



Risk and Vulnerability Assessment
Methodology Development Project (RiVAMP)

Linking Ecosystems to Risk and Vulnerability Reduction

The Case of Jamaica

Results of the Pilot Assessment



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Cover photo: Berm scarp along Long Bay beach. The constrained length of scarps can indicate beach replenishment, © UNEP – October 2009

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Executive summary

Over 2.2 million people have lost their lives globally in natural hazard-related disasters (excluding epidemics) over the last three decades (1975-2008). While population growth and migration to areas of high risk, such as urban centres and coastal areas, raise the number of people affected by hazards, environmental change and degradation further contribute to disaster statistics. According to the 2009 Global Assessment Report on Disaster Risk Reduction, ecosystems degradation is one of the major drivers of disaster risk. As climate change is expected to magnify disaster risk, there is emerging global interest to better understand the role of ecosystems and environmental changes in influencing hazards and vulnerability.

Small Island Developing States (SIDS) such as Jamaica, with their limited territories and often heavily populated coastal areas, are at the front line of experiencing ecosystems decline, natural hazard-induced disasters and climate change impacts. SIDS are amongst the countries most at risk from tropical cyclones, with the highest proportion of their population exposed. Sea level rise exacerbates impacts of storm surges and flooding associated with tropical storms and cyclones. While SIDS are not major contributors to climate change, they can play a proactive role in adapting to climate change and building resilience against the impacts of natural hazards.

Efforts to reduce the impact of natural hazards often require risk information to identify potential hazards and vulnerability of human lives, livelihoods and critical assets to the damaging impacts of those hazards. Although numerous risk assessments are available, common standards and guidelines have only been recently developed. Moreover, assessment methodologies do not yet adequately identify how environmental factors influence patterns of risk and vulnerability. As a result, these assessments fail to incorporate critical aspects of risk and thus do not consider the potential of developing ecosystem-based risk reduction options.

About RiVAMP

The Risk and Vulnerability Assessment Methodology Development Project (RiVAMP) was conceived to

develop a methodology that takes into account environmental factors in the analysis of disaster risk and vulnerability. While different types of risk and vulnerability assessments are available, what is new about RiVAMP is that it recognizes ecosystems and climate change in the risk assessment process. The purpose of RiVAMP is to use evidence-based, scientific and qualitative research to demonstrate the role of ecosystems in disaster risk reduction, and thus enable policymakers to make better-informed decisions that support sustainable development through improved ecosystems management. In this regard, the targeted end-users of RiVAMP are national and local government decision makers, especially land-use and spatial development planners, as well as key actors in natural resource management and disaster management.

As a pilot initiative, the RiVAMP methodology is intended mainly for application in SIDS or coastal areas, and focuses on tropical cyclones and their secondary effects (coastal storm surges, flooding and strong winds). Accelerated sea level rise (ASLR) associated with climate change is also considered as an important factor contributing to risk of storm surges and beach erosion. The long-term view is to develop related methodologies under RiVAMP which could be applied to other types of ecosystems, namely mountains, river basins and drylands.

Jamaica as a pilot country

Jamaica was selected as the first country for the RiVAMP pilot for several reasons, including: its high vulnerability to tropical cyclones and sea level rise; diverse ecosystems and rich biodiversity which are under pressure as a result of population growth, economic development and a strong international tourism industry; high-level government commitment to hazard mitigation and climate change adaptation; and strong partners through the University of the West Indies and UNEP's Caribbean Environment Programme (CEP) based in Kingston, Jamaica.

Following a consultative process driven by the government at the national-level, Negril located in the western end of the country was chosen as the study

area for the pilot assessment. Like many coastal areas around Jamaica, Negril's natural environment is under threat from growing urban and touristic development. The results of the pilot assessment are thus applicable to other coastal, particularly tourism-dependent areas in Jamaica.

The RiVAMP methodology

The initial framework and guidance material for the RiVAMP methodology have been developed through consultations with environmental and risk assessment experts from around the world (see List of Contributors). UNEP's GRID-Europe further developed the scientific component of the methodology, building on previous work following the South Asian tsunami in 2004 and the Pakistan earthquake in 2005.

