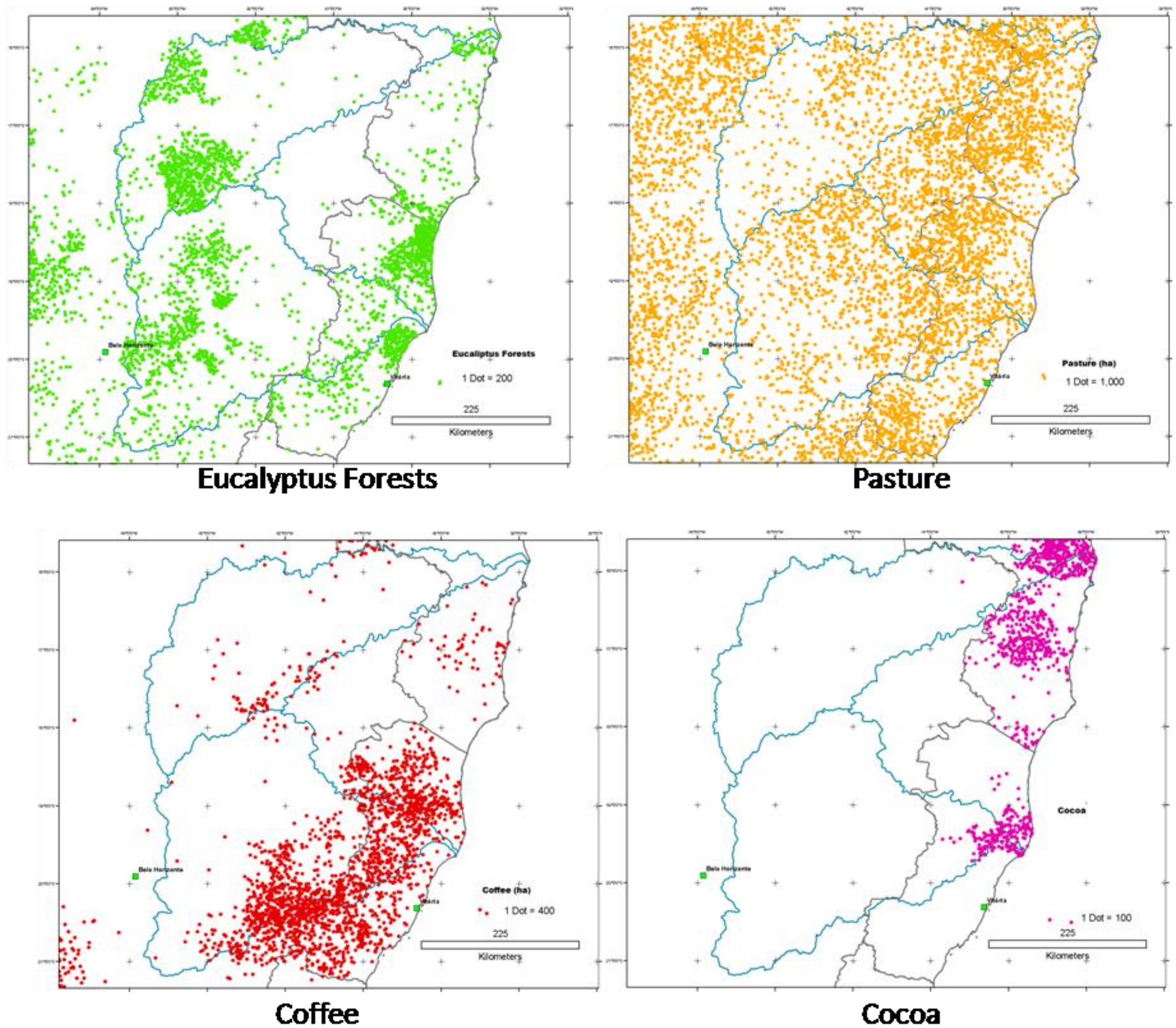


Figure 3. Crop maps in the three basins. Each dot represents different crop areas: eucalyptus = 200 hectares, pasture = 1,000 hectares, coffee = 400 hectares, and cocoa = 100 hectares (Prepared by Tiago Pinheiro, Conservation International Brazil).

b) Economic Sectors

Fishing is the main economic activity for most of the coastal population in the region, including indigenous communities. Although closed seasons for shrimp, crabs, lobsters and sea bass (*Centropomus spp*.) have been established, there is no effective management of fisheries and closed seasons are not effectively implemented (Dutra *et al*, 2012). In the study area within the Bahia state, there are 23 fishing ports, with fleets ranging from 2 to 259 boats, where fisheries are entirely artisanal. In the study area within the Espírito Santo State, however, there are commercial fisheries for tuna, snapper, scad, and swordfish, representing around 31% of Espírito Santo fishery activity (IBAMA 2007). The state of Bahia alone contributes 8.3% of Brazil's national fisheries value, and state of Espírito Santo contributes 4% of national fisheries value.

Currently, the nearshore fishery in the region can be classified as subsistence and commercial with production in several municipalities running into thousands of tons annually. Data from 2005 (CEPENE 2007) shows that Alcobaça had the greatest production (Table 1). It is difficult to know how many people depend on fisheries directly for most of their livelihood, because most employment in the sector is informal. The number of boats can give an idea of how many people are working in fisheries, but it is important to highlight that some kinds of fishing, such as crabs, urchins and octopus catch, is done without boats (Table 2). In average, 3 people work on a boat, so it is possible to estimate, that at least 4,000 people depend directly on the fisheries for most of their livelihood. Most fishing families (87%) have the main income from selling fish (MMAS report, 2005). It is likely that similar or greater numbers derive part of their income from fishing or depend indirectly on the nearshore fishery.

Table 1. Number of fishing boats and total population by municipality in the study area (Source: MMAS 2005).

Municipality	Fishing Boats	Total population (2012)
Alcobaça	273	21,271
Caravelas	257	21,414
Mucuri	92	36,016
Nova Viçosa	327	38,556
Porto Seguro	71	126,929
Prado	304	27,627
Total	**1324**	**271,813**

Table 2. Estimated production (in ton) and production value (in US dollars) of nearshore fisheries by municipality in the study area (Source: CEPENE 2007)

Municipality	Estimated production (ton)	Production value (US$)
Alcobaça	1,521	6,117,052
Caravelas	1,166	2,295,201
Nova Viçosa	2,170	3,413,352
Prado	1,790	4,641,881
Total	**45,631**	**110,389,350**

Tourism is an important economic driver in the region. There are two tourism centers in the extreme south of Bahia, the Discovery Coast (centered on Porto Seguro) and the Whale Coast (including Prado, Alcobaça, Caravels, Nova Viçosa and Mucuri) and one in the northern state of Espírito Santo, the tourism center of Green and Waters (including Conceição da Barra, Linhares, São Mateus and Sooretama). The major tourist attractions of the coast are the beaches, although the diversity of natural settings, including the Abrolhos Marine National Park and whale watching, are also important attractions. In Porto Seguro alone, the number of tourists exceeds 900,000 per year. The amount of public money invested and to be invested in the Discovery Coast is about US$325 million until 2020, which corresponds to 10% of all public investments in the tourism sector for the entire Bahia State, and private investments in this tourism center are estimated to reach US$1.6 billion until 2020.

Agriculture covers extensive areas within the study region. Sixty three percent of the study area is covered by pasture for cattle, 13% by coffee and cocoa (permanent crops), 5% by bean, cassava and maize cultivations (temporary crops) and 6% by Eucalyptus plantations. The first eucalyptus plantation in the region was established in the 1960s, due to the favorable conditions of soil and climate, the relatively low price of land and the proximity of the ports of Vitoria and Ilhéus (Superintendência de Estudos Econômicos e Sociais da Bahia – SEI, 2002).

Based on the Eucalyptus crops, the state of Bahia is currently the second most important producer of cellulose and paper in Brazil and the study area is the most important producer in Bahia state (Souza & Oliveira 2002). Although the Gross Domestic Production (GDP) increased in the region after the establishment of the eucalyptus plantations, social improvements in the region are almost imperceptible.

c) Cultural History and Indigenous Groups

The extreme south of Bahia consists of one of the first areas to be populated in Brazil as it includes the point where the settlers arrived from Europe in the sixteenth century. The native population was formed by Indians from several tribes, such as Tupiniquins, Pataxós, Maxacali, Botocudo, Puri and Kamaka. In the early stages of colonization, many of those indigenous groups were decimated or migrate to other areas after conflicts with settlers and the government.

Members of the Tupiniquins currently live only in the north of Espírito Santo with a current population of 1,000 people, members of the Pataxós in the south of the Bahia State with a population of about 11,000 people, members of the Maxacali in the northeast of the Espírito Santo State with a population of 1,500 people, and members of the Botocudo currently live in Minas Gerais state with a population of only 300 people. The tribes Puri and Kamaka are now extinct. Some Indigenous lands from the Pataxós in the study area are currently being regulated by the government, including 8,000 out of the 22,000 hectares of the Monte Pascoal National Park.

2. Ecosystems

Marine and terrestrial ecosystems are intimately related in the region. Marine systems are sensitive to sedimentation and pollution flows from terrestrial watersheds. Coastal land is protected from erosion by extensive coral reefs whose condition is deteriorating. Incomes for many families comes from a mix of marine and terrestrial sources, for instance from families who fish and maintain crops, or who participate in tourism service sectors that include both marine (e.g., diving) and terrestrial (e.g., hotels and restaurants) components.

a) Terrestrial ecosystems

The Atlantic Forest is one of the 40 terrestrial biodiversity hotspots identified around the world (Myers et al 2000) and it is estimated that this biome contains from 1 to 8% of the global biodiversity (Silva and Casteleti, 2005). The original extent of the Atlantic Forest covered three countries (Brazil, Argentina and Paraguay) and 17 Brazilian states. Around 70% of the Brazilian population lives in the Atlantic Forest distribution area, spread out in more than 3,000 municipalities (IBGE 2000). The Atlantic Forest's current distribution area is only 8% percent of its original area, spread out in tens of thousands of small fragments (Silva and Tabarelli, 2000) and in a few, larger blocks of forest in the southeast region of Brazil. The most threatened sector of the Atlantic forest is in the northeast region of Brazil (Dias et al 1990), where the majority of the Atlantic forest has been converted into agricultural land, with only 2% of the original forest remaining (Viana et al 1997, Ranta et al 1998). In the study area, the situation is not different, as you can see in Figure 4.

Despite centuries of intense and uncontrolled exploitation, the Atlantic Forest still has high levels of biodiversity and endemism, and is considered a global heritage area for conservation. The Atlantic forest consists of a mosaic of several vegetation types [as recognized by the Brazilian Council for Environment (CONAMA), as stated in the law 750/93 (Brazilian Environmental Institute)]: Dense and Open Rainforests, Mixed and Seasonal Rainforests, Semidecidual Forests, Pioneer Formations, Fields of Altitude, Refuge Vegetation and Areas of Ecological Tension. In the list of threatened species from IUCN (2000), 276 plant species and 185 vertebrate species, including 118 birds, 16 amphibians, 38 mammals, 13 reptiles and 59 fresh water fishes, and more than 500 species of plants, birds, mammals, reptiles and amphibians are officially recognized as endangered (Tabarelli et al 2005).

Human exploitation of the Atlantic Forest resources has taken place for centuries but only recently has rapid expansion and irreversible levels damage occurred. Prehistoric indigenous communities, for example, practiced agriculture in the region in the Pleistocene (Galindo-Leal, 2005). However, major impacts began shortly after arrival of Europeans around 1500 with the large-scale exploitation of Brazil wood (*Caesalpinia echinata*). At that time, it is estimated that the Atlantic Forest covered about 15% of the Brazilian territory. The opening of the forest for occupancy, for crop plantations, and for defense purposes by the Europeans also had serious consequences. Later on, the extensive cattle ranching, the establishment of sugar cane and coffee plantations, urbanization, and expansion of the timber industry became the main causes of degradation of the Atlantic Forest. Currently, the Atlantic Forest is recognized as a heritage area by the Brazilian Constitution and as a Biosphere Reserve by the United Nations Educational, Scientific and Cultural Organization (UNESCO). In addition, several legal initiatives currently exist for the preservation of this biome. One of the most recent is the Municipal Plan of Conservation and Restoration of the Atlantic Forest, which aims to promote the involvement of municipalities totally or partially located in this biome in the protection, conservation and restoration of native vegetation in a proactive way. The conservation of forest fragments and the promotion of functional connectivity of the vegetation are critical to reverse the trend of isolation and degradation of remaining forest and reduce the risk of extinction (Ribeiro *et al*, 2009). Thus, one of the main targets for the conservation of this biome is forest restoration. One of the initiatives for this purpose is the Restoration Pact of the Atlantic Forest, a movement formed by different sectors and over 200 entities to integrate the actions of forest restoration. Those actions include the recovery of high diversity characteristic of tropical forests in economically marginal agricultural areas, through mechanisms that enable the use of native wood and non-wood products.

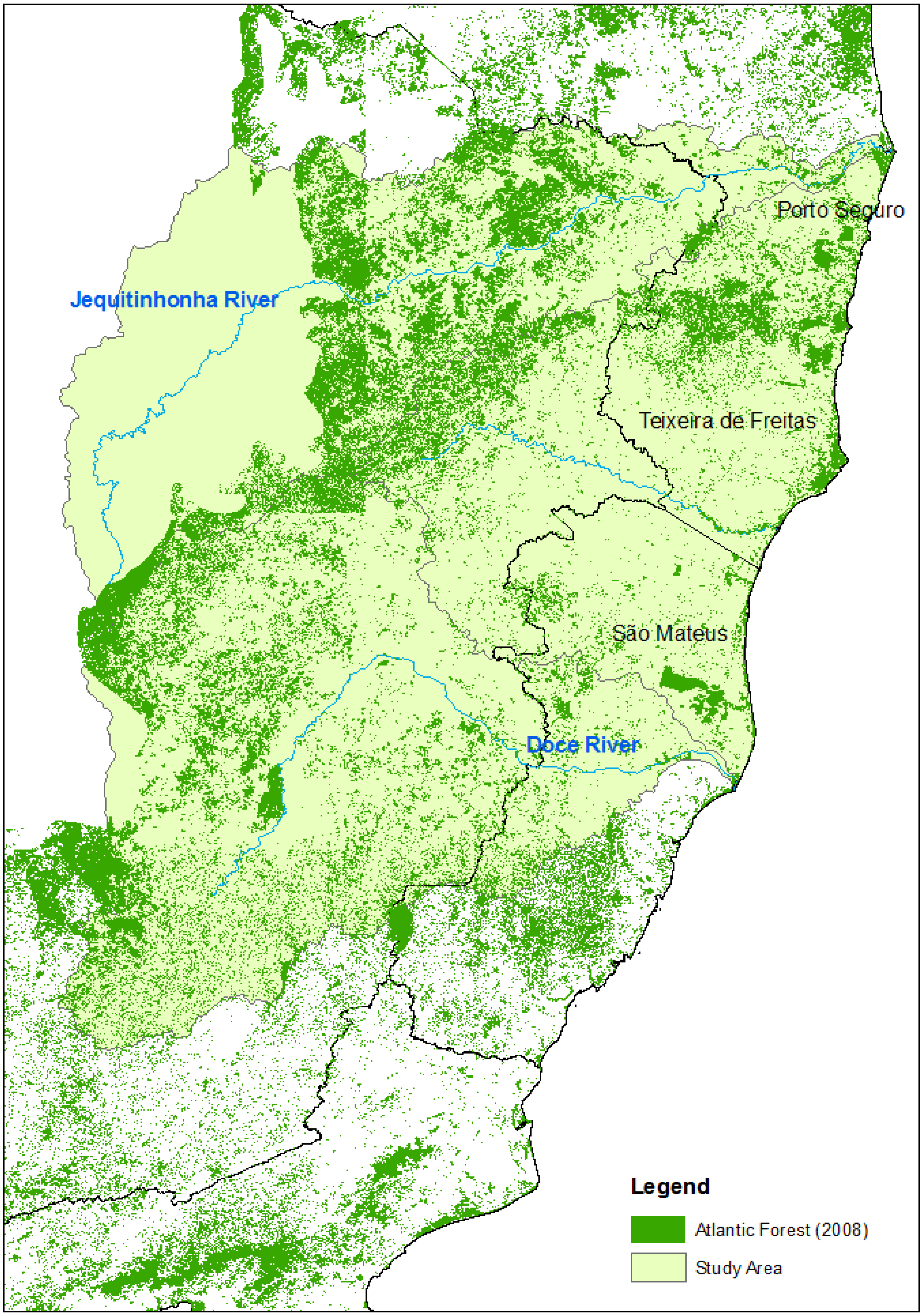


Figure 4. Forest fragments in the study area (Prepared by Renata Pereira, Conservation International-Brazil)

Furthermore, the biodiversity corridors, i.e. the Central Corridor (Figure 5), where this vulnerability assessment was conducted, have been conceived for the region to promote the maintenance of ecological processes that sustain ecosystem services in the long-term. In addition, the southern Bahia features the Mosaic of Protected Areas of Southern Bahia, which covers the municipalities of Santa Cruz de Cabrália, Porto Seguro and Prado, and includes 12 protected areas and their buffer zones. The aim of this initiative is to promote the integrated management of these areas.

Figure 5. Central Corridor of Atlantic Forest

b) Marine ecosystems

The Abrolhos region includes the Abrolhos and the Royal Charlotte Banks (Figure 6), and is highlighted as a conservation priority in the Atlantic coast of Brazil by the Brazilian Ministry of Environment (MMA, 1999). The southern boundary of the Abrolhos region is located at the mouth of the Doce River and the northern at the mouth of the Jequitinhonha River, with the eastern limit in the isobath of 200 meters. The Abrolhos Bank is an extension of the continental shelf, and has an area of approximately 46.000km^2, with a depth range of about 30 meters. The Abrolhos bank has rich continuous habitats, including estuaries, mangroves, sandy and muddy bottoms, banks of calcareous algae, seagrasses, and reefs with different characteristics along the platform (Dutra *et al*, 2012). The Royal Charlotte Bank is located in the north of the Abrolhos bank, totaling an area of approximately 10.000km^2.