The RiVAMP assessment framework is based on measuring four key components consisting of approximately ten indicators (see Annex 1). The four main areas that are assessed include the following:

- Ecosystems and ecosystem services;
- Environmental change, as a result of human activities and climate change;
- Local livelihoods and vulnerability; and
- Environmental governance.

These four areas aim to establish a systemic understanding of human and ecological interactions, and to identify the driving causes of ecosystem degradation and the consequences to increasing hazard vulnerability and exposure. By focusing on governance, RiVAMP seeks to determine opportunities for integrating ecosystems-based approaches in land-use planning, livelihoods development, disaster risk reduction and climate change adaptation strategies.

The RiVAMP methodology combines the use of applied science, stakeholder consultations and interviews which allows for improved data triangulation, as the technical analysis is balanced with local knowledge and real experiences. The science-based component consists of satellite imagery analysis and other remote sensing techniques (e.g. use of aerial photographs), Geographic Information System (GIS) mapping and analysis, statistical analysis and modelling the buffering effects of coastal ecosystems on the coastline under conditions of sea level rise and

storm surges. Scientific analyses are complemented by stakeholder consultations that have been undertaken at the national and parish levels and in two selected communities in Negril, namely Whitehall and Little Bay. (Further details on the pilot assessment process are provided in Annex 2).

This report details only the findings and results of pilot-testing the RiVAMP methodology in Jamaica. A separate publication of the RiVAMP methodology which provides a detailed, step-by-step guide on how to apply the methodology will be released, following a formal evaluation of the pilot in May 2010.

Practical decision support outputs

Specific outputs generated from the RiVAMP pilot in Jamaica include the following:

- Satellite imagery analysis to determine the distribution of coastal ecosystems, specifically coral reefs and sea grasses, and to estimate beach erosion in Negril over the last 40 years;
- Hydrodynamic modelling using different offshore wave regimes (i.e. local wind waves, swell waves and extreme storm conditions) and sea levels to study the effects of coral reefs on shoreline protection;
- Statistical analyses (using multiple regressions) to establish the correlation between coral reefs and sea grasses and beach erosion, taking into account other factors (i.e. beach slope and nearshore wave regime) that may influence beach loss;
- Estimations of future scenarios or risk of beach erosion in Negril under rising sea levels and worsening storm conditions in the region;
- A theoretical model of exposure to storm surges and associated flooding in Negril based on a 10 and 50-year return storm period;
- Local community-generated maps to illustrate environmental degradation over the past 40 years and the corresponding increase of vulnerability to floods and storm surges, which validate the scientific analyses; and

- Reports of the national, parish and community-level workshops that provide an overview of ecosystem benefits, and the major drivers of ecosystem degradation as well as proposed solutions.