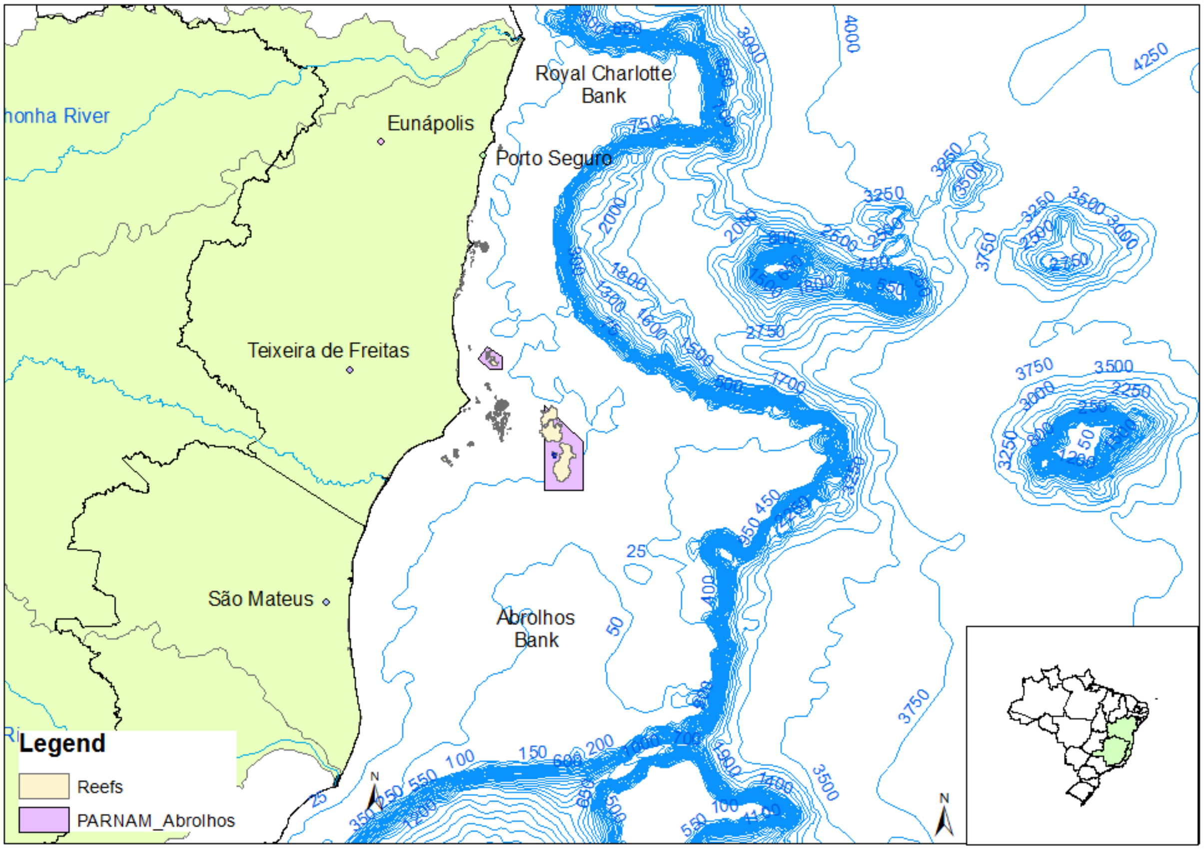


Figure 6. The Abrolhos region, including the Royal Charlote and the Abrolhos Banks (Prepared by Renata Pereira, Conservation International-Brazil).

The Abrolhos region presents the highest marine biodiversity and the largest reefs in the South Atlantic. In 2005, a Rapid Marine Biodiversity Assessment of the Abrolhos Bank assessed nearly 1,300 species from six biological groups surveyed, corals, fishes, algae, polychaete, worms, mollusks and crustaceans (Dutra *et al*, 2005). However, this biodiversity is at risk due to the negative impacts from shipping connected to the oil and cellulose industries (e.g. dredging and marine traffic), overfishing, illegal fishing and tourism. More than 50 species that occur on Abrolhos bank are in some level of threat.

All Brazilian coral reef species occur on the Abrolhos Bank. Six species are endemic to Brazil (*Mussismilia braziliensis, M. hispida, M. hartti, Siderastrea stellata, Favia gravida and F. leptophylla*) (Leão, 1999) and two are endemic to the Bahia state (*M. braziliensis* and *F. leptophylla)*. The Abrolhos bank has the largest rhodolith (calcareous algae) bed in the world, which covers 43% of Abrolhos Bank seafloor and is the largest biogenic $CaCO_3$ deposits in the world (Amado-Filho *et al*, 2012). These habitats of the Abrolhos Bank are home to a significant diversity of reef fish species, including the blue parrot fish (*Scarus trispinosus)*, an endangered species that represents 28% of total fish biomass in Abrolhos.

Twenty eight percent of the of 43 species of cetaceans recorded in Brazil are found in the Abrolhos region, including the humpback whale (*Megaptera novaeangliae*), southern right whale (*Eubalaena australis*), common dolphin (*Delphinus spp*.), Atlantic spotted dolphin (*Stenella frontalis*), rough-toothed dolphin (*Steno bredanensis*), bottlenose dolphin (*Tursiops truncatus*), and tucuxi (*Sotalia guianensis*). The humpback whale population in Abrolhos, which is the main breeding ground in the South Atlantic, is the largest in the world with more than 2,000 individuals visit the region every year.

Different types of protected areas were established in the Abrolhos bank, including the Abrolhos Marine National Park (MNP Abrolhos), created in 1983, and the Extractive Reserves of Corumbau and Cassurubá. Dutra *et al* (2012) argues that the network of protected areas in the region is not complete, given that some habitats, such as reefs at a depth of 20 to 50 meters and banks of calcareous algae, are not included in the protected areas network. The MNP Abrolhos is recognized internationally by UNESCO and by the Ministry of Environment as a Natural World Heritage Site and a Biosphere Reserve, respectively, and is a Ramsar site.

Mangroves are important and fragile ecosystems, providing many environmental services, such as groundwater recharge, flood control, stabilization and shoreline protection, erosion control, sediment retention, export of biomass, scenic beauty, biodiversity maintenance and coastal fish stock (Figure 7). Some of the commercially important species that occur in the mangrove are mangrove oyster (*Crassostrea rhizophorae*), mussels (*Perna perna*) and the mangrove crab (*Ucides cordatus*). Additionally, Mangroves are important for food security of traditional and riverine communities. Despite being protected by the Brazilian law as areas of permanent preservation, Mangroves are being degraded and removed due to human settlement and industrial exploitation, such as shrimp farming and shipping ports.

Figure 7. Mangrove area in Caraíva (Source: Conservation International-Brasil).

3. Climate and Seasonality

The northeast region of Brazil is characterized by semi-arid or dry winters. On the coast, the climate is humid with average temperature of 24° C in the winter and 27° C in the summer. The average water temperature is 24.5° C in the winter and 27.5° C in summer. The average annual rainfall in the coastal area adjacent to Abrolhos is 1,750 mm (Marchioro *et al*, 2005). In the study area, there is more rainfall inland during the summer months (December, January and February) and more rainfall in the coast during the winter months (July, August and September) (figure 8).

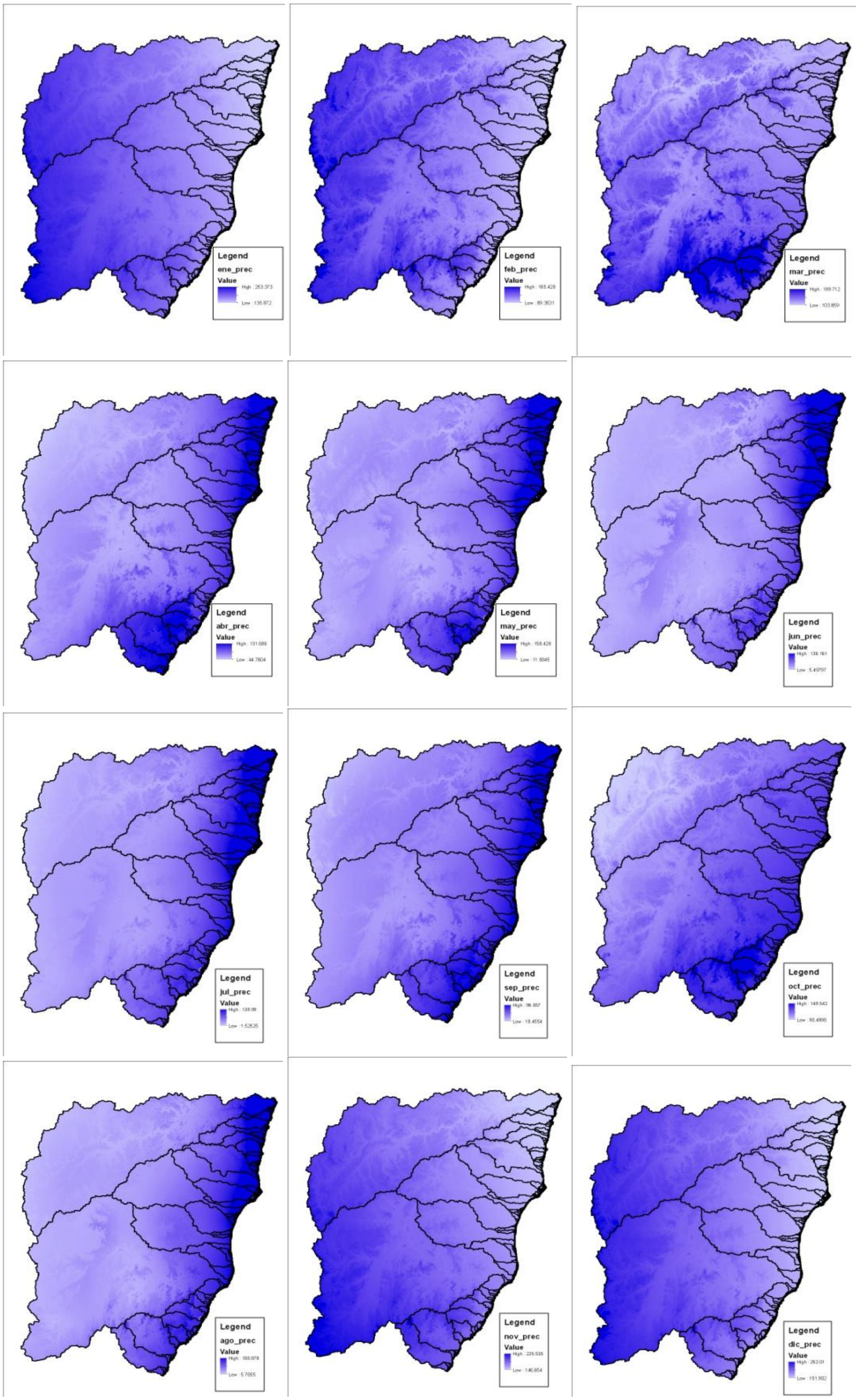


Figure 8. Rainfall climatology (mm year^{-1}) in each month for the study area. January is represented by the upper map in the left and December is represented by the lower map in the right. Darker areas represent higher rainfall (Prepared by Leonardo Saenz, Conservation International).

The climate conditions in the Abrolhos Bank are regulated by three air masses: Atlantic Equatorial, during autumn and winter; Atlantic Tropical, during summer and spring and Equatorial Continental, during January and February of the summer months (NIMER, 1979). The last two, when combined, cause weak winds and short waves. The Abrolhos Bank is located in the southern part of the trade winds. In spring and summer, the winds are dominantly from northeast and east, and in the fall and winter the winds are from the southeast, that is caused by the anticyclonic cell migration to the southern South Atlantic in the winter and to the northern South Atlantic in the summer.

The dominant ocean wave fields are driven by the seasonal winds. During spring and summer, the waves are driven by the east northeast winds and can reach heights of 1 meter and periods of 5 seconds (Leão, 2002). This causes a transport of sediment by longshore drift heading south. During fall and winter, the waves are prevalent from the southeast and south-southwest, with heights up to 1.5 m with periods of 6.5 seconds, causing transport northward along the coast. The changes in the winds are associated with changes in the high pressure over the Atlantic that also reflect in changes in the western boundary current.

III. Summary of the Vulnerability Assessment Workshop

An expert workshop to support the vulnerability assessment of the Bahia region was coordinated by Conservation International, and held from September 17th to 20th, 2012, in Porto Seguro, Bahia. Participants in the workshop were experts in climate change in the regions, its impacts on livelihoods and economies, biological consequences and alteration of ecosystem services and on physical consequences such as shoreline erosion. The interaction of these specialists gave the assessment expert input into the sensitivity, exposure and adaptive capacity of communities in the region. It allowed development of expert- and research-based Ecosystem-based Adaptation (EbA) responses to climate change, as well as allowing incorporation of traditional knowledge and local perceptions of climate change into the assessment of impacts and EbA responses.

The objectives of this workshop were to review current data and identify the main climate change vulnerabilities in the region, including the current and future climate impacts on social and natural systems, the linkages between marine and terrestrial environments in the study area and EbA opportunities. The overall format of the workshop was a review of available evidence in plenary, development of expert-derived storylines of impact in breakout sessions, formulation of adaptation responses with an emphasis on EbA in continuing small-group work, and plenary validation of workshop storylines, adaptation responses and recommendations.

The workshop had the participation of experts and stakeholders from public and private sector institutions, including members from academia, national and state government, non-governmental organizations, private companies, protected area managers, as well as CI staff who assisted during the workshop (Figure 9). A full list of workshop participants is presented in Appendix 1.

The workshop started with a brief presentation of the analyses conducted for the assessment. Those results discussed the possible impacts of climate change on the vulnerability of the coast, on the distribution of plants and vertebrates species, on sediment yield and water availability and on ocean primary productivity. Additional presentations were made on the socio-economic vulnerability in the study area, on the status of the fisheries in Espírito Santo and Bahia, and on the expected changes in climate based on the downscaling of Regional climate models (Hedley) and global circulation models (CNRM and MIROC, respectively representing a wetter future condition and a drier future condition).

Figure 9. Group leaders of the Vulnerability Assessment workshop.

Those presentations were the basis for the following working sessions. The goal of the first working session was to identify the main impacts of climate change in each of the components (i.e. plants, vertebrates, hydrology, agriculture, eucalyptus, wave dynamics, sediment dynamics, etc) of terrestrial and marine systems. The goals of the second working session was to identify the main cascading impacts (how impacts in one component will affect the other ones) of climate change. Once direct and indirect impacts of climate change were identified by the participants, five dominant "storylines" or important processes that may be affected by climate change in the study area, were identified. Those storylines were: 1. Impacts of climate change on the Brazil current, affecting upwelling patterns, benthic production and fisheries; 2. Impacts of climate change on sedimentation in rivers and reefs and in tourism and fisheries; 3. Impacts of climate change on wave dynamics and coral reefs, affecting erosion and sedimentation, causing impacts in estuaries and tourism; 4. Impacts of climate change on forest fragmentation and fire, causing loss of biodiversity and changes in species distribution; and 5. Impacts of climate change on river flow and saline water intrusion, affecting biodiversity.

Each one of those five storylines were then reviewed, discussed and described by the participants of the workshop, and adaptation recommendations to address the climate change impacts on the processes were identified. This activity allowed us to capture the complexity of the socio-ecological interactions in the study area, while it enabled a more focused understanding of climate vulnerability and possible adaptation options. Two additional storylines was developed after the workshop, as updated results on water availability show that uplands areas located in the north of the study area will be key for water availability in some costal municipalities in future climate conditions, and as updated results on crop suitability show that coofee suitability may decrease considerably in the study region in future climate conditions. The final versions of those descriptions and the adaptation recommendations for the problems identified are presented in the next sections of this report.

IV. Climate Impacts and EbA Storylines

Storyline 1:

Climate Impacts on the Brazil Current, Upwelling Systems, and Fisheries

Current Conditions

Located in a wider part of the Brazilian Continental Shelf (about 200 km wide), the Abrolhos Bank hosts the largest and richest coral reefs in the South Atlantic (Laborel, 1970; 1994, 1996; Leão et al., 1988; Castro, 1994). Important fisheries are located at the outer edge of the Bank while near-shore reefs support small scale fisheries and diving opportunities for the beach tourism industry. The Bank is also well-known for humpback whale watching between the months of July and November.

Marine conditions on the Abrolhos Bank are dominantly driven by the Brazil Current (BC) which flows from north to south along the Brazilian coast. The BC, in turn, is driven by the South Equatorial Current (SEC), which flows west across the Atlantic Ocean before dividing into two dominant ocean currents on the Brazilian coast[1] : the south-flowing Brazil Current (BC) and the north-flowing North Brazil Current (NBC) (Figure 10). The BC flows south along the Abrolhos coast, and is strongest during summer months (December, January and February) when the SEC bifurcation point reaches its northern-most position (Matano et al. 1993). Similarly, the BC is weakest when the bifurcation point reaches its southern-most point, near the Abrolhos Bank, during the Southern Hemisphere winter months (July, August and September).

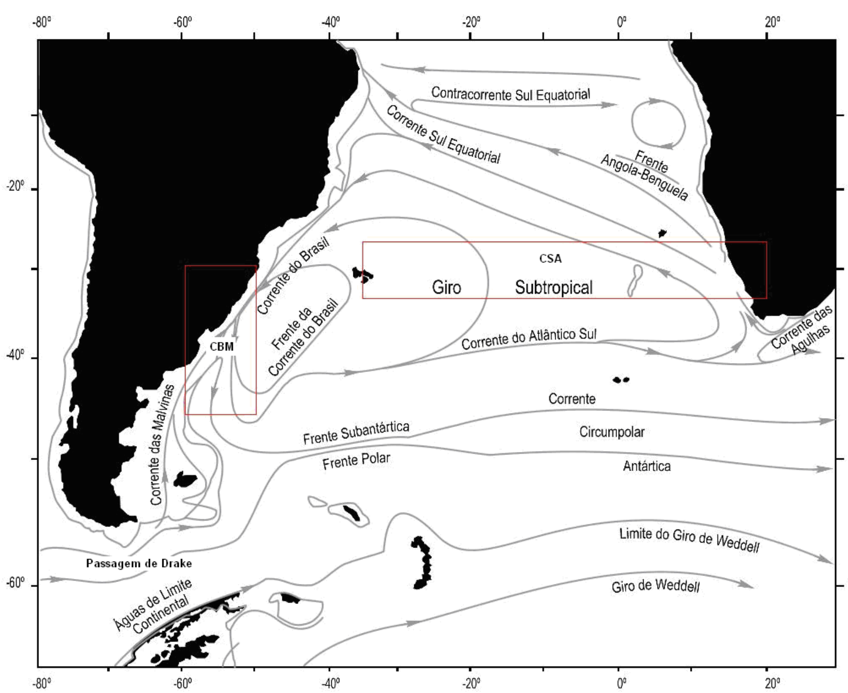


Figure 10. Main currents in South Atlantic. Modified from Peterson & Stramma (1991). Avaiable on http://www.inpe.br/crs/pan/pesquisas/oceanografia.php.

[1] A bifurcation point is the location where a current that flows perpendicular and towards a coastline splits into two currents flowing parallel to that coastline upon meeting it.

The seasonal nature of the BC greatly influences oceanic conditions on the Abrolhos Bank, with strong impacts on productivity and fisheries. Productivity is increased with upwelling (movement of cold, nutrient-rich, waters upward towards the surface) and decreased with stratification (where mixing of cold and warm water is inhibited by a thick layer of warm water near the surface). Productivity is highest during the winter months (May, June, July) when a combination of favorable winds and a close-at-hand nutrient-rich water mass creates increased vertical mixing and an burst of primary production. The opposite occurs during the summer months (October, November, December) when the BC is stronger, stratification is maximized by warm surface waters, and vertical mixing is reduced to its minimum for the year.

Fisheries in the Abrolhos region are divided roughly into offshore fishing, which is industrial and controlled by non-local fleets, and nearshore fishing, which is more artisanal. The species in the offshore fishery are diverse, but focus especially on large snappers, groupers, and queen triggerfish among the demersal (sea bottom) species, and jacks, mackerels, and other pelagic fishes in the blue water fishery. Nearshore fisheries include certain reef fishes along with members of the drum family (Sciaenidae) in the genus *Cynoscion* (especially *Cynscion acoupa*), locally known as "pescada."

The nearshore fishery is at its peak during the summer months when water clarity is high as a result of the stronger BC. Demand for nearshore fishes coincides with the tourist season peaks (December- February). Offshore fisheries catch ramps up when productivity is high and predators are most concentrated, near upwelling areas in the winter months. Fishers come to these offshore areas from great distances, and most of the fish that is caught in the offshore fishery is destined for export.

During the summer, increased stratification and reduced sediment loads from terrestrial sources produce very clear water conditions on the reef that should be favorable for reef-building corals (lower rainfall levels in the Summer reduce the sediment flow into coastal waters). The reduced sediment from rivers also reduces the stress on corals. However, the summer also brings an intensification of other key stressors on reefs and dependant fish populations: fishing pressure, water temperature, and coastal pollution. These stressors have numerous impacts including:

- A strong local market has developed for the largest local blue parrotfish (*Scarus trispinosus*) taken mostly by spear as a delicacy served to tourists in urban restaurants and beach hotels. Overharvesting of blue parrotfish, an ecologically dominant reef herbivore, aggravates the vulnerability of nearshore coral reefs to overgrowth by fleshy algae (seaweeds).

- In the last 10 years, corals on the Abrolhos shelf been severely damaged by outbreaks of potentially lethal coral diseases. These diseases are associated with unseasonably high sea surface temperatures attributable largely to global climate change.

- Although terrestrial runoff is lower in summer than winter, domestic waste is still discharged largely untreated into coastal waters. These pollutant streams are nutrient rich and can accelerate the growth of fleshy algae on reefs, impacting the growth and resilience of corals on reef surfaces.

What has been observed, however, is a rapid decline in the health and resilience of coastal coral reefs in Bahia in the past eight to ten years.

Impacts of Climate Change

Climate change will impact the near-shore fisheries through increased ocean temperatures and ocean acidification. Increased water temperatures cause bleaching in corals - water temperatures in excess of specific thresholds, causes corals to expel symbiotic algae leaving the coral white or "bleached" and weakened. Bleached corals often die, weakening reef regeneration. Ocean acidification is a direct effect of dissolving greenhouse gases (CO^2) from the atmosphere into the oceans. It impacts corals by reducing the calcium carbonate in seawater that they need to build reefs (coral skeletons). The combination of bleaching and acidification will greatly reduce the reef-building ability of inshore corals, reducing the healthy reef substrate necessary to support the reef-based ecosystem, including the fish populations that support a robust nearshore fishery.

The fishery reduction caused by coral bleaching and acidification will be compounded by synergies between these climate change impacts and existing pressures on the reef such as coral diseases, sediment, overfishing and sewage contamination. The combined threat of coral disease, sewage and over-fishing, with the climate change impacts of bleaching and acidification, may spell drastic reduction of reef fisheries in Bahia and Espírito Santo this century.

Climate change scenarios for ocean circulation off the Abrolhos Bank region were projected based on outputs from the Model for Interdisciplinary Research on Climate (MIROC) global circulation model (GCM). The model indicates that there will be a weakening of the Brazil Current as a result of a falling off of winds parallel to the coast, combined with a strengthening of easterly winds, thus creating increased winter-like conditions. This should mean that the region will experience longer periods of vertical mixing and high productivity with expected positive impacts for off-shore fisheries, which may became another threat to the fishes stocks if industrial fisheries increase in the region.

Consequences of loss of reef fisheries

Tens of thousands of people in the study region depend on fisheries directly or indirectly and will be negatively impacted by if climate change reduces fish populations, with potentially hundreds of millions of dollars in lost annual production and significant income and livelihood impacts. There is a strong tradition of fishing in the region and it is unlikely that the sector will be quick to adapt to deteriorating resource conditions. Many fishers in the area come from families that have been fishing for generations. The fisheries context in the extreme south of Bahia has gone through several transformations throughout its history. It started with the grouper fishery in the 1700s, and was involved in the whale hunt in the 1800s. Since then, the population in that region uses the marine resources as source of food, income and social aggregation, and also contributes to export (Nicolau, 2007).

Knowledge Gaps

It is currently not possible to quantitatively assess the possible outcomes of climate change on the Abrolhos Shelf fisheries without a more specific understanding of the interdependence of the fisheries on ocean and other conditions. For example, while climate change will bring more easterly winds that induce upwelling, increased sea surface temperatures will promote stratification and counteract the upwelling process. It is not clear what the net effect will be on productivity and fisheries. The increase in sea surface temperatures during winter months will probably not affect the high productivity during those months, but the increase in winter-like conditions, as described above, could be dampened during May and September (early and late winter), abbreviating the season of maximum production.

There is a need to study results from more than one GCM for the Abrolhos Bank. For terrestrial conditions, for example, we were able to use the cm3 and MIROC3 GCM results which tend to capture more extreme wet/dry conditions for the periods 2050-2069 and 2070-2099. It should therefore be a priority to understand the range of likely future conditions.

The source and movement of sediments, and the role these play in coral health requires further attention. If corals in this region are better adapted to high turbidity background levels, they could be of scientific importance for global coral reef communities. On the other hand, if future sediment conditions add additional stress to these fragile ecosystems, other adaptations that reduce riverine sediment loads should be also be investigated.

Storyline 2:

Ridge to Reef – Impacts of Terrestrial Change on Marine Systems

Current Conditions

With expansive stretches of fine white sands and warm water, the beaches of the Discovery and Whale Coasts are some of Brazil's most valuable for tourism. Each year, tens of thousands of visitors enjoy the hotels, restaurants and water-based attractions of the region. The region's economy is driven by bustling resorts (Porto Seguro), lively night scenes and cosmopolitan enclaves (Arraial d'Ajuda and Trancoso), as well as smaller beach and fishing towns (Caraíva, Corumbau, Cumuruxatiba, and Mucuri). Beachgoing, dining, hospitality, and nightlife are staples of the tourist sector in the region. The study area accounts for over 20% of Bahia's 11,000,000 tourists and US $3.9 billion in tourism revenue each year.

The marine life of this region is among the most unique in the world, providing both an attraction for tourism and vital physical protection for beaches and buildings along the coast. The reefs absorb the erosive power of the Atlantic Ocean's waves, sheltering beach sands and preventing erosion. The reefs nurture a vast array of marine species, including endemic corals, fish, crustaceans and mollusks that are the focus of a growing dive industry, as well as marine turtles and mammals important for boat-based viewing. Around 100,000 local residents work as fishermen or in coastal and marine tourism, depending on the ocean for their livelihoods. Reef degradation thus imperils crucial elements of the Discovery and Whale Coast's marine, coastal, and economic systems.

The reefs, and the beaches they protect, are increasingly threatened by terrestrial sediment transported through the rivers and deposited in the coastal oceans. Human activities have deforested the landscape since the 1500s, intensifying with agriculture and urban development, and accelerating since the 1970s with arrival of a coastal highway and growth of eucalyptus and sugar cane industry. Where forests have been leveled, sediment is washed over the land surface by rains and carried downstream and out to reefs, impacting the corals by smothering, abrasion, and light deprivation, all of which inhibit coral growth and can lead to disease and coral death. As dead reefs erode, beaches lose shelter from wave action and storm events, and diving operations and fisheries lose income. The natural beauty, tourist appeal, and economic importance of reefs on the Abrolhos shelf are thus all endangered by deforestation and delivery of sediment to reefs.

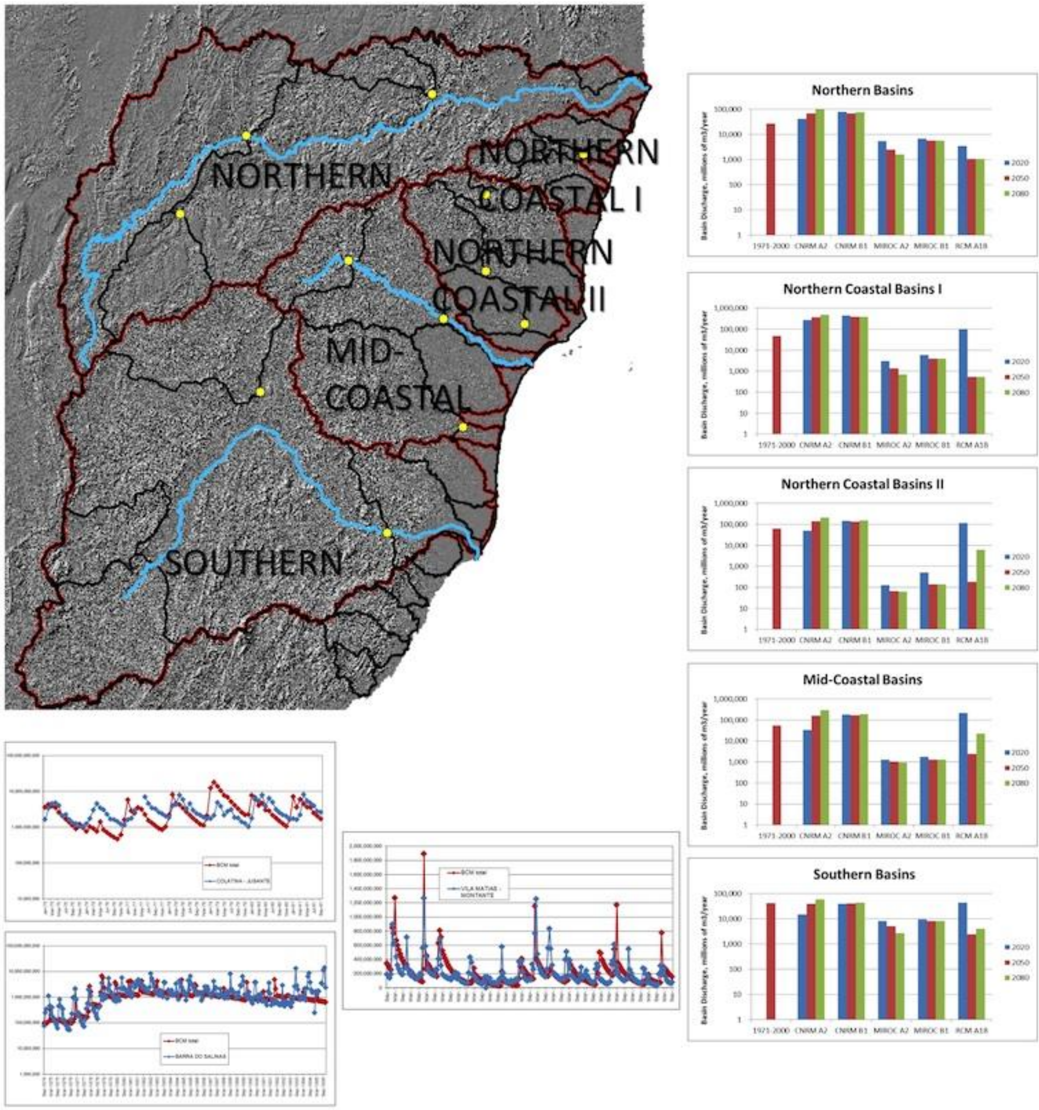
The deforestation-driven surge in sediment loads since 1970 has exceeded the tolerances of local corals. Physical, chemical and photosynthetic impacts of sediment, including smothering, abrasion, light blocking, and inhibited recruitment (Segal et al 2008), have spiked mortality rates among *M. braziliensis* and other corals and suppressed their ability to regenerate. The shore-adjacent inner arc of reefs is the most highly impacted; alongshore currents and protection offered by the inner arc block most terrestrial sediment from reaching the mid (60km offshore) and outer (150-200km offshore) shelves. The inner arc is currently in a highly-degraded state and deteriorating faster than the others (Leipe et al 1999).

Sedimentation impacts are compounded by those from other runoff-derived processes. Agrochemical nutrient loading causes reef mortality in eutrophication events, and fosters bioerosion by coral-boring species such as *Cliona celata*. Bioerosion also feeds back on coastal turbidity, pulverizing reefs into carbonaceous sediment which becomes suspended in the water and settles on living reefs. Finally, the rapid spread of coral diseases, first recorded in the region in 2005, is largely attributable to sediment, nutrient, and bacteria loading. The most alarming of these diseases is the "white plague," which at its current rate of progression is projected to decimate 40% of *M. braziliensis* cover by 2057, and more than 60% by 2100 (Francini-Filho et al 2008).

Climate Change Impacts

The Atlantic Forest adjoining the Abrolhos shelf experienced relatively constant rainfall before 1970, followed by a marked drop-off in 1970-2000 (Box 1). Drying has been greatest inland surrounding the headwaters of major rivers, particularly in the Jequitinhonha basin and coincides with deforestation following the construction of coastal highway BR-101 in the 1970s. A causal relationship between the two is suspected; in fact Webb et al (2005) showed a strong effect of deforestation inhibiting rainfall in nearby São Paulo state. Expecting runoff and streamflow to reflect diminished rainfall, we analyzed 11 small river flows (average <10 m^3/s) across three periods (1969-82, 1983-96, 1997-2010) finding significant decreases in average monthly flow between periods for 9 of 11 stations. For larger rivers (average >25 m^3/s), 15 of the 16 stations showed a significant decrease in average across periods.

Projected rainfall increases in the wet scenario, dramatically reversing the recent diminution of runoff and streamflow; projected surface flows in fact pose serious risks to coral reef health and biodiversity. By 2050, annual precipitation is projected to increase 30%; discharge is projected to increase 151% in northern basins, 490% in mid-coastal basins, and 48% in southern basins over the 1971-2000 baseline period (Figure 11).



		Basin Discharge, in millions of m3/year							Change from 1971-2000				
Northern Basins		1971-2000	CNRM A2	CNRM B1	MIROC A2	MIROC B1	RCM A1B		CNRM A2	CNRM B1	MIROC A2	MIROC B1	RCM A1B
	2020	26,714	41,822	78,458	5,448	6,759	3,519	2020	57%	194%	-80%	-75%	-87%
	2050		67,000	69,163	2,531	5,589	1,074	2050	151%	159%	-91%	-79%	-96%
	2080		98,854	75,811	1,616	5,589	1,080	2080	270%	184%	-94%	-79%	-96%
Northern Coastal Basins I		1971-2000	CNRM A2	CNRM B1	MIROC A2	MIROC B1	RCM A1B		CNRM A2	CNRM B1	MIROC A2	MIROC B1	RCM A1B
	2020	46,720	266,638	444,739	2,955	5,928	95,888	2020	898%	1565%	-89%	-78%	259%
	2050		376,816	392,947	1,335	3,909	536	2050	1311%	1371%	-95%	-85%	-98%
	2080		492,099	379,391	708	3,909	536	2080	1742%	1320%	-97%	-85%	-98%
Northern Coastal Basins II		1971-2000	CNRM A2	CNRM B1	MIROC A2	MIROC B1	RCM A1B		CNRM A2	CNRM B1	MIROC A2	MIROC B1	RCM A1B
	2020	62,970	50,894	146,973	128	507	116,110	2020	91%	450%	-100%	-98%	335%
	2050		139,220	132,222	66	139	181	2050	421%	395%	-100%	-99%	-99%
	2080		208,590	154,122	64	139	6,160	2080	681%	477%	-100%	-99%	-77%
Mid Coast Basins		1971-2000	CNRM A2	CNRM B1	MIROC A2	MIROC B1	RCM A1B		CNRM A2	CNRM B1	MIROC A2	MIROC B1	RCM A1B
	2020	54,188	33,889	180,892	1,274	1,801	213,514	2020	27%	577%	-95%	-93%	699%
	2050		157,701	162,836	1,030	1,294	2,357	2050	490%	510%	-96%	-95%	-91%
	2080		293,229	193,575	935	1,294	22,275	2080	998%	625%	-97%	-95%	-17%
Southern Basins		1971-2000	CNRM A2	CNRM B1	MIROC A2	MIROC B1	RCM A1B		CNRM A2	CNRM B1	MIROC A2	MIROC B1	RCM A1B
	2020	42,407	14,767	38,442	8,113	9,493	43,520	2020	-45%	44%	-70%	-64%	63%
	2050		39,519	40,964	5,055	8,259	2,449	2050	48%	53%	-81%	-69%	-91%
	2080		59,768	44,013	2,738	8,259	4,068	2080	124%	65%	-90%	-69%	-85%

Figure 11. Projected river discharge estimates. Source: Basin Characterization Model, 2050, Lorraine Flint, USGS).

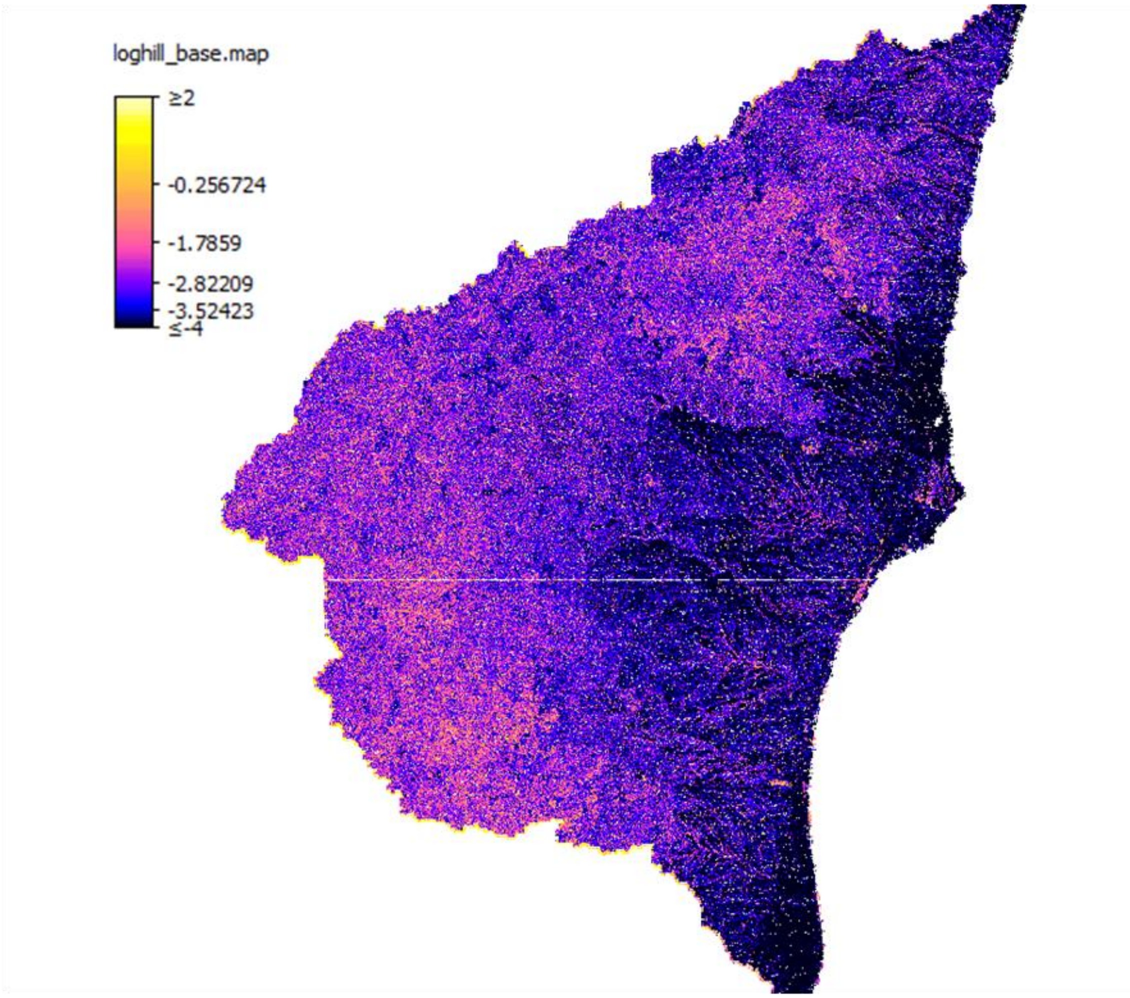


Figure 12. Changes in soil erosion according to the model FIESTA/WaterWorld implemented using the CNRM model and compared against the baseline scenario using local data for climate. Due to wetting of the area, under this scenario there is an increase in soil erosion, can occur in the most mountainous parts towards the northwest and southwest. The map is presented as a log 10 of soil erosion in mm/ha/year due to the significant range of variability of this variable across the study area (Prepared by Leonardo Saenz, Conservation International).