Key findings

- 1. Ecosystems provide important services that support economic development, local livelihoods and hazard mitigation, but they are under significant threat from both natural and anthropogenic (or human-induced) sources.** Major types of ecosystems include coral reefs, coastal vegetation such as sea grasses, mangroves, sand dunes and other types of beach vegetation, wetlands (peatlands), and forests. Each of these ecosystems is in overall decline in Jamaica, particularly in Negril. External drivers of ecosystem degradation include the increasing frequency and intensity of tropical storms and cyclones in the region that can cause major environmental damage, rising sea levels and ocean water temperatures due to climate change and variability, and invasive species. Human activities in Jamaica that contribute to ecosystem degradation primarily include land-based sources of pollution associated with crop cultivation, urbanization and coastal and touristic development.
- 2. Coastal ecosystems, particularly coral reefs and sea grasses, play a crucial role in supplying beach sand material and protecting the shoreline.** Hydrodynamic modelling illustrates that coral reefs attenuate or dissipate nearshore wave energy and thus mitigate against beach erosion. On the other hand, sea grasses are a major source of beach sand supply in Negril. The observed rate of maximum beach erosion from 1968-2008 was found to be negatively correlated with the width of coral reefs and dense sea grass meadows. This means that beach areas shielded by coral reefs and thick sea grasses experienced less erosion, suggesting that these ecosystems provide protection to the beach. The degradation of nearshore ecosystems will therefore result in a diminished beach sediment supply, as well as increased vulnerability to beach erosion and storm surges caused by tropical storms and cyclones.
- 3. Ecosystems degradation is a contributing factor to increased local hazards to flooding and storm surges.** Deforestation as a result of urbanization and housing development has increased flooding downhill affecting several sections of the Whitehall community. Hurricane impact on coral reefs, illegal sand mining activities and unsustainable resource use (e.g. destructive fishing practices, removal of mangroves, sea grasses and other types of coastal vegetation, and agricultural runoff) have contributed to beach degradation and increased storm surge hazards in Little Bay.
- 4. Scientific evidence shows that over the past 40 years, Negril's beaches have been experiencing severe and irreversible shoreline erosion and retreat.** Bloody Bay in the northern section of Negril has experienced lower erosion rates than Long Bay, with sections of Long Bay beach without coral reef cover showing higher rates of erosion. The highest erosion rates have occurred after 1991, when beach recovery after storms has been slower, and these trends are likely to continue. It is expected that long-term sea level rise, changing patterns of tropical storms and cyclones in the region (in terms of both frequency and intensity), diminishing sand supplies due to coastal ecosystem degradation as well as coastal development will exert an even higher toll on Negril's beaches.
- 5. Estimations based on global projections of long-term or accelerated sea level rise (ASLR) together with local predictions of extreme storm waves and surges show that, by 2060, the combination of ASLR and extreme wave surges will have a devastating impact on Negril's beaches and the coastal infrastructure behind it.** Even under the lowest projections of ASLR for 2060, an extreme event (i.e. the 50-year return storm) will result in the total loss of approximately 35 percent of the beach (in terms of length), while another 50 percent of the beach will lose more than half of its present width.
- 6. Taking into account sea level rise, exposure to storm surges and subsequent flooding are expected to put approximately 2,500 people or 14 percent of the total coastal population at risk during a 50-year return storm event,** affecting mainly the Long Bay coastline, the Great Morass environment, the West End cliffs and the New Savannah River area.

7. **Ecosystems degradation, coupled with beach erosion and the increasing impacts of tropical cyclones, may over time undermine resource-dependent livelihoods, such as fishing, farming and tourism, which are vital to the local and national economy.** For instance, declining fish stocks in Little Bay over the past decade have forced many women and men out of the fishing sector, contributing to unemployment or underemployment and thus an overall reduction in household income. The tourism sector has provided *the* main source of alternative employment, but this sector is equally vulnerable to worsening environmental and climatic conditions. Ongoing beach erosion in Negril will therefore continue to have drastic impacts on local livelihoods as well as the overall economy.

Proposed way forward

Given the importance of ecosystems to shoreline protection and livelihoods and taking into account the expected climatic changes, a “business as usual” approach is no longer viewed as a viable option. Significant corrective measures are required to avert not only the destruction of coastal ecosystems and infrastructure, but also to protect a critical resource that supports Jamaica’s vital tourism industry. UNEP recommends that a longer-term strategy and integrated approach is necessary to establish a more sustainable development course in Negril.

Establishment of a comprehensive, cross-sectoral Negril Development and Management Plan should be a priority. The plan would guide the development of the area by establishing a framework that takes into account disaster risk and climate change and includes the critical role of ecosystems. The plan would inform land-use planning and development of infrastructure, housing and commercial buildings, thereby mainstreaming environmental and disaster risk management into local development planning processes.

An integrated strategic environmental assessment (SEA) process would provide the initial basis for establishing the development framework, which should be informed by a comprehensive understanding of the current status of ecosystems, disaster risk patterns and trends as well as the multiple stakeholders who need to be involved at the various levels (national, parish and community) including government, civil society, academia and the private sector.