Our sediment transport model shows an average increase of soil erosion of 23% across the study areas (from 1.9 m3 ha -1 year-1 to 2.3 m3 ha -1 year-1) by 2059 (Figure 12), with the greatest localized increases in mountain streams, where erosion in stream channels can reach around 150 m3 ha -1 year-1 (For instance, in degraded areas of the Jucuruçu river watershed). However, maximum increase in hillslopes can only reach up to 8.4 (m3 ha -1 year-1) (still four times more than the average for the study area). Rainfall in a wet future scenario (based on the CNRM general circulation model and the IPCC A2 emissions scenario) would thus significantly increase sediment delivered to reefs, particularly those in the vulnerable inner arc.

Oceanographic impacts of climate change will intensify the threat posed by these sediments to coral reefs. Increased near-floor orbital velocities will increase and prolong sediment suspension. Sea level rise will further increase sediment exposure with longer reef submersion times, allowing more sediment to settle on and smother reefs. Our wave models show sea level rise will also usher in stronger wave action along the entire coast, especially in sections facing nearshore reefs. Cliff erosion will therefore increase in precisely those areas where it can do the most damage to nearshore reefs.

Consequences of Forest Loss for Reefs and Beaches

The primary first-order impacts of reef sedimentation are coral mortality and an ensuing collapse of fish stocks. Second-order societal impacts include degradation of natural beauty, tourism offerings, and fisheries whose stocks depend on reefs and related habitats for a portion of their lifecycles. As reefs degrade and fail to rebuild, fish populations will dwindle as they lose the habitat and substrate they need for nutrition, survival, and reproduction. Collapses in vulnerable fish populations can cause cascading impacts across food webs, potentially diminishing the Abrolhos shelf's globally-important biodiversity in foreseeable rapid and non-linear events. Abrolhos reef and shore fish fauna comprise more than 266 species, including at least one endemic coral reef fish species, a cryptic viviparous brotula belonging to genus *Ogilbia* (Dutra *et al* 2005). Local and global extinctions are therefore both possible as a result of activities which increase coral reef sediment loads.

Catch numbers for economically important fishing species will also plummet. Artisanal fishermen will be most heavily impacted, especially those fishing for subsistence or with no significant alternative source economic livelihood. Local economies and food security will be affected by reduced availability and higher prices for fresh seafood, which is a centerpiece of the Abrolhos tourist offering. The value of the shelf's primary eco-tourism activity, scuba diving, will be greatly diminished by reduced underwater visibility and disappearance of charismatic marine species. Rising costs and lower value may cause divers and vacationers to select alternative vacation destinations, further impacting the local economy through lost tourism revenue.

Knowledge Gaps

To reduce uncertainty, sediment models should account for dams on larger rivers (Jequitinhonha, Doce, Mucuri), and ideally also small dams used for irrigation. This includes understanding rates of sediment interception at dam reservoirs, using field observations and models based on characteristics of dam, reservoirs, water flow, and sediment. Models should be able to forecast the likelihood and magnitude of sediment loss from reservoirs during extreme events, and quantify the relative importance of sediment inputs (large rivers, smaller rivers, coastal drainages, coastal cliffs, bioerosion from reefs). We recommend special focus on river sections downstream of dams, to understand the degree to which dam-driven alterations in river morphology create offsetting increases in erosion and sedimentation. Finally, models should be able to predict the fate of sediments upon entering waterways (i.e. settling on river banks as silt vs. reaching river mouth and ocean). Time and cost constraints prevented such modeling from being performed for this assessment.

Understanding the causes of recent rainfall changes will improve projections for the study area. We found the decrease in rainfall concurrent with major deforestation events over 1970-2000. This is supported by Webb et al (2005, 2006) who associated deforestation with fewer rain days in São Paulo state, while Coe et al (2011) associated deforestation with increased discharge in the Cerrado region. These findings are compatible, as deforestation decreases evapotranspiration and increases percent runoff, river discharge, and erosion (Coe et al 2011). However, because the 1970-2000 period is coeval with global climate change, research is needed to decouple the two effects and understand their relative importance for patterns and timing of rainfall. The effect of deforestation on runoff is highly location-dependent, as evidenced by our findings of decreased runoff with deforestation. Many factors contribute to the ultimate response of runoff and discharge to deforestation. Rainfall is clearly important, as drying can overwhelm higher percent runoff for a net decrease in runoff. Geomorphology, geology, and soil characteristics are also important, and further research on their interplay is needed in the study area to understand the (perhaps unusual) behavior of this system.

Our comparison of 15 global climate model (GCM) outputs shows a wet scenario to be slightly less likely than a dry scenario for the Atlantic Forest. Rainfall increased in 47% of models in A1b and A2 emissions scenarios, and 53% in B1, with mean precipitation decrease of 1-2% in each of the three emissions scenarios. Although the wet scenario is slightly less likely to occur, its more significant risks and adaptation measures prompted its use as the focus of this storyline. The slim preference for wet scenario in this ecosystem, and the high uncertainty associated with GCMs in general, underscores the importance of ongoing climate monitoring, modeling, and adaptive management. Decision makers must monitor how current climate is tracking model predictions, and know how adaptation plans should be altered to fit changes in expected future climate.

Box 1. Study Area River Flow (Source: Hidroweb with analysis by Camila Donatti, Conservation International).

Rivers averaging <10m3/s

- 11 stations with at least 41 years of data were analyzed
- Those were chosen because they have at least 41 years of data AND show low water flow (<10m3/s in average)

Comparision of average monthly flow for three periods (1969-82, 1983-96, 1997-2010)

- In general, average water flow per month is larger in the first period
- 9 of the 11 stations show a significant difference in average across periods, with highest values of average water flow in the first period

Comparison of average flow per month before and after 1970**:**

- 5 of 11 stations have data prior to 1970 (Entroncamento: 1963-2011, Itajupe: 1935-2011, Matuipe: 1954-2011, Nazare: 1949-2011, Tesouras: 1952-2011)
- 4 of 5 show a higher average water flow before 1970 than after 1970

Rivers averaging >25m3/s

- 16 stations with at least 41 years of data and that have more than 25m3/s

Comparision of average monthly flow for three periods (1969-82, 1983-96, 1997-2010)

- In general, average water flow per month is larger in the first period
- 15 of the 16 stations show a signficant difference in average across periods, with highest values of average water flow in the first period

Comparison of average flow per month before and after 1970:

- 12 of 16 stations showed data prior to 1970
- 4 show a higher average before 1970 than after 1970
- 2 show a higher average after 1970 than before 1970
- 6 show show significant difference between those 2 periods

Storyline 3:

Vulnerability of Beaches to Sea Level Rise

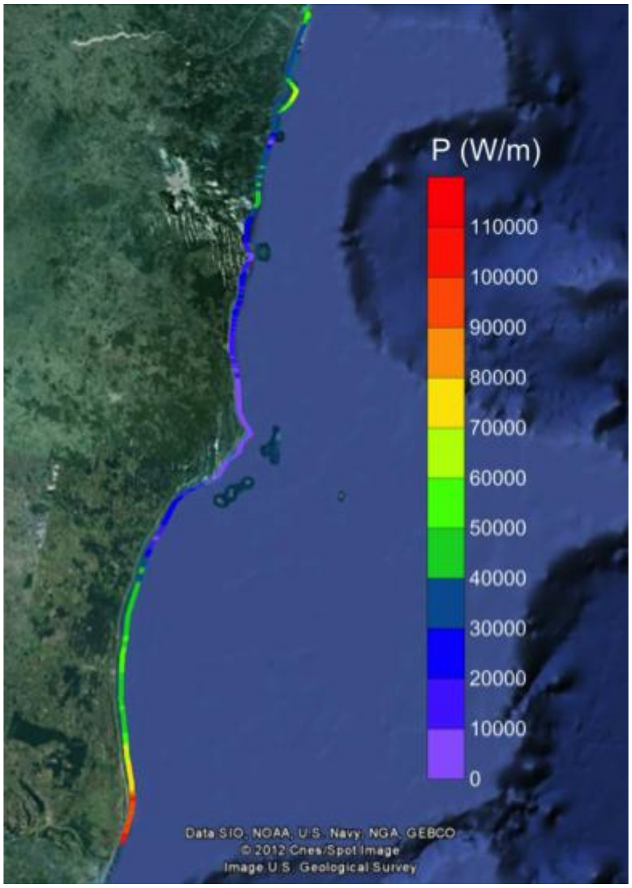
Current Conditions

Almost all of the environments along the coast of Bahia - sandy beaches and spits, mangroves, restinga, and estuaries - are dependent on the natural processes that drive sand and sediment delivery and erosion. Coastline features such as rocky outcrops, vegetation (mangroves, seagrasses etc.), man-made features (seawalls, breakwaters etc.) all shape the coastline on local scales. Sediment is transported by rivers from upland areas to coastal waters. However, the size, direction and seasonality of the dominant waves on the coast are the most dynamic influence on the amount and location of coastal erosion and deposition (Siegle 2012).

Coastal erosion can cause both environmental (loss of coastal habitat) and economic (loss of human structures) damage (Figure 13) (Dawson et al., 2009, Mallmann & Araujo, 2010). Recent work has mapped the current vulnerability of the coastal beaches of Bahia to erosion from the mouth of the Rio Doce (Espírito Santo) to the mouth of the Rio Jequitinhonha (Bahia) (Siegle 2012). Factors generally affecting the susceptibility of a beach to increased erosion include: a) Beach profile – wider beaches and steeper beaches are less vulnerable; b) The presence and density of human communities immediately next to the beach; c) The presence of vegetation, estuaries, sand dunes; and d) Engineering infrastructure (such as breakwaters and seawalls)

Figure 13. Typical current patterns of erosion at sites on the Bahia coast (Prepared by Eduardo Siegle)

All the beaches assessed in Bahia have a moderate to high vulnerability to coastal erosion. However, beaches that were adjacent to coral reef areas are less vulnerable than others. This was the case for the beaches around Caravelas, Corumbau and Porto Seguro (Figure 14). Although other factors contributed, this pattern results from the action of the reefs offshore to reduce the size of waves reaching the coast and hence to reduce the erosion – and in some cases increase sand deposition - at these beaches.



Given the significance of reefs for beach vulnerability to erosion in Bahia, the natural resilience of those coral reefs - their capacity to regenerate, grow and maintain their integrity – has direct implications for the amount of coastal erosion on the beaches they protect. Overfishing, destructive fishing practices, increased sedimentation from sources such as river outflows and pollution all impact the health of reefs and hence their capacity to attenuate waves and maintain natural protection against beach and coastline erosion (Young, 1989, Leão & Kikuchi, 2005). In Bahia, the health of the coral reefs are being impacted by overfishing of key herbivores, especially the blue parrotfish, *Scarus trispinosus*, coral disease, bleaching, sedimentation that may in part be due to deforestation and poor land management in the watershed, and possibly also coastal eutrophication and other effects of pollutants (Leão & Kikuchi, 2005, Francini-Filho et al 2008a, Francini-Filho et al 2008b).

Figure 14. Wave impact on the Bahia coast. Areas immediately adjacent to reefs have the lowest levels of wave impact (Prepared by Eduardo Siegle).

Climate Change Impacts

Sea levels are estimated to rise between 0.18 and 0.79 m this century (IPCC, 2007). Sea level will have multiple impacts on the Bahia coastline. Increases in sea level will increase the depth of water across the coastal area of Bahia, potentially flooding many coastal areas and habitats and making many areas currently not subject to erosion vulnerable, especially during storm events (Dawson et al 2009). Increasing water depths over coral reefs will have the impact of decreasing the relative impact of reefs or other submerged structures on attenuating waves approaching the coast (Young, 1989). Hence, although the beaches protected by coral reefs are currently the least vulnerable to erosion, sea level rise will have the greatest impact on erosion in these areas by reducing the relative moderation of waves by reefs and, as a result, increasing erosion on these beaches by up to 90% (Siegle 2012). Caravelas, Corumbau and Porto Seguro beaches would be most affected (Figure 15). In contrast, the impact on beaches not protected by coral reefs will be less, relative to current wave conditions (Siegle, 2012).

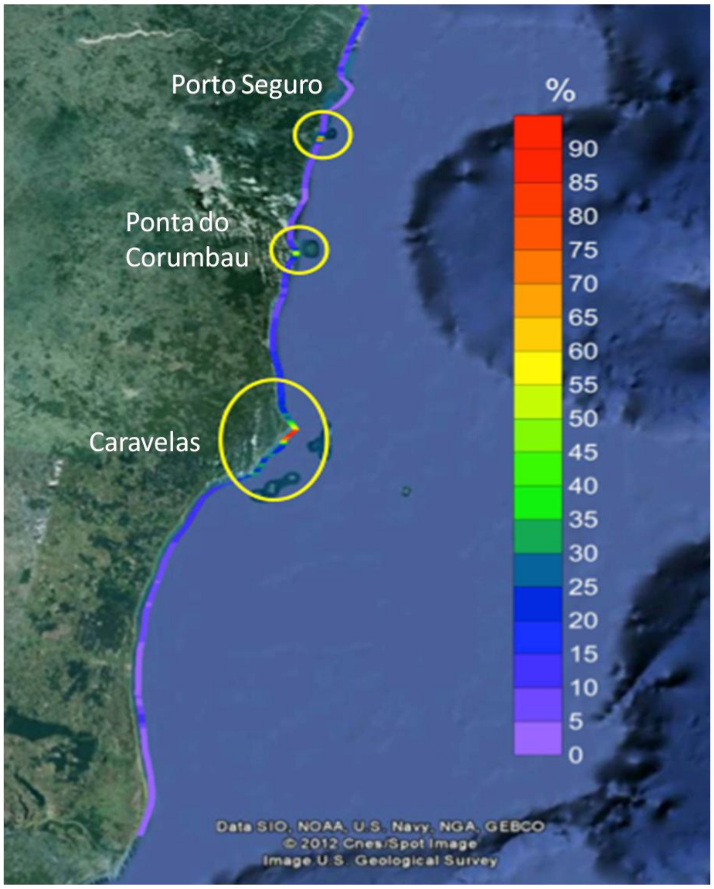


Figure 15. Percentage increase in wave impact on the Bahia coast resulting from 0.5 m sea level rise. Areas immediately adjacent to reefs have the highest relative impact of sea level rise on wave impact (Prepared by Eduardo Siegle).

Increases in sea level will increase the velocity at which the waves move the water throughout the depth of the coastal ocean resulting in increased stress on and near the ocean bottom. This will impact bottom ecosystems (increased stress on corals, seagrasses, etc.) and will cause greater resuspension of sediments from the seafloor. Increased water depth, especially with increased suspended sediments will reduce light levels throughout coastal waters. Sea level will also result in changes to the tide (including the timing and magnitude), which will have consequences for water and sediment flow into and out of estuaries and other coastal areas.

Temperature effects of climate change will interact with rising sea level to increase impacts on beaches, and oceanfront homes, hotels and restaurants. Increasing ocean temperatures causes coral bleaching, which retards coral growth and can lead to coral death. High summer temperatures are also implicated in a seasonal coral disease, particularly "white plague" syndrome that afflicts *Mussismilia spp*., the primary framework builders in this region, and most especially *M. brasiliensis*, which is endemic to the region (Francini-Filho et al 2008b, Francini-Filho 2010).

Ocean acidification reduces the corals ability to grow and to form new carbonate skeleton, the primary source of reef accretion. Both increasing ocean temperatures and ocean acidification reduce coral growth and recovery rates and hence the capacity of the reefs to respond to and keep up with sea level rise. There may also be a feedback cycle in which reef degradation results in increased coastal erosion, which in turn increases the turbidity of coastal waters and consequently further limits reef growth. Increased sediment on the reefs will increase disease and hinder growth, and decreased light levels will retard growth rates. Changes in wave heights and directions due to climate change-driven alterations in ocean circulation have the potential to further degrade reefs and enhance suspended sand. These climate change impacts on the coral reefs will act synergistically with existing pressures to reduce the effectiveness of coastal coral reefs as a habitat for fishes and a host of other marine organisms, while also feeding the cycle of reef degradation. Since any disruption to the coral reef, reduces its capacity to attenuate the waves reaching the coast, reef degradation leads to an increase in beach erosion.

Changes in erosion patterns will have clear impacts on beaches and shorelines. Even with moderate changes in wind and wave patterns and sea level rise, areas of shoreline will be lost to erosion while sediment deposition will expand the coastline in other areas (eg enlarging sandbanks, dunes etc.). The areas currently protected by coral reefs will have the largest relative loss to erosion. These shifts in the shoreline will have major impacts on the coastal ecosystems and the associated industries and communities. Beach dependant species, such as turtles and birds dependant on beaches for nesting sites, will be significantly impacted by these changes if alternative appropriate sites are not available.

Consequences of loss of beaches and coastal erosion

The impacts of climate change on the coast will have significant implications for the communities and urban areas of Bahia. Changes in erosion patterns and flooding from sea level rise will directly impact local hotels, homes, and restaurants. Infrastructure located on or near the coastline including roads, electrical transmission lines, sewage and water infrastructure, and bridges are subject to damage. This will be exacerbated by the loss of coastal ecosystems (mangroves, apicum etc) that mitigate coastal flooding and erosion. Significant loss of income and potential migration of communities away from these coastal areas will result, with increased pressure on resources in the areas of resettlement.

The beaches of Corumbau, Caravelas and Porto Seguro will be the most impacted by beach erosion, among the 11 analyzed for this assessment. In Corumbau 90 houses, two hotels and a resort are located between 20 and 150 meters from the shoreline, in a 3-km beach (Ponta do Corumbau) that is protected from erosion by the coral reef. With changes in sea level rise and wave climate, those houses will be highly affected, and the beach may disappear, generating a drop in the income of the local people that rely on tourism. The loss in the tourism sector in this location as a result of damages caused by beach erosion may be between 0.5 - 1 million dollars and the losses in terms of assets may be in the order of one million dollars. In Caravelas, about 95 houses and one resort are located in less than 100 meters from the shoreline of the Barra beach, which has about 7 km of extension. The loss in the tourism sector may not be that high, as there is only one resort in this area, but the loss in houses and assets can be of about one million dollars.

In Porto Seguro, the situation may be much worse than described above. Porto Seguro is the most important tourism destination in Bahia state and the most visited beach in Porto Seguro, Taperapuã, will be the highly affected by beach erosion. This beach, which has about 3 km of extension, has about 50 restaurants located from 10-60 meters from the shoreline and, therefore, those constructions are highly vulnerable to beach erosion. In addition, in walking distance from this beach, there are 43 hotels, including 10 resorts with space for 300-400 guests. As at least 10 % of the tourists stay in hotels located in walking distance to this beach, and using the estimation of the amount generated from the tourism sector in Porto Seguro for 2014 (Bahiatursa 2002), we estimate that about 58 million dollars in the tourism sector may be at risk with climate change, with an additional 2 million dollar loss in assets located on this beach.

Estuaries, mangroves, apicum, restinga and other coastal ecosystems provide food (fisheries, shellfish), income (fisheries, tourism) and cultural resources for the local community. Climate change driven loss of these ecosystems will impact the local community through reduction or loss of these resources. This is particularly important as the communities most dependants on these resources are the most resource poor and the least able to find alternative sources of food and income. Fisheries across the region will be impacted by losses of coastal ecosystems, which provide critical habitat for different lifestages of many of the commercial fish and shellfish species. Changes in navigation routes and port access due to shifts in sediment will also have potentially significant impacts for fishing fleets.

Coastal habitats will migrate inland as sea levels rise if appropriate buffer areas are immediately adjacent. If no appropriate buffer areas are available, the habitats will be lost, including the resources associated with them (biodiversity, fisheries, shellfish), which has implications for numerous other related ecosystems. For example mangroves are important nursery habitat for coastal fish and invertebrate species, while restinga, apicum and tidal swamp forest are rich in both biodiversity and key ecosystem services.

Knowledge gaps

The most significant gaps for integrating adaptation actions for the physical impacts of climate change on coastal systems into coastal management in Bahia are specific local estimates of vulnerability and likely change. This includes change in biophysical (erosion, wind, beach profile, ecosystems) and economic processes (fisheries, incomes, livelihoods) in Bahia.

Storyline 4:

Fragmentation, Fire and Ecosystem Services

Current Conditions

The Atlantic forest in the northeast of Brazil is a center of species endemism in South America (Silva & Casteleti 2003), shelters insect pollinators that are key to maintain the productivity of several crops and provides important opportunities for diversifying tourism in the region if the three national parks in the study area (*Pau Brasil*, *Descobrimento* and *Monte Pascoal)* are better developed for ecotourism. This section is the most threatened sector of the Atlantic forest domain (Dias et al 1990). Only 2% of the original forest distribution is left, mainly due to urban development (Viana et al 1997, Ranta et al 1998) and exploitation for timber, agriculture expansion and mining. Fragmentation leads to a rapid loss of species (Turner 1996) and an explosion of light-demanding native and exotic tree species (With 2004). These effects follow from high mortality rates of canopy trees due to microclimate changes and increased wind turbulence near forest edges (Laurance et al 1998, 1998b).

Fragmentation creates a perimeter of abrupt forest edge with different microclimatic ecological conditions than those in the center of the fragment, promoting larger and more frequent burning of the forest. The forest edge allows sunlight and wind to penetrate into the forest fragment, increasing desiccation, generating more combustion material (Malhi et al 2008), which ultimately leads to a high flammability and as a consequence increase in the frequency of fires. This combination of factors is posing a much more serious threat to forest remnants than previously imagined. Recent studies show that forest edges continue to gradually recede, diminish the size of fragments and cause them to collapse inwards (Gascon et al 2000), preventing regeneration and compromising the very few forest remnants that remain. The sustainability of the remaining fragments in the study region, regardless of their level of protection, is at risk because the forest is unable to buffer its interior from drying and fire, and because the matrix that surrounds those fragments, composed of pasture, is often burned as a part of its management strategy. This is not legal in Brazil.

Fires in these forests are penetrating deeper into remaining forest blocks and burning larger areas of forest. Burned areas provide additional edge to the forest, creating a cycle of forest destruction by fire and deterioration by edge conditions. As tropical forests have a substantial influence on regional climate, deforestation may reduce regional evaporation, making the region even more vulnerable to fire. Rainfall in the region has already been reduced (Figure 16), associated with the large-scale forest clearing of the past six decades. Thus, both local (forest edge/burning) and regional (forest loss/reduced rainfall) effects are creating a downward spiral in which even large forest fragments may be reduced to degraded scrub.

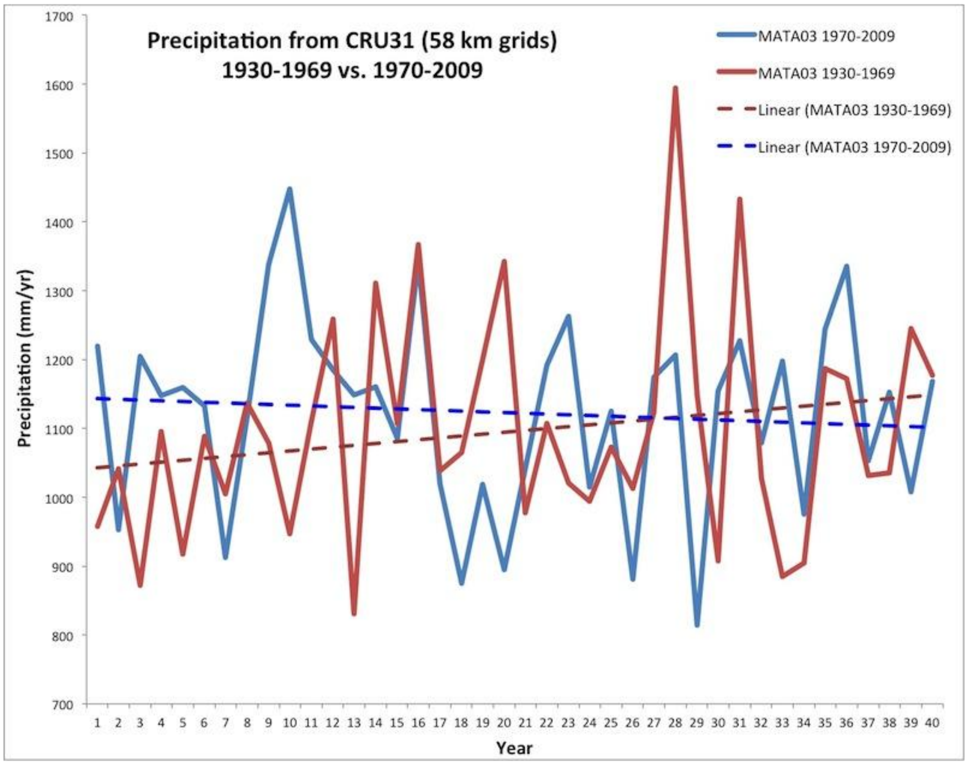


Figure 16. Decline in rainfall in the region from 1930 to 2009. Rainfall in the region has decreased during the recent period of heavy deforestation, indicating a likely association between rainfall and forest cover, as demonstrated for other parts of the Atlantic Forest (Source CRU data with analysis by Lorraine Flint, USGS).

Climate change impacts

Climate change is increasing the positive feedbacks among local climate, fire and fragmentation (Laurence & Willamson 2001). The interaction of climate change, fragmentation and fire may prevent forest regeneration, due to a high incidence and frequency of fires and to the conditions that accompany the edge effects, as described above.

This region may experience less rainfall and high temperatures as a result of climate change, which is likely to drive more frequent fires in the future. Climate change models for the region identify both possible increases and decreases in rainfall. In drier future climatic conditions, an increase in the frequency of fire is expected, which would result in new forest edges being created—and more vulnerability to further burns (Cochrane et al. 1999). In our study area, it is expected that the drier conditions will occur mainly on the extreme northeast and on the south of the region (Figure 17).

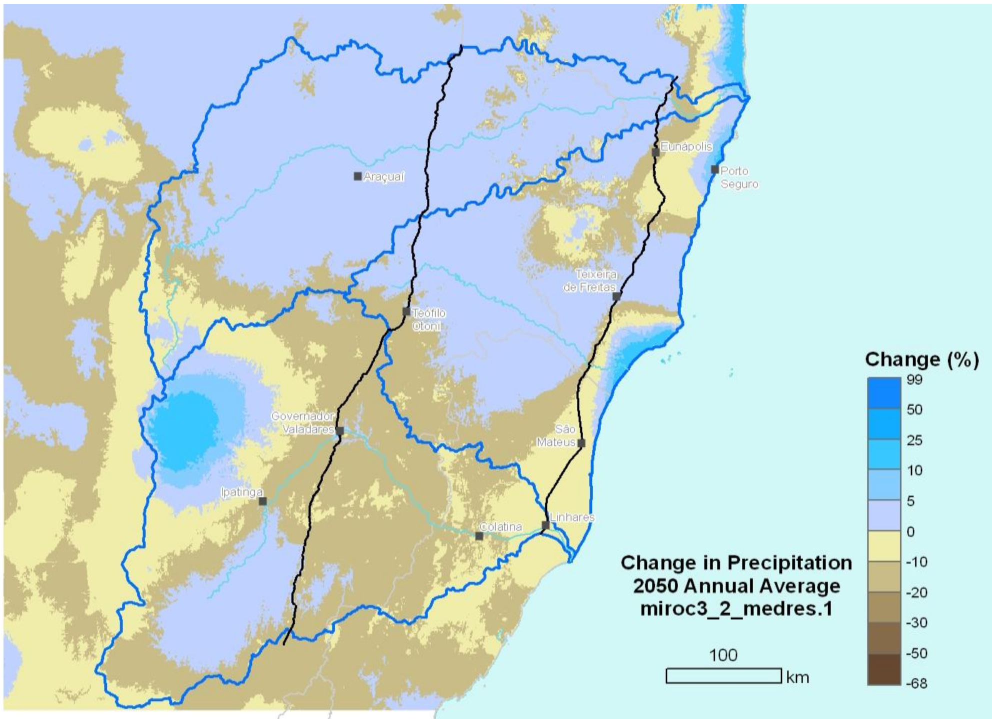


Figure 17. Percentage changes in precipitation in the study area for 2050, based on the MIROC model (Prepared by Karyn Tabor and Kellee Koening, Conservation International).

Climate change may further compound these effects by interfering with natural forest regeneration. Species distribution modeling shows that the number of seed disperser species will decrease considerably, especially around Porto Seguro. Seed dispersal is an essential function for forest recovery and maintenance, so the loss of seed disperser diversity may compromise the ability of the forests to regenerate naturally and recover from fire. The loss of common key species that eat fruits and therefore disperse seeds may affect the process of recovery and the first stages of forest succession, with dramatic consequences to forest function. A consequence of the projected loss in diversity of seed dispersers is therefore that natural forest regeneration will likely be slower in the future and the costs of forest recovery will likely be very high.

Consequences of fire and forest degradation

Climate change will affect the ability to diversify tourism in the region, as well as impacting ecosystem services to local people such as water provision and crop pollination. Tourism to forest reserves is just opening up in this region. Nature tourism built on mass beach tourism is a highly successful model that has built major nature tourism economic sectors in countries such as Kenya and Thailand. The ability to use forest tourism to expand and diversify the tourism sector in Southern Bahia is seriously jeopardized by climate change. Expanding this tourism sector is a multi-year process that will be undercut if the resource is being degraded relative to other tropical forest destinations.

The tourism sector in Porto Seguro is growing 6% per year in average and is estimated that the amount generated from this sector in 2014 will be over 580 million dollars (Bahiatursa 2002). This sector brings about 1 million tourists to the region each year, which has the largest hotel capacity in the northeast of Brazil and the third largest in Brazil. Given that the region has three national parks, Pau Brasil, Monte Pascoal and Descobrimento, and a tourism sector already well established, there is a huge potential to incorporate the national parks as popular tourist attractions. The upcoming World Cup that will take place in Brazil is expected to bring an investment of more than 300 million dollars to be applied directly to the infrastructure of several Brazilian national parks, which can be a big push for the development of forest tourism in this region. The loss of forested areas will compromise this potential and the opportunity to diversity the tourism sector in the region, which is currently almost exclusively focused on marine ecosystems (see Introduction). If we assume that forest tourism might one day make up 5 % of the total tourism in the region, almost 20 million dollars per year may be at stake if climate change erodes the forest resource.

Crop pollination will likely be affected by loss of forest, especially in the south of our study region, which is projected to experience drier conditions. Loss of forest through burning and edge effects reduces habitat for native pollinators and results in lower pollination rates for crops, with a consequent loss in productivity. Coffee plantations may be among the most impacted agricultural activities, because pollination by insects is key to promote high levels of coffee production (Klein et al. 2002). In the study region, 9% of the agriculture land is designated for coffee plantations totaling 286,000 hectares. The south of Bahia and the north of Espírito Santo produces an average of 1.45 tons of coffee grains per hectare (from IBGE aggregated data bank), with a coffee production of about 415,000 tons per year. Experiments have shown that farms located close to forested areas showed an increase of at least 11% in the coffee production compared to farms located far from forest fragments due to an increase in the pollinating services (de Marco & Coelho 2004). Therefore, coffee production in the region may be impacted if forest is lost due to the combined direct impacts of deforestation and indirect impacts of climate change, with as much as 45,000 tons of coffee grains or about 93 million dollars per year at risk.

Knowledge gaps

Further work is required to understand better the role of deforestation and climate change on waterflow decline. We have evidence of a decrease in rainfall concurrent with major deforestation events in the study area, but the time period coincides with global climate change. Research to decouple the two effects and understand their relative importance for patterns and timing of rainfall is thus needed.

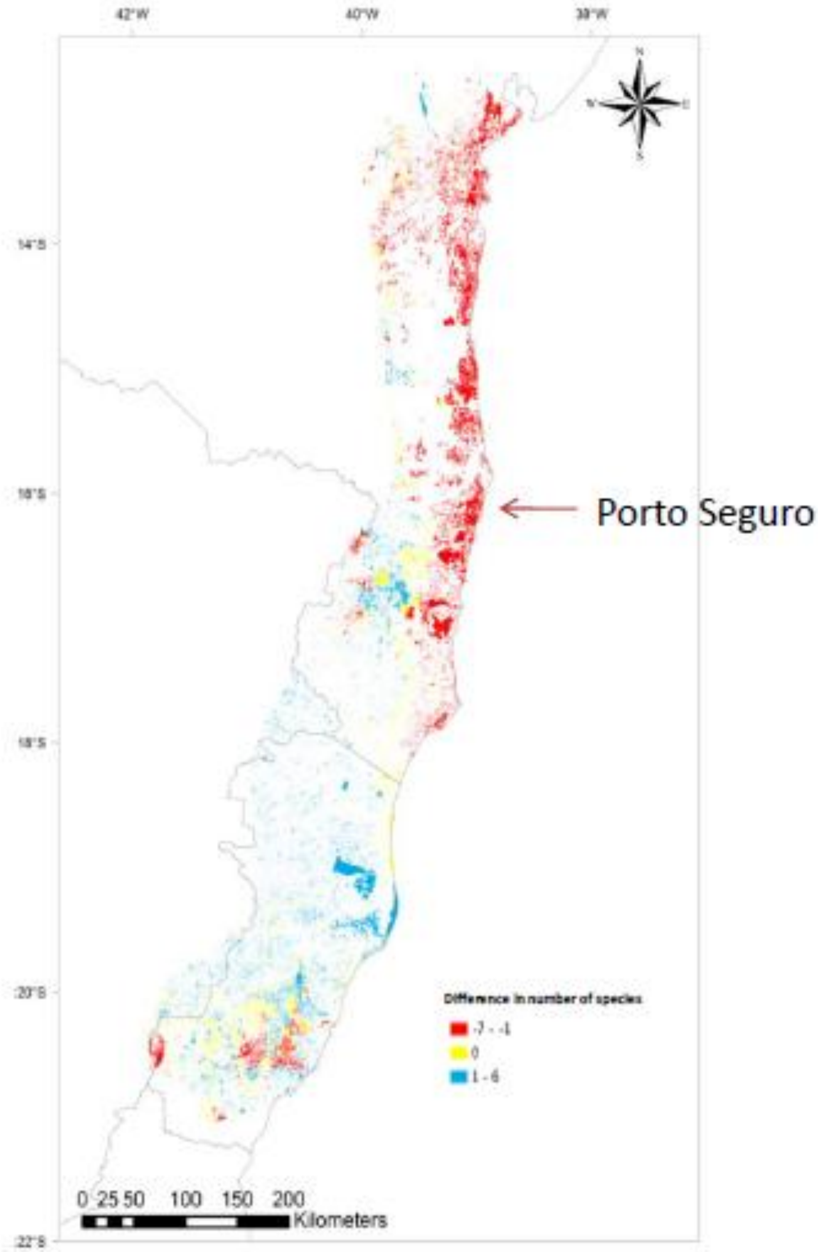


Figure 18. Predicted species richness loss in 2050 superimposed on the current forest remnants in the area of the Central Corridor using ensembled 17 climatic models (Prepared by Paulo de Marco Jr., Adriano Paglia, Carolina Nóbrega and Daniella T. Rezende).

Storyline 5:

Freshwater Squeeze

Current Condition

Mangrove estuaries teem with life along the Abrolhos coast, providing nursery for fisheries which are worth nearly R$ 52,500,000 per year in Bahia alone (ICMBIO 2006). Mangroves around Canavieiras, Belmonte, Santa Cruz de Cabrália, Porto Seguro, Corumbau, Alcobaça, Caravelas, and Conceição da Barra are critical incubators for income from marine fisheries (WWF 2012). These mangroves support young fish and fish larvae survival to adulthood by offering refuge in shallow brackish water surrounded by primary production, organic sediments, and shelter from waves and predators (Manson et al 2005, and citations therein). Abrolhos' mangroves are nurseries and forage grounds for fish, crustaceans, mollusks, and dolphins, and offer temporary habitat to many species of migratory water birds and sea turtles (WWF 2012). Local fisheries and marine tourism operations, critically important to the coast's economy, depend largely on species which require estuaries at some point in their life cycles.

These valuable mangrove resources face a "freshwater squeeze" from climate change. Sea level will rise, driving mangroves inland, while if climate change brings a drier future, there will be less river flow to support mangrove estuaries. As the ocean rises, coastline migrates inland, swallowing beaches and flooding estuaries with seawater. Mangroves, suddenly submerged in water beyond their salinity tolerance, begin to die. Cliffs rising abruptly from the coastal lowlands constrain the area available for migration inland, and in a drier future, less freshwater is discharged by rivers to balance the saline influx. The Abrolhos estuaries and mangroves could dramatically shrink in a relatively short span of time. This could compound existing degradation of mangroves from urban expansion, industrial pollution, commercial forestry, and shrimp farming.