Based on stakeholder consultations, three main pillars would constitute the Negril Development and Management Plan: strengthening environmental governance, identifying ecological-based solutions for risk reduction, and promoting environmental education for effecting behavioural change and local actions.

Priority areas for action include the following:

- Initiate a multi-stakeholder, integrated SEA process to establish a sustainable development framework for the Negril area;
- Restore and rehabilitate coastal ecosystems, particularly coral reefs, sea grasses and other types of coastal vegetation, as a strategy for risk and vulnerability reduction and climate change adaptation;
- Assess and develop capacities of national and local authorities in mainstreaming environmental and disaster risk management in land-use and development planning;
- Develop alternative employment opportunities and skills that support sustainable resource management; and
- Enhance environmental awareness of beach dynamics and the role of ecosystems in beach protection and hazard mitigation, targeting vulnerable communities and the private sector.

The full list of proposed recommendations is summarized in Table 1, which are based on inputs from stakeholders who participated in national, parish and community-level workshops conducted during the RiVAMP pilot. Suggested recommendations should be regarded as a starting point for establishing meaningful dialogue between a broad range of stakeholders and defining future development in Negril.

In conclusion, the RiVAMP pilot exercise has shown that a more comprehensive methodology for risk and vulnerability assessments can factor in ecosystem and climate change concerns, based on an evidence-based approach utilizing applied science and local knowledge and experience. RiVAMP can thus feed into development planning processes at the local and national-levels and help construct a more risk-sensitive and environmentally sustainable development path.

Table 1. Summary of proposed recommendations, as suggested by stakeholders at national, parish and community-level workshops

1. Strengthening environmental governance	
1.1.	Re-examine, update and revise environmental policy and legislative frameworks
(i)	Develop a combination of positive incentives (e.g. tax breaks, rewards) together with enforcement to achieve greater compliance
(ii)	Ensure that environmental impact assessments (EIAs) incorporate hazard and risk information and result in the enforcement of recommendations
(iii)	Incorporate the cost of environmental damages in post-disaster assessments to ensure that environmental protection and recovery is considered in overall plans for disaster response
1.2.	Integrate multiple hazard and environmental assessments as part of land-use planning and zoning
(i)	Reassess current setbacks to establish a more adequate buffer zone between the beach and coastal infrastructure
(ii)	Better enforce land-use regulations to discourage illegal housing settlements
(iii)	Mainstream local disaster plans into local development and land-use plans
1.3.	Clarify institutional mandates and minimize potential for overlap
1.4.	Empower and strengthen capacities of local authorities in environmental management, development planning (including land-use and zoning) and disaster risk management
(i)	Provide additional human, technical and financial resources to improve overall governance
(ii)	Ensure that a portion of the tourism revenue (e.g. Tourism Enhancement Fund) is used for ecosystem maintenance and support of sustainable livelihood activities
(iii)	Establish strong government accountability mechanisms through broader stakeholder participation in decision-making processes
1.5.	Strengthen cross-sectoral, multi-stakeholder mechanisms for collaboration and coordination
(i)	Establish a common institutional platform that can bring together stakeholders across various sectors (e.g. agriculture, fishing, tourism) at different levels (national, parish and community)
(ii)	Strengthen existing multi-stakeholder mechanisms, such as the Negril Area Environmental Protection Trust (NEPT) and the Negril Green Island Area Land Planning Authority (NGIALPA)
2. Identifying ecological-based solutions for risk reduction	
2.1.	Apply a “hills-to-oceans” approach to address root causes of ecosystem degradation and mainstream within the wider context of development planning
2.2.	Utilize applied scientific research to inform policies and actions
(i)	Use science-based models as well as environmental vulnerability assessments to provide trends regarding emerging threats to the environment, including climate change and sea level rise projections
(ii)	Apply scientific analysis to maximize the risk reduction functions of ecosystems
(iii)	Balance the use of scientific information with local knowledge and priorities
2.3.	Apply cost-benefit analyses to balance competing stakeholder interests
2.4.	Develop alternative employment opportunities and skills to support sustainable resource management (For specific recommendations pertaining to each ecosystem, see Table 3 in Section 6).
3. Promoting environmental education for effecting behavioural change and local action	
3.1.	Initiate a public education campaign in Negril to raise local understanding of beach dynamics and the role of ecosystems in beach protection and hazard mitigation
(i)	Target multiple groups including fishers, hoteliers, watersports and dive operators, tourists, farmers, students, youth and local government authorities as well as vulnerable communities
(ii)	Develop tailor-made communication tools and materials, including multiple forms of media to reach a wider audience
(iii)	Channel tourism revenue to support environmental education initiatives