Disappearance of the Abrolhos seascape's "marine nurseries" means that many species of fish, crustacean, mollusk, and marine mammal will dwindle toward local extinction. Artisanal and commercial fisheries, dive tourism, and hospitality, the pillars of this coastal economy, would suffer. A carefully planned and adaptive climate change management strategy is thus critical to preserving Abrolhos' globally-important natural resources and the livelihoods of its human population.

The fisheries supported by mangroves are an important source of protein and revenue to local economies, with substantial markets in coastal towns and larger cities including Porto Seguro, Eunápolis, Teixeira de Freitas, São Mateus, and Linhares. Of 15 coastal communities surveyed between Jequitinhonha and Mucuri Rivers (Figure 18), seven listed fishing as the primary economic activity and four listed it as the second-most important. Five communities reported fishing as primarily for local consumption; eight reported it was primarily for sale (Table 3). Such economies therefore stand to be heavily impacted by loss of estuarine habitat. Estuaries are also habitat for large populations of baitfish which feed many of the above fishery species as well as endemic and migratory birds, turtles, and dolphins.

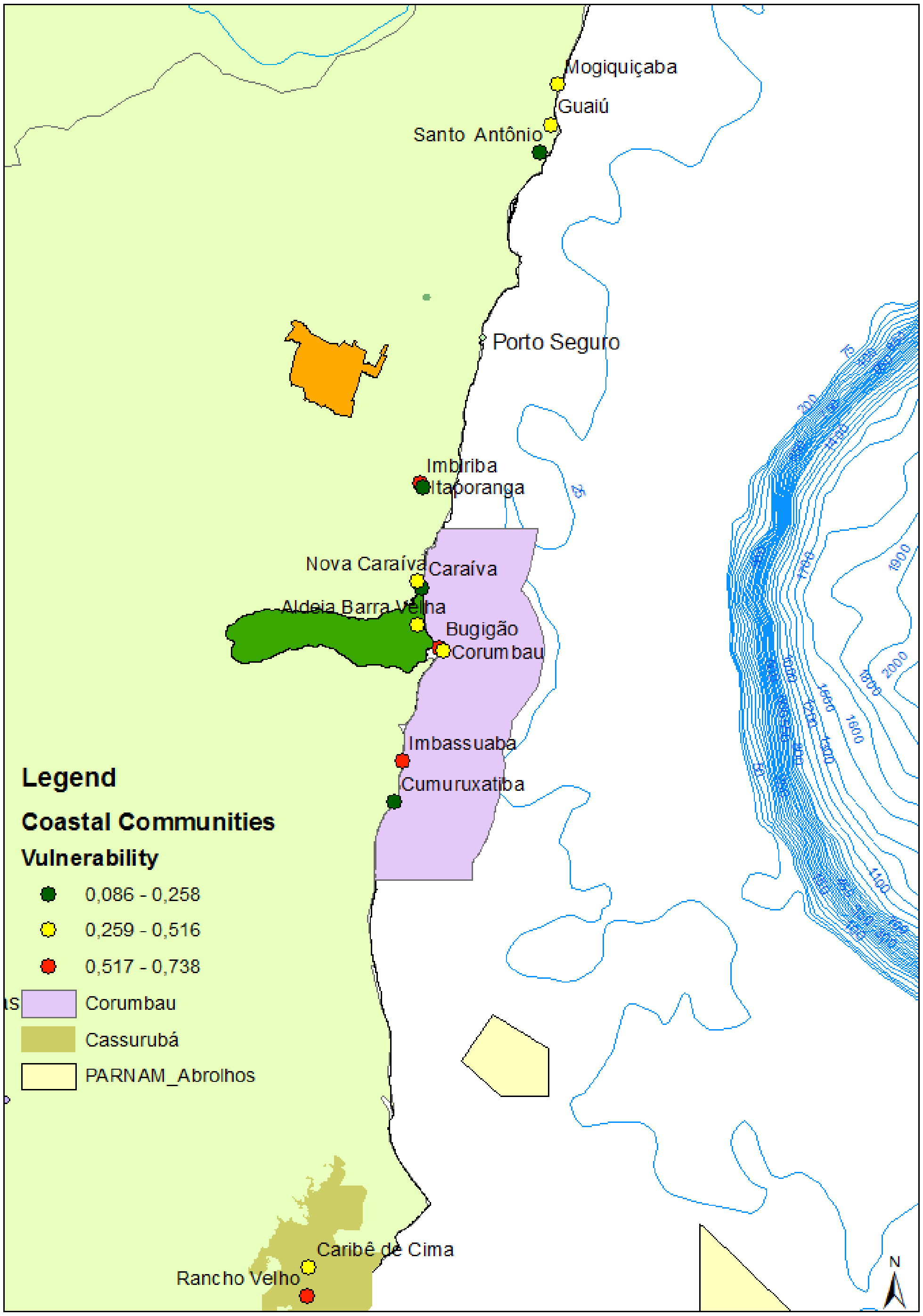


Figure 19. Surveyed Coastal Communities (Prepared by Tiago Pinheiro, Conservation International)

Table 3. Species caught by coastal communities, seasonality and main destination (Prepared by Tiago Pinheiro, Conservation International-Brazil).

Fisheries – Main species																					
	4	5	2	2	6	9	1	1	7	4	1	2	2	3	2	1	1	1	3		
Community	Shark	Cynoscion sp	Micropogamas furnieri	Genidens sp	Snapper / Lutjanus sp	Snook / Centropomus	Lujanus synagris	Sororoca	Shrimp	Octopus	Snapper / Ochrysurus	Caranx llatus	Carangoides crysus	Mugil sp	Rays / Oasystus sp	Mycteropeca bonaci	cangauá	Chetodipterus faber	Lobster	Best season	Destination
Mogiquiçaba	1	1	1	1	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	Summer	Sell
Barra Velha	-	-	-	-	1	-	-	-	1	-	-	-	-	-	-	-	-	-	-	Winter	Consumption
Corumbau	-	-	1	-	1	-	-	-	1	1	-	-	-	-	-	-	-	-	-	Winter	Sell
Bugigão	-	-	-	-	1	-	-	-	1	-	1	1	1	-	-	-	-	-	-	Winter	Consumption
Santo Antônio	1	1	-	1	-	1	-	-	1	1	-	-	-	-	1	-	-	-	1	Summer	Sell
Guaiú	-	-	-	-	-	1	-	-	-	1	-	-	-	1	-	-	-	-	-	Summer	Consumption
Imbassuaba	1	1	-	-	1	1	-	-	-	1	-	1	1	1	-	-	-	-	-	All year	Sell
Cumuruxatiba	-	-	-	-	1	-	-	-	1	-	-	-	-	-	1	1	-	-	1	Winter	Sell
Nova Caraíva	-	-	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	All year	Consumption
Imbiriba	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caraíva	1	1	-	-	-	1	1	1	1	-	-	-	-	-	-	-	-	-	1	Summer	Sell
Itaporanga	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Caribê de Cima	-	-	-	-	-	1	-	-	-	-	-	-	1	-	-	-	1	1	-	Summer	Sell
Rancho Velho	-	-	-	-	1	1	-	-	-	-	-	-	-	-	-	-	-	-	-	All year	Consumption
Barra Velha	-	1	-	-	-	1	-	-	1	-	-	-	-	-	-	-	-	-	-	All year	Sell

Climate Change Impacts

With climate change, estuaries are expected to suffer a freshwater “squeeze” from two directions – increased salinity on the seaward side, and from upriver, diminished freshwater discharge – with the overall effect of reduction in estuarine habitat. As the squeeze intensifies, estuaries will eventually become unable to support species which depend, at some point in their life histories, on the brackish water environment. Fish stocks, endemic and migratory bird and turtle populations, and marine mammals will all be negatively impacted, some more critically than others. Already-threatened species with restricted ranges and high dependence on estuaries, such as *Myrmotherula urosticta* and *Pontoporia blainvillei* are at greatest risk.

Sea level rise is likely to cause unprecedented reductions in estuarine habitat in this region. Global sea level is projected to rise 50-100 cm by 2100 in northeast Brazil (Costa et al 2010). In the study area, inundation of coastal lowlands will reduce beach area and destroy coastal property and habitat. Inland migration of the underground salt water wedge will cause its infiltration into coastal aquifers and rivers, reducing freshwater habitat and biodiversity. Estuaries will lose seaward biomass to inundation. Facilitated upstream migration may be used to compensate some amount of habitat loss, but this adaptive capacity is limited by the available basin area between current estuary limits and coastal hills.

The second half of the freshwater squeeze comes from reduced river flows, which are projected under dry scenarios typical of the MIROC global climate model, which shows diminished rainfall, reducing freshwater supply to estuaries and increasing siltation and infilling. Reduction in freshwater supply is expected to intensify with increased human pressure on coastal groundwater stores, especially with increased migration from water-stressed agricultural areas to overpopulated coastal urban centers. Water table drawdown will facilitate inland penetration of the saltwater wedge, with consequent impacts on freshwater availability for human consumption, freshwater bodies, and estuaries. Human influence on water availability is likely to be strongest during high tourism season (Dec-Feb), a period of sharply increased freshwater demand (though this may be balanced by greater inland rainfall during the same season).

Consequences of the freshwater squeeze

Fisheries worth 26% of Bahia's fishery value and 2% of Brazil's are likely to be the most direct and heavy impact of the freshwater squeeze. Human populations, particularly communities which depend primarily or secondarily on fishing as a source of protein or income will lose employment and income if estuaries are lost to climate change.

The study area spans roughly a third of the Bahia coastline and 40% of the Espírito Santo coastline. There are substantial marine, freshwater, and aquaculture/mariculture fisheries in both states: Bahia alone contributes 9% of Brazil's national fisheries value (8.3% of marine, 13.9% of freshwater, 7.6% of mariculture, and 2.6% of freshwater aquaculture), whereas Espírito Santo contributes 3.6% of national fishery value (4.0% of marine, 0.5% of freshwater, 0.9% of mariculture, and 1.8% of freshwater aquaculture). Fisheries are entirely artisanal in Bahia, though commercial fisheries for tuna, snapper, scad, and swordfish account for 31% of the Espírito Santo fishery (IBAMA 2007).

White shrimp is by far the most economically important, representing alone 14% of all fishery value. This shrimp depends on estuaries during the postlarval stage, migrating back into open waters upon reaching maturity. In Porto Seguro fishery, snappers account for 38% of catch, followed in importance by mahi-mahi, greater amberjack (*Seriola dumerili*), and tunas (*Thunnus albacares* and *T. atlanticus*) (Costa et al 2003). Of 15 communities surveyed between Jequitinhonha and Mucuri Rivers (Figure 18), the most commonly fished species were snook (9), shrimp (7), snapper (6), and croaker (5) (Figure 19), species dependent on estuaries in juvenile stages. All of which is at risk of reduced catch if estuaries are lost to the freshwater squeeze posed by climate change.

Tourism consequences of the freshwater squeeze include reduced potential in the growing reef diving tourism sector. Loss of juveniles and baitfish for important reef species will reduce the biodiversity and diving tourism attraction of local reefs. More importantly, it will make it difficult or impossible to regenerate colorful reef fish assemblages coveted by divers, so that the growth of this tourism sector will be unlikely to reach its full potential. Reduction and extinction of charismatic fish will greatly diminish the eco-tourism appeal and natural beauty of the study area's coastal and marine environments.

Knowledge Gaps

A better understanding of aquifer geology is required to accurately model the effect of sea level rise on saltwater intrusion into aquifers, as well as the transport of freshwater from river basins to estuaries. As with sediment transport models (Storyline 2), hydrologic models should include the effect of water retention by large dams and reservoirs, as well as mid-river dams and draws for agriculture and drawdown of coastal aquifers.

Predictions about freshwater supply to estuaries are based on assumptions about relationships between forest cover, rainfall, and river discharge. For example, Webb et al (2005) showed a strong effect of deforestation (at scales of at least 1000 km^2) inhibiting rainfall in nearby São Paulo state, indicating that a similar mechanism may apply here. However, drying also coincided with the onset of global climate change, so further research is needed to understand the relative importance of these drivers, and the (perhaps unusual) behavior of these systems within the study area. See storyline 2 for further detail.

Storyline 6:

Water Availability and Fog Interception Areas

Current Conditions

In the Atlantic forest, it is estimated that over 120 million people are supported by freshwater provided by this Biome. In the study area, 365 municipalities and up to 6.2 million people depend on water originating in interior forested areas, including forests that capture fog inputs and turn them into clean water in rivers. Forests have an effect on water quality, quantity and even on the constancy of flow. Forested watersheds generally offer higher quality water than watersheds under alternative land uses, not only because fewer pollutants enter headwaters but also because forests often help to regulate soil erosion and reduce sediment load. Therefore, in most cases, the presence of forest around watersheds can reduce the need and the costs of water treatment (Stonton & Dudley 2007).

Cities may be in water deficit, but still have adequate river water thanks to watersheds that run deep inland, into areas of water surplus. In the study area, water yield varies from close to 3,000 mm/year in the highest parts in the north of the study area to negative values towards the coast, more prominently from Caravelas to the south of the study area, indicating surface water deficits. Some of the driest areas are found in the south of the study area in proximity to the Linhares Biological reserve (Figure 20).

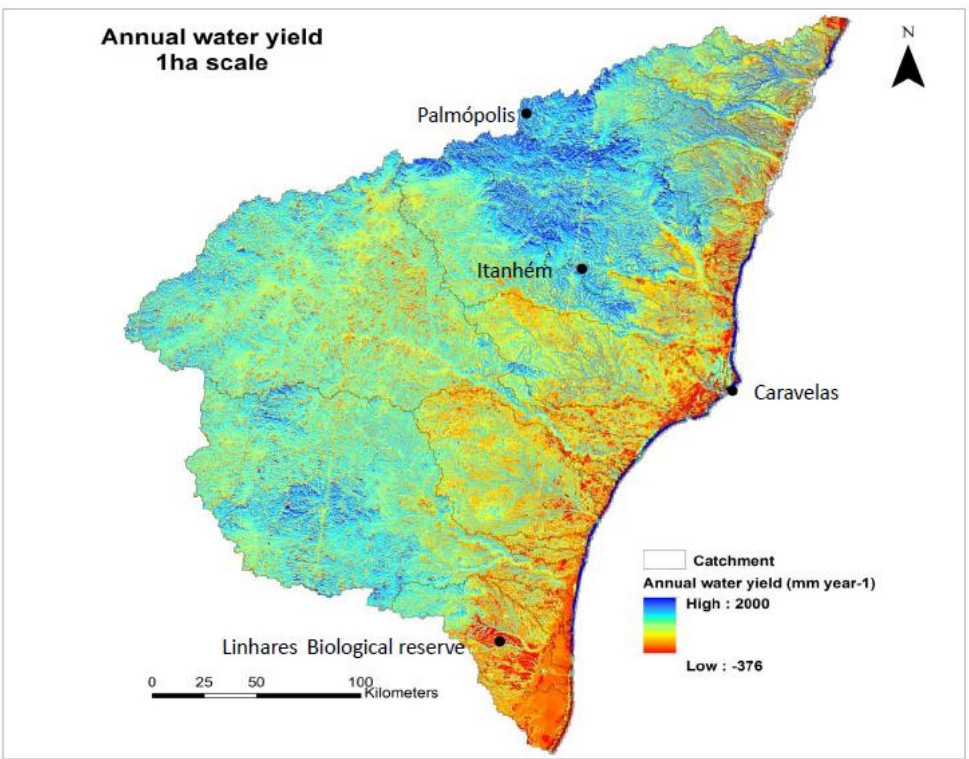


Figure 20. Annual water yield (in mm/year) in the study site. Blue shades represent areas with high water yield and red shades represent areas with low water yield (Prepared by Leonardo Saenz, Conservation International)

Much of this variation in water availability across the study site is due to differences in topography. In the north of our study area, in the proximities of Palmópolis and Itanhém, the topographical exposure to trading winds and rain, as well as their high fog inputs, explain the high water availability. Modeling shows that this particular area has the highest percentage of the total precipitation that comes from fog inputs, with a high percentage of the runoff derived from fog (Figure 21). This is consistent across the whole year, including the wetter months.

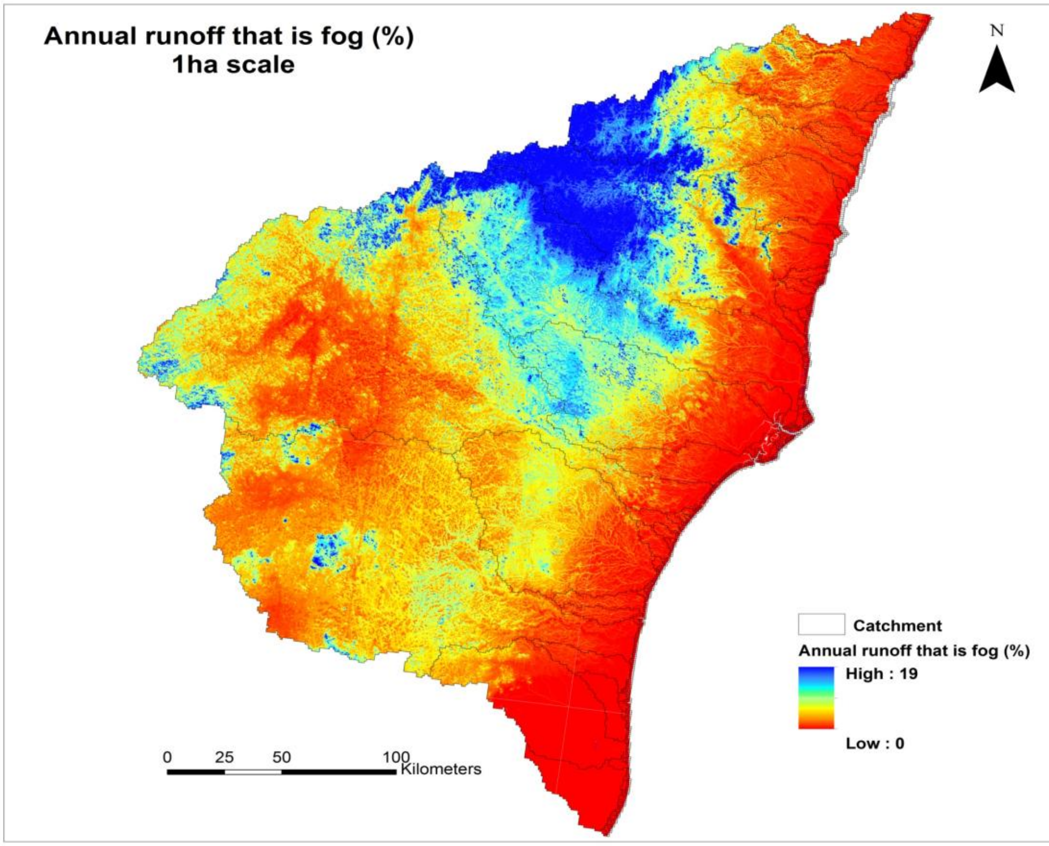


Figure 21. Fog inputs as percentage of total annual precipitation. Blue shades represent high values of fog input as total precipitation and red shared represent low values of fog input as total precipitation (Prepared by: Leonardo Saenz, Conservation International, Source: Conservation International).

Climate change impacts

Major changes in water availability with climate change are expected in some parts of the study area. Declines in water yield are expected to be more prominent along a strip in the coast from Prado to Alcobaça, from this municipality towards Nanuque, and in the mountainous areas surrounding the Alto Cariri State Park and Palmópolis, which drain to Porto Seguro's basin systems (Figures 22). The municipality of Prado is expected to have low water availability in the future, regardless of the future climate condition (Figure 23), highlighting the importance of protecting the head waters of the rivers Itanhém and Jucuruçu that drain water to the watershed used by the municipality of Prado, in order to provide hydrological resilience to potential drier downstream areas. Although Porto Seguro is expected to have an increase in water availability with climate change regardless of the future climate condition, the protection of the forests around the Rio do Mangue watersheds that drain water to this municipality is crucial for the continue provision of fresh water.

Figure 22. Watersheds in the study area (Prepared by Leonardo Saenz, Conservation International).

Modeling of water production shows the importance of upland areas in fog interception. The forest in the upland areas in the north of the study area (in the proximity of Alto Cariri State Park, Palmópolis and Itanhém are the wettest parts of the system and are likely to maximize the process of fog capture and its incorporation in the hydrological cycle (Figures 21 and 22). This particular area in the north of the study region has the highest percentage of the total precipitation that comes from fog inputs. This is consistent along the year, including in the wetter months, when taking into account both current and future climate conditions. If the forest is removed from these areas, and as forests maximize the process of fog capture, drying impacts would be exacerbated downstream, likely decreasing the availability of fresh water to the municipality of Porto Seguro and increasing the water deficit in the municipality of Prado. Many of those upland forested areas are not currently protected by the Brazilian law and, therefore, the protection of some of those areas, in addition to gallery forests around watersheds that provide water to those large cities, are key adaptation strategies that should be pursued.

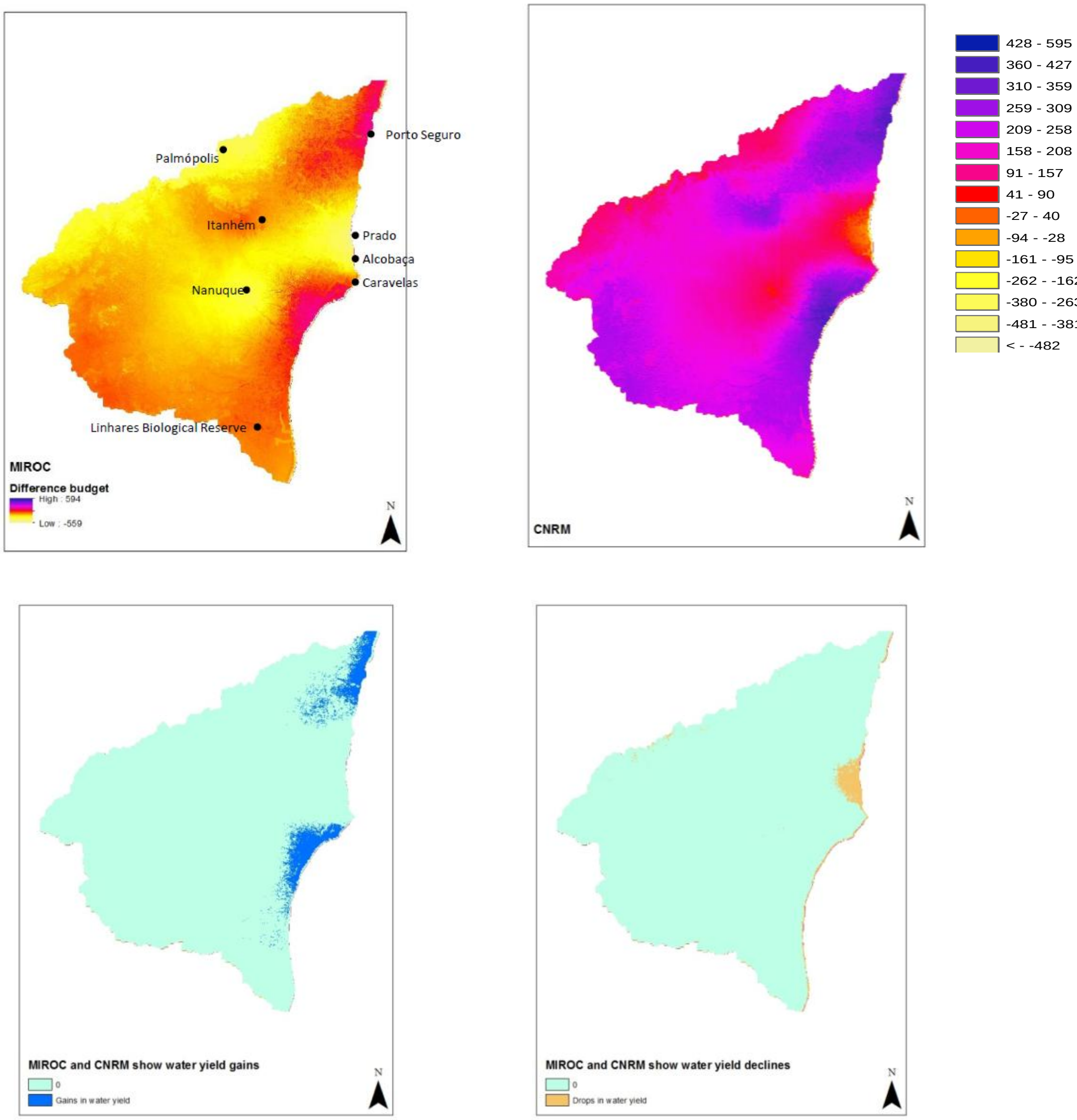


Figure 23. Differences in Water yield (mm/year) between baseline conditions and MIROC and CNRM climate scenarios. a. differences between baseline conditions and MIROC results. b. differences between baseline conditions and CNRM results. c. Areas where the two Climate scenarios agree on water gains. d. areas where the two Climate scenarios agree on drought exacerbation. (Prepared by Leonardo Saenz, Conservation International).

Consequences of water availability declines

As most of the municipalities in the study area rely on tourism as one of their main economic activities, with some municipalities having a 20% increase in the population size during the peak of the tourism seasons, water availability is a key issue in the study area. About 5.8 million people that live in the study area (IBGE 2012) —in addition to the one million tourists that visit the region every year, directly or indirectly depend on a proper management or conservation of forests for freshwater provision, either those that are located around important watersheds or those that are located in uplands that have a role on fog interception. It is possible then that at least 6.8 million people may be at some degree of risk of water scarcity or of decrease in water availability if forested areas located around watersheds or in areas of high fog interception are not properly protected or managed. Therefore, not only the maintenance of gallery forest along rivers, especially those that provide water to Porto Seguro, Eunápolis and Prado, but also the protection of upland areas that have a key role in fog interception, are key strategies to assure water provision in the future for the study area.

Storyline 7:

Declines in suitable areas for coffee agriculture

Current conditions

Agriculture is the most important economic activity in the study area, and coffee is the second most important crop in terms of planted area. Agriculture activities generate 10% of the formal jobs in the study area and coffee plantations occupy the second largest area, just behind the pasture lands, totaling 9% of the area available for agriculture. The south of Bahia and the north of Espírito Santo produce an average of 1.45 tons of coffee grains per hectare (from IBGE aggregated data bank), totaling 415,000 tons of coffee produced per year and generating about 900 million dollars annually.

The study area concentrates one of the most important producers of Arabica coffee in the world. Coffee plantations are concentrated in the south of the south and southeast of the study area (Figure 24). Those producers are located in the south of the Doce river basin (Figure 24) and this region is considered the third most important for arabica coffee production in the world.

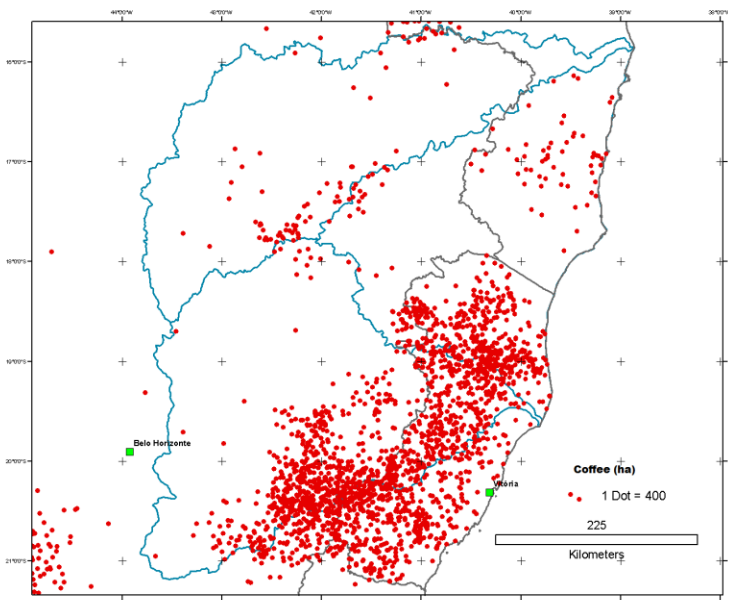


Figure 24. Coffee maps in the three basins, which are highlighted by the blue lines (Jequitinhonha on top, Doce on bottom and Mucuri in between). Each dot represents an area of 400 hectares of coffee plantation (Prepared by Tiago Pinheiro, Conservation International Brazil).

Climate change impacts

Coffee (*Coffea arabica*) (Figures 25a-c) is projected to undergo a large decline in area of suitability in the future (~2050). In order to explore the impacts of Climate change in the region's crop suitability, we combined the results of crop suitability for 17-19 GCMs using eight bioclimatic variables. In the most optimistic scenario, there was a 53%- reduction in the future suitable area for arabica coffee when compared to the present suitable area. In the higher-impact scenario, there was a 56%-reduction in the future suitable area for arabica coffee when compared to the present.

Whereas most of the study area is suitable for coffee in the present, the future suitable areas for arabica coffee are very limited. The areas with potential future distribution for the arabica coffee were limited to the east of the Bahia state. The extreme south of Bahia state and the extreme north of the Espirito Santo state, which are the areas with the highest number coffee plantations at the moment (see Figure 25) will no longer be suitable for arabica coffee. Part of one of the most important regions for arabica coffee production worldwide (south of the Doce river basin) is predicted to no longer be suitable for arabica coffee.

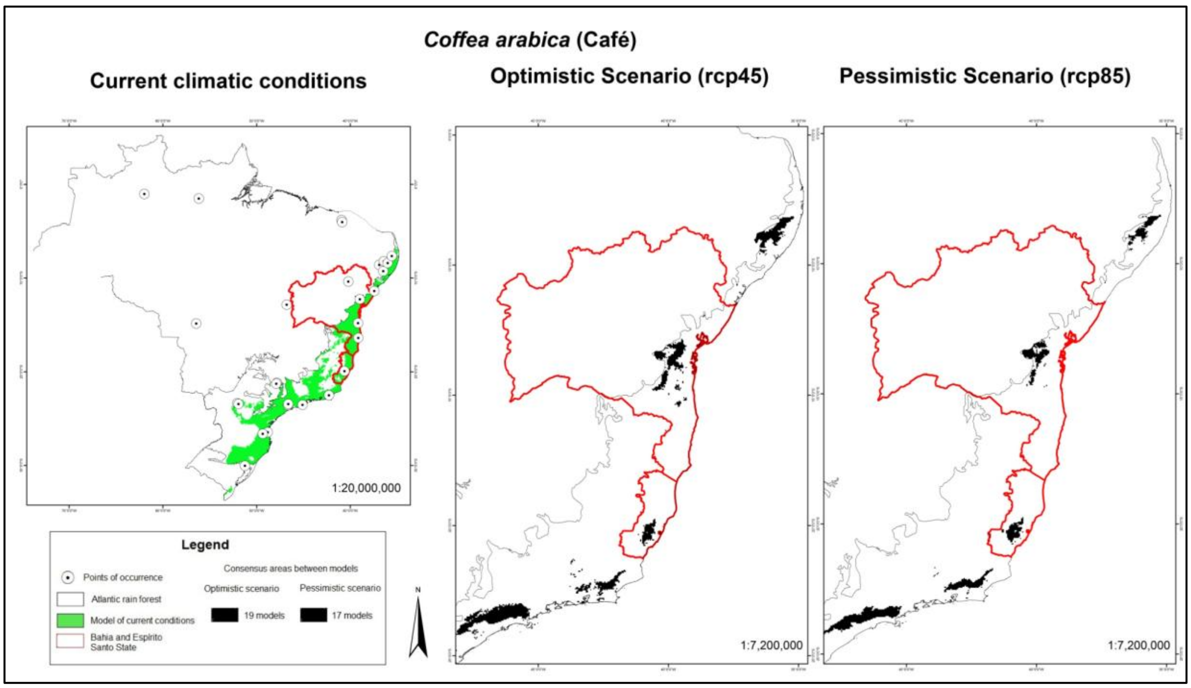


Figure 25 a. Map of Brazil with the current suitable areas for arabica coffee in green. The boarders of the states of Bahia and Espirito Santo are in read. b. Areas in black represent the future suitable areas for arabica coffee in the most optimistic scenario. c. Areas in black represent the future suitable areas for arabica coffee in the most pessimistic scenario (Prepared by Ingrid Koch and Alessandra Rocha Kortz).

Declines in coffee suitability in the region have also been demonstrated in other studies. Declines in the suitable areas for coffee was shown for the Atlantic forest domain when using a different set of GCMs, (Hannah et al in press) and for the study area for both robusta and Arabica varieties (Saenz 2012).

Consequences of declines in coffee suitability

As coffee is one of the main agriculture activities in the study areas, a large monetary loss is expected with the reduction in suitable areas for coffee with climate change. In the study area, the production of coffee is about 415,000 tons per year, which generates about 900 million dollars annually. As our modeling work shows that the distribution of suitable areas for coffee is expected to decrease to, at least, 47% is possible that this change will lead to a loss of over 450 million dollars per year, if climate change adaptation strategies by smallholder and large-scale producers (i.e the use of other coffee varieties such as the robusta coffee, the change to other crops that will be more suitable in the future, incentives to shaded coffee) are not implemented.

V. Adaptation Recommendations

The climate change storylines have described the impacts on the ecosystems and communities of the region. Adaptation to these impacts is necessary to ensure that the ecosystems continue to provide the services on which the population of the region critically depends.

The following adaptation action recommendations are have been derived and consolidated from the storylines. They include both Ecosystem-based Approaches and planning-social awareness approaches. We begin with marine recommendations, proceeding to terrestrial recommendations, emphasizing interconnections between the two. This order has been adopted for convenience and is not an order of priority. We emphasize that the marine and terrestrial systems are intimately connected in the region, both biophysically and in the economic activities of local families.

1. Implement sustainable and adaptive fisheries management

Implementing effective ecosystem-based management of fisheries will increase the capacity of the region to respond to changes in fish populations, and ensure the long-term viability of species and fisheries communities. Fisheries on the Abrolhos shelf are critical to the region's economy and livelihoods. Climate Change will have significant impacts on the fish populations, including the distribution, population and food webs. In the immediate future, adaptation actions in response should include:

- enforcement of existing no-take areas
- Implement monitoring programs for fisheries to provide specific accountability and adaptive feedback for fisheries management (including nearshore reef fisheries and commercial fisheries further offshore)
- ban on fishing species critical for ecosystem resilience (such as parrot fishes)
- reduce impacts on and increase protection of critical fish habitat (reef areas, mangroves, seagrasses, algal beds) to increase the long-term resilience of these habitats.
- implement capacity building programs for fishing community on climate change, its likely impacts on fisheries and fisheries critical habitats in the region and the range of adaptation responses possible.

In the long-term, a community-supported fisheries management plan for the region that is capable of responding to change should be implemented. Further, coastal planning and infrastructure development should ensure the long-term conservation and adaptive capacity of critical fish habitats (see recommendation #2).

2. Increase Coral reef resilience

Actions to promote the long-term resilience of the coral reefs of the Abrolhos are essential to ensure they continue to provide a number of critical ecosystem services to the coastal areas of the region including: attenuating waves and reducing erosion of the coast; providing habitat to essential fisheries; and providing habitat for endemic biodiversity. Coral reefs are severely threatened by changes in ocean temperature and acidification associated with climate change. A number of actions are needed to increase the resilience of coral reefs in the Abrolhos to these impacts.

- Decrease current impacts of destructive and unsustainable fishing on coral reef areas through implementing marine protected areas, strengthening fisheries cooperatives, and enforcing bans on the take of herbivorous reef fishes.
- Promote sustainable and non-destructive tourism use of the reefs (capacity building for tourism operators and tourists, moorings and other infrastructure to reduce boat impacts etc.)
- Implement monitoring programs for reef health (including coral disease) to provide specific accountability and adaptive feedback for climate adaptation interventions.
- Reduce sewage and pollutant releases onto the Abrolhos shelf through the construction of treatment facilities and improved wastewater infrastructure.
- Implement capacity building programs for local government, coastal and fishing communities on climate change, its likely impacts on coral reefs and dependent species in the region and the range of adaptation responses possible.

Terrestrial sources of sediment, specifically from upland erosion into streams and rivers that flow onto the Abrolhos shelf, have a major impact on the coral reefs, reducing coral resilience to the impacts of climate change. Reducing sediment flow into the coastal ocean must therefore be a priority. This will require reforestation and protection of existing forests in river corridors. Note that there are a number of regulatory and policy issues that may be obstacles to this process.

3. Strengthen coastal planning and management

Coastal planning and management in the region, including infrastructure and urban development, must explicitly incorporate climate change impacts such as potential shifts in coastline and erosion patterns, changes in storm patterns and ecosystem responses to climate change. Important components that must be addressed include:

- Establish an adaptive, ecosystem-based management system for the region.
- Protect and restore protective coastal ecosystems that stabilize coastlines (mangroves, dunes, apicum etc.)
- Identify and protect buffer areas adjacent to mangrove, apicum and other vegetation that will allow for these ecosystems to migrate inland in response to sea level rise.
- Incorporate buffer areas into infrastructure construction and urban planning along the coast to reduce the risk of erosion or flooding impacts. Reduce the presence of infrastructure and communities along coastal areas identified as vulnerable to increased erosion.
- Educate coastal managers, schools, coastal and traditional communities, tourism and fisheries communities on the likely coastal impacts of climate change.
- Ensure the full impact of engineering based adaptation actions are assessed before implementation. For example, river dredging in response to sedimentation, road construction etc. can all have unintended secondary impacts on erosion patterns.
- Implement coastal ecosystem, morphology and socio-economic monitoring programs. Ensure these are connected to management and planning in the region to ensure effective response to climate change impacts.