Acronyms and abbreviations

ASLR	Accelerated sea level rise
CARICOM.....	Caribbean Community
CARIFTA	Caribbean Free Trade Association
CBO	community-based organization
CCA	climate change adaptation
CDEMA.....	Caribbean Disaster Emergency Management Agency, formerly known as the Caribbean Disaster Emergency Response Agency (CDERA)
CLOD	coralline algae lethal disease
CRED.....	Centre for Research on the Epidemiology of Disasters
CWBS.....	Coralline White Band Syndrome
DEPI.....	Division of Environmental Policy Implementation
DEWA	Division of Early Warning and Assessment
DRR	disaster risk reduction
EIA	environmental impact assessment
EM-DAT	Emergency Events Database
EPA	Environmental Protection Area
FAO	Food and Agriculture Organization
GAR.....	Global Assessment Report
GDP.....	gross domestic product
GEF	Global Environment Facility
GIS	Geographic Information System
GPS	Global Positioning System
GRID-Europe	Global Resource Information Database-Europe
ha	hectares
HDI	Human Development Index
HFA.....	Hyogo Framework for Action
IBR.....	Inverse Barometric Pressure Rise
IWCAM	Integrated Watershed and Coastal Areas Management
IPCC.....	Inter-governmental Panel on Climate Change
IUCN.....	International Union for the Conservation of Nature
J\$.....	Jamaican dollars
km.....	kilometre
km ²	square kilometre
m	metre
m ³	cubic metre
mm.....	millimetres
MSL.....	Mean Sea Level
NCRPS	Negril Coral Reef Preservation Society
NGIALPA	Negril Green Island Area Land Planning Authority
NEPA.....	National Environment and Planning Agency
NEPT	Negril Area Environmental Protection Trust
NGO.....	non-governmental organization
NWC.....	National Water Commission
ODPEM.....	Office of Disaster Preparedness and Emergency Management
PCJ.....	Petroleum Corporation of Jamaica
PIOJ.....	Planning Institute of Jamaica
PREVIEW.....	Project for Risk Evaluation, Vulnerability, Information and Early Warning
RIVAMP	Risk and Vulnerability Assessment Methodology Development Project
SCCAR	Saffir-Simpson Categories
SEA	strategic environmental assessment
SIDS	Small Island Developing States
SMHW	mean high water on springs
SSCat	Saffir-Simpson Category
SWI	Smith Warner International
TEF.....	Tourism Enhancement Fund
UDC.....	Urban Development Corporation
UNDP	United Nations Development Programme
UNEP.....	United Nations Environment Programme
UNEP-CEP	UNEP Caribbean Environment Programme
UNEP ROLAC.....	UNEP Regional Office for Latin America and the Caribbean
UNFCCC	United Nations Framework Convention on Climate Change
UNISDR	United Nations International Strategy for Disaster Reduction
USAID.....	United States Agency for International Development
USD.....	United States dollar
UWI.....	University of the West Indies
yrp.....	year-return-period

Glossary of terms

Bathymetry: Bathymetry is the study of underwater depth. A bathymetric map or chart usually shows floor relief or terrain as contour lines (called depth contours or isobaths).

Beach morphodynamics: Beach morphodynamics refers to the study of the interaction and adjustment of the seafloor topography and fluid hydrodynamic processes (i.e. waves, tides and wind-induced currents) and the sequences of change involving the motion of sediment (i.e. beach sands). While hydrodynamic processes respond instantaneously to morphological change, morphological change requires the redistribution of sediment.