4. Grow the value of Forest Fragments

Forest fragments in the area can be restored and valued to provide adaptation services as climate changes. Forests in the region currently have degraded edges and are being degraded by fire. At the same time, there is little constituency for improving the condition of forest fragments, even though they provide valuable pollination benefits and water regulation. Growing the value of forest fragments involves building constituencies for their protection, especially through tourism, as well as improving the biological integrity of fragment edges.

Building forest tourism benefits the regional economy and creates a constituency interested in conservation of the forests. The tourism industry can expand its resource base by creating new offerings away from the coast. Adding tourism away from coastal and marine habitats will provide a wider range of experiences and help encourage longer tourism stays. Developing tourism revenue streams from alternative resources (e.g. national parks and forests) will strengthen the tourism sector, making it more robust to change. Widening the economic base will foster resilience to climate change by providing alternative income streams for communities currently relying primarily on resource extraction. The upcoming World Cup that will take place in Brazil is expected to bring an investment of more than 300 million dollars to be applied directly to the infrastructure of several Brazilian national parks, which can be a big push for this alternative tourism at the moment. Tourism initiatives that will build climate adaptation capacity include:

- Allowing forest tourism in National Parks
- Encouraging tourism in forests managed by indigenous communities
- Building tourism infrastructure (trails, guided activities, visitor centers)
- Promoting forest tourism linked to beach tourism in marketing campaigns
- Policies promoting construction of lodging near forest parks
- International marketing campaigns featuring forest and beach tourism

The biological integrity of forest fragments can be improved by restoring degraded edges of forest fragments. Assisted natural regeneration of areas around national parks and large fragments ensures that these forests will be less vulnerable to fires. This will maintain their value for ecotourism and ensure that they are large enough to continue to support crop pollination by native insects. “Regrowing” forest can be accomplished by:

- Creating habitat for native seed dispersers
- Planting pioneer native species
- Protecting large seed-bearing trees from fire
- Increasing fire protection budgets
- Establishing cooperative programs with neighboring landowners to control fire and create habitat for seed-dispersing native birds and mammals

Fragments around Porto Seguro should be highest priority for edge restoration and expansion, as models show animal seed dispersers in this area may decline by 2050 due to climate change (see Figure 18, Storyline 4). This means that natural seed dispersal processes can help regenerate forest edges in the near-term, but by mid-century restoring edges may have to be largely accomplished in this area by artificial restoration, which is more expensive. Priorities for restoring edges are therefore:

- Porto Seguro area forests
- Areas where forest tourism can be built on day trips from beach tourism

5. <u>Ensure freshwater availability</u>

Freshwater availability is a central concern as climate changes, despite climate model disagreement on precipitation trends and regional patterns. In the face of this uncertainty, protecting fog-intercepting upland forests is a sensible insurance policy against coastal drying. In wetter conditions, limiting siltation in municipal water supplies is the larger concern.

Payment for ecosystem services (PES) is a strategy for dealing with the erosion increases associated with a wetter future. PES mechanisms such as financial compensation for actions to increase clean water provision can encourage farmers to protect and restore gallery forests. As the percent of deforestation in the region is already extremely high, incentives to “zero deforestation” must be implemented. Those could be done, for example, through payments for carbon sequestration, which would avoid deforestation of the remaining forest fragments not currently protected by law. PES schemes should be targeted toward key erosion prevention zones, such as:

- Hillslopes
- Gallery forests
- Areas adjoining agricultural lands

Conserving upland areas that trap rainfall can maintain water availability as climate changes. The forest areas with the highest values of fog interception within our study area, especially those around the watersheds of Itanhém, Batinga and Jucuruçu rivers (Figure 22) are extremely important for securing future water provision. Modeling work shows that an area in the north of the study region has the highest percentage of the total precipitation that comes from fog inputs which provides a high percentage of the runoff in key watersheds. The legal protection of those areas is key. Elements of this strategy include:

- Identify forests vulnerable to clearing
- Acquire vulnerable forests in private ownership
- Develop conservation agreements with landowners

Protection and restoration of forested areas around municipal watersheds will maintain water availability for important cities in the region, such as Eunápolis, Porto Seguro and Prado. Forested watersheds help maintain consistency of water supply and quality in future climate, against a backdrop in which waterflow is already declining and the climate will possibly get drier. Some of the important watersheds for this adaptation action are *Mangues* and *Buranhém* as they provide water, directly or indirectly, to Porto Seguro and Eunápolis, which are among the main cities in the region. The same is true for the watershed of the Jucuruçu River that provides water to the municipality of Prado. Actions to conserve and restore these forests may pay valuable dividends in reducing reef vulnerability due to siltation as well. Actions include:

- Complete municipal forest plans
- Restore and reconnect forests

- Dialog with landowners willing to reforest
- Payment for water provision services of key parcels

Maintenance of the water table is important in water deficit areas. In areas with surface water deficit, ground water plays a key role in the maintenance of vegetation. In the south of our study area, the high water deficit may compromise the maintenance of important forest fragments, the Linhares Biological Reserve, the Sooretama Biological Reserve and the Vale Natural Reserve, and may contribute to the intrusion of salty water in the system (see storyline 5), in case ground water is not protected or properly managed. Proper land-use management in this area of water deficit, such as the use of native species rather than exotic ones (i.e. eucalyptus) and the use of water-efficient crops, are key to maintain the water table level. The communication of those findings to pulp and fiber companies is important to make sure an ideal management is done if eucalyptus needs to be planted in this particular area. Groundwater protection actions include:

- Careful planning of new tree plantations
- Adoption of water efficient crops
- Adoption of water efficient farming practices
- Use of native species for planting
- Monitoring of groundwater in sensitive areas

6. Shaded coffee

Climatic suitability for coffee is projected to decline across important coffee growing regions of the study area. The drivers of this decline are rising temperatures and, in some GCM simulations, drying. Shade coffee can be an effective adaptation mechanism, reducing microclimatic temperatures around coffee trees and helping to retain soil moisture. Early actions to promote shade coffee include:

- Establishment of nurseries for shade coffee tree species
- Developing extension and farmer-to-farmer education programs on shaded coffee

VI. Pilot Interventions

Based on the Vulnerability Assessment storylines and the adaptation recommendations, the project has designed two pilot interventions for implementation. One demonstrates improved coastal planning and coral reef protection, while the second contributes to municipal watershed protection, restoration of forest fragments and reduction of reef sedimentation through development of a municipal plan of conservation and restoration of the Atlantic forest.

Intervention 1: Adapting to climate change impacts on the coast of Ponta do Corumbau beach, Bahia.

A climate change vulnerability assessment for the Discovery Coast and Abrolhos shelf in Brazil highlighted the fragile system of coral reefs, fisheries and certain coastal communities in this region. In particular, the impacts of climate change on the coastal and marine systems will likely include the following:

- A decline in the health of the coral reefs due to changes in ocean temperature, storm frequency, wave dynamics, and by ocean acidification. These direct impacts of climate change on coral reefs will be particularly severe if the natural resilience of the reefs has been reduced through other pressures. Along the Discovery Coast, the dominant existing and future non-climate change pressures on the corals are unsustainable fisheries and elevated levels of sediment in coastal waters resulting from increased erosion from terrestrial sources (such as erosion due to deforestation) causing increased sediment loads in local rivers.
- Coastal erosion resulting from climate change-driven shifts in coastal wind and wave patterns. These shifts will have significant impacts on the biodiversity and human communities that are dependent on the coastline for their livelihoods. This impact will be exacerbated by loss of coastal ecosystems that stabilize the coastline (such as mangrove and restinga) and coastal engineering structures that change coastal sediment patterns (such as seawalls and breakwaters). Further, degradation of coral reefs will reduce their natural attenuation of waves and hence increase wave erosion on currently sheltered beaches.
- Coastal flooding resulting from sea level rise and increased storm events will impact local communities, particularly in areas with limited natural protection such as that provided by mangroves and restinga.
- A decline in near-shore fisheries is expected due to the negative impacts of increased ocean temperature and ocean acidification on coral reefs.

The impacts of climate change on the coastal and marine areas of the Discovery Coast and Abrolhos shelf will have significant impacts on the coastline and biodiversity with consequences for livelihoods across the region, including fisheries and the local tourism industry, and broadly on local human communities. A less healthy coral reef will result in less biodiversity, which would affect the local communities that rely on fisheries or on tourism as their livelihoods. Likewise, a degradation of local coral reefs may increase coastal erosion as their mediating effect on waves is reduced, which when combined with expected levels of sea level rise and changes in wave dynamics, will also impact tourism and local communities. Coastal erosion and flooding will have severe impacts on the beach-based tourism industry and communities located at the shore.

The climate change vulnerability assessment identified the communities around *Ponta do Corumbau* as some of the most vulnerable to climate change in the study area, due to their high exposure to climate variability and extreme events and due to their high dependence on coastal and marine natural resources for fisheries and coastal protection. In addition, the coastline of *Ponta do Corumbau* is highly vulnerable to coastal erosion: the adjacent *Itacolomis* coral reefs currently provide critical coastal protection by moderating oceanic waves and hence reducing erosion. This protection, however, may be reduced by climate change for the reasons outlined above.

Addressing the impacts of climate change on the coastal and marine ecosystems around *Ponta do Corumbau* and reducing the vulnerability of the communities' dependent on them will require an integrated, multifaceted approach. Based on the results of the climate change vulnerability assessment, this project has designed a program of ecosystem-based activities that will build the region's resilience and capacity to adapt to climate change. Implementation of this program in Ponta do Corumbau will initially focus on maintaining and improving the health of coral reefs, combined with activities that promote more appropriate coastal planning. Improving the coral reef health by addressing the impact of unsustainable fisheries will increase the resilience of this critical ecosystem and hence increase its capacity for coastal protection and the provision of longterm fisheries. Similarly, integrating climate change related issues into the municipal plan of protection and restoration of the Atlantic Forest, such as protection and restoration of restinga and mangrove areas, and promoting climate-smart development along the coasts, will address many of the climate change vulnerabilities identified. Through these activities, our goal is to reduce, by 2025, the vulnerability of two fishing communities to the negative impacts of climate change on fisheries and coastal protection in Ponta do Corumbau.

Among the activities that have been prioritized for maintaining or improving the health of the corals around *Ponta do Corumbau* are: a) the re-enforcement of the no-take zones in the coral reef areas, and b) awareness building among local people on climate change and the importance of coral reef health to climate change adaptation, including the role of parrotfish in maintaining coral reef health and resilience to climate change. Activities that will contribute to climate-smart coastal planning in the region include: a) the education of private owners in key areas (i.e. areas that are more vulnerable to coastal erosion such as areas adjacent to protective coral reefs) on the importance of a coastal planning for the health of corals and for the maintenance of the services they provide, and b) supporting the integration of protection or restoration of *restingas* and mangroves that stabilize sediment and mediate coastal erosion and flooding into the municipal plans of restoration and protection of the Atlantic forest. More specifically the following activities will be implemented:

1. Advocate for the inclusion of certain mangrove and restinga areas, as well as forest areas along rivers that drain into areas adjacent to coral reefs, as high priorities in the municipal plan of restoration and protection of the Atlantic forest in Porto Seguro (in Prado also if possible).
2. Support the reinstitution and the enforcement of fisheries no-take zones over the coral reefs within the Abrolhos shelf. This activity will help maintain and improve the health of the corals in no-take zones.
3. Monitor the rate of fishermen compliance with the largest no-take zones in the *Itacolomis* reefs.

4. Implement an experiment of calcification vs. bioerosion to assess the growth of the reef in no-take zones and fishing areas. This activity will allow us to test if coral growth is improved in no-take zones and hence if this action is improving coral reef health and resilience in the longterm.
5. Monitor fisheries in the region, in order to evaluate the effectiveness of the no take area and other management regimes on increasing the fish catch per unit effort.
6. Reevaluate coastal erosion or accretion in order to understand the importance of reef protection on it. This activity will allow us to address if healthy coral reefs maintain or improve coastal protection.
7. Articulate with the council of RESEX Corumbau, municipality councils, and PA Mosaic council the adoption of EbA recommendations from the vulnerability assessment in the municipality of Porto Seguro . This activity will allow us to present the results and the recommendations of the vulnerability assessment to various institutions.
8. Educate private owners established in key areas within the Ponta do Corumbau (those that are more vulnerable to coastal erosion and those that are adjacent to coral reefs) on the importance of a coastal planning for addressing climate change by mediating coastal erosion, maintaining the health of coral reefs and for the maintenance of the services reefs, mangroves and other ecosystems provide. This activity will increase awareness of private owners on the importance of coastal planning.
9. Engage the local communities of Ponta do Corumbau in the importance of adaptation in the area, and on the role of herbivorous fish (particularly parrotfish) to maintain reef health. This activity will increase the awareness of the local communities on the importance of climate change adaptation in the region and the role that herbivorous fish provide on the health of coral reefs.
10. Re-analyze the systematic conservation planning scenario for the Abrolhos region including the impacts of climate change and the recommendations identified in the vulnerability assessment

Intervention 2: Incorporation of Ecosystem-based adaptation in the Municipal Plan of Conservation and Restoration of Atlantic Forest in Porto Seguro, Bahia

This climate change vulnerability assessment highlighted the vulnerability of forested areas and water resources in the study area to the impacts of climate change. In particular, the impacts of climate change on terrestrial systems will likely include the following:

- An increase in the feedback among local climate, fire and forest fragmentation, increasing the frequency of forest fires in the future as a result of a scenario of less rainfall and high temperatures, which would generate new forest edges and more vulnerability to further burns. Climate change may further compound these effects by interfering natural forest regeneration due to the loss of seed dispersers diversity.
- A negative effect on the sustainability of the remaining fragments, regardless of their level of protection, as forest fragments are unable to buffer its interior from drying and fire. Without the sustainability of the remaining forests, many ecosystems services, such as crop pollination, will be at risk.
- Declines in water yield are expected to be more prominent along a strip in the coast from Prado to Alcobaça, from this municipality towards Nanuque, and in the mountainous areas surrounding the Alto Cariri State Park and Palmópolis, which drain to Porto Seguro's basin systems.

Those impacts of climate change on forests and water resources will have significant consequences for local communities and cities that depend on the tourism and natural resources for their livelihoods. The climate change vulnerability assessment identified the municipalities of Porto Seguro and Prado as some of the most vulnerable to the impacts of climate change. These two municipalities include the three largest national parks in the study area, which are key to providing several ecosystem services, such as fresh water provision, pollination services and ecotourism. Water supply for Porto Seguro in the future depends on the protection of the forests around key watersheds and the protection of forest located in areas of high fog interception. The population of Porto Seguro is relatively small (~ 140,000 people), but it has an 8-fold increase during the peak of the tourism season, when it reaches almost 1 million people. During this time of the year, there is an increase in water consumption, emphasizing the importance of protecting and restoring forested areas around watersheds that directly or indirectly provide fresh water to this municipality.

Addressing the impacts of climate change on forest fragments and water resources in Porto Seguro will require an approach that focuses on the protection and restoration of several key forested areas, including those around the national parks and those that are located around important watersheds that provide water to Porto Seguro. The protection and restoration of forested areas, taking into account not only the current but also future climate conditions, will be achieved through the development of a municipal plans that aim to establish guidelines and priorities for projects and public policies in the area.

By 2014, we will elaborate the Municipal Plan of conservation and restoration of the Atlantic forest in Porto Seguro, which will take into account the Ecosystem-based adaptation recommendations identified in this report. The Brazilian government encourages the municipalities to elaborate their Municipal Plan of Conservation and Recovering of Atlantic Forest (Law 11.428/06) and the goal of this plan is to establish guidelines and priorities for projects and public policies in the area, regarding this issue. The developments of those municipal plans are encouraged by the Brazilian government but none of them so far have taken climate change impacts into consideration. Therefore, the Municipal Plan of conservation and recovering of the Atlantic forest in Porto Seguro will be the first in Brazil to address climate change and to have Ecosystem-based adaptation recommendations. Examples of recommendations that we are planning to include in the Municipal Plan of Conservation and Recovering of Atlantic Forest in Porto Seguro are: 1) the protection of forested areas in watersheds that directly or indirectly provide water to Porto Seguro, 2) the assisted natural regeneration of non-forested areas around those key watersheds 3) the connection among forest fragments, and 4) the promotion of agroforestry systems and crops that are "water- efficient" in non-forested areas around those watersheds. The activities that will be conducted to develop the Municipal plan of restoration and protection of the Atlantic forest are the following:

1. Engage Porto Seguro municipal council of environment and other forums in the elaboration of Porto Seguro Municipal Plan of Conservation and Protection of the Atlantic Forest.

2. Conduct an assessment of policies and of the biophysical and socioeconomic aspects not accessed in this report, such as the identification of permanent protected area (APPs) and legal reserves, private, public and indigenous land, areas with potential for seed and seedling collection, ecological corridors, rivers and creeks, and a diagnostic of the native forest, among others.

3. Elaborate the Porto Seguro Municipal Plan of Conservation and Restoration of the Atlantic Forest with local stakeholders including, but not limited to, members of the NGOs that work in the area, managers of the protected areas, members of the governmental organizations and local communities. A participatory elaboration of the Municipal Plan will ensure that all voices and concerns will be heard.

4. Submit the plan to the Secretary of the Environment for revision.

5. Submit the plan to the City Council of the Environment for approval.

6. Support Porto Seguro municipality to apply for funds of the Atlantic Forest government grant.

VI. Conclusions

This report summarizes an assessment of the climate change vulnerability in the south of Bahia State and north of Espírito Santo State, which includes some of the most threatened tropical forests in the world which exist in juxtaposition to a rich and unusual coral reef. Forest and coral reefs provide important ecosystem services in this area, including fisheries, coastal protection, freshwater, prevention of sedimentation and crop pollination.

The adaptation recommendations presented in this report focused on Ecosystem-based adaptation (EbA), which is the use of biodiversity and ecosystem services as part of an overall adaptation strategy to help people to adapt to the adverse effects of climate change. As one of the possible elements of an overall adaptation strategy, ecosystem-based adaptation uses the sustainable management, conservation, and restoration of ecosystems to provide services that enable people to adapt to the impacts of climate change. The main recommendations identified through this vulnerability assessment process are: a) to implement adaptive fisheries management, b) to increase coral reef resilience, c) to strength coastal planning and management, d) to growth the value of forest fragments, e) to ensure freshwater availability and f) to promote shaded coffee practices. The main actions related to each one of those recommendations are described in the report.

Two potential adaptation interventions have been presented for potential implementation in the municipalities of Porto Seguro and Prado, in Bahia state. One aims to protect coastal infrastructure and improve fisheries in the face of sea level rise and changes in wave dynamics by developing activities that promote more appropriate coastal planning and by protecting offshore coral reefs. The other aims to increase resilience and reduce vulnerability of people, ecosystems and ecosystems services by adding Ecosystem-based adaptation recommendations in a municipal plan of conservation and restoration of the Atlantic Forest.

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NP: National Park
RVS: Wild life reserve
RESEX: Extractive Reserve
UF: Federal University