Climate change: The United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as change that can be attributed “directly or indirectly to human activity and that alters the composition of the global atmosphere, which is in addition to natural climate variability observed over comparable time periods”. However, scientists often use the term for any change in the climate, whether arising naturally or from human causes. Each of these perspectives is relevant. There is now strong evidence of increases in average global air and ocean temperatures, widespread melting of snow and ice and rising average global sea levels. Climate change is expected to impact on vital sectors, namely water, food production and health, as well as contribute to extreme weather events.

Disaster risk: The potential significant losses, in lives, health status, livelihoods, assets and services, which could occur to a particular community or a society over some specified future time period. Risk is often described as a result of the combination of: the exposure to a hazard, the conditions of vulnerability that are present, and insufficient capacity or measures to reduce or cope with the potential negative consequences.

Hazard: A hazard is a dangerous phenomenon, substance, human activity or condition that may cause loss of life, injury or other health impacts, property damage, loss of livelihoods and services, social and economic disruption, or environmental damage. There are different types of hazards: natural hazards, technological and biological hazards. Natural hazards are natural processes or phenomena, such as earthquakes, droughts and tropical cyclones, that may constitute a damaging event, but their occurrence and scale of impact are often influenced by human-induced activities as a result of inappropriate land use, poor building codes and environmental degradation.

Ecosystem services: An ecosystem is a dynamic complex of plant, animal and micro-organism communities, and the non-living environment interacting as a functional unit. Ecosystem services are the conditions and processes through which natural ecosystems, and the species that compose them, sustain and fulfil human life. These include “provisioning services” such as food, water, timber and fibre; “regulating services” that affect climate, floods, disease, wastes and water quality; “cultural services” that provide recreational, aesthetic, and spiritual benefits; and “supporting services” such as soil formation, photosynthesis and nutrient cycling.

Environment: The environment is the sum of all external conditions affecting the life, development and survival of an organism. Environment refers to the physical conditions that affect natural resources (climate, geology, hazards) and the ecosystem services that sustain them (e.g. carbon, nutrient and hydrological cycles).

Exposure: People, property, systems, or other elements present in hazard zones that are thereby subject to potential losses. Measures of exposure can include the number of people or types of assets found in hazard zones.

Groyne: In the context of coastal engineering, a groyne is a rigid hydraulic structure built from an ocean shore that interrupts water flow and limits the movement of sediment. In the ocean, groynes create beaches or avoid having them washed away by longshore drift. Ocean groynes run generally perpendicular to the shore, extending from the shoreline or beach into the water. Groynes may be submerged or seen above water, and generally made of wood, concrete or rock piles.

Natural resources: Natural resources are actual or potential sources of wealth that occur in a natural state, such as timber, water, fertile land, wildlife and minerals. A natural resource qualifies as a renewable resource if it is replenished by natural processes at a rate comparable to its rate of consumption by humans or other users. A natural resource is considered non-renewable when it exists in a fixed amount, or when it can not be regenerated on a scale comparative to its consumption.

Resilience: The ability of a system, community or society exposed to hazards to resist, absorb, accommodate and recover from the effects of a hazard in a timely and efficient manner that minimizes hazard impacts and contributes to reducing risk and vulnerability.

Vulnerability: The characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard. Vulnerability is the result of the whole range of economic, social, cultural, institutional, political and even psychological factors that shape people's lives and create the environment that they live in. In other words, defining vulnerability also means understanding the underlying factors or root causes of vulnerability.

Section 1. Introduction

1.1 Background

Over 2.2 million people globally have lost their lives in natural hazard-related disasters (excluding epidemics) over the past three decades (1975-2008).¹ In the same period, associated economic losses were USD 1,527.6 billion, with developing countries bearing most of the cost. Population growth and migration to areas of high risk (e.g. coastal areas, drylands and urban centres) are raising the numbers of those affected by hazards - turning hazards into disasters. More and more infrastructure is built in areas that are exposed to natural hazards, setting up development investments to be overturned by disasters.

Environmental degradation contributes to the above statistics. The Global Assessment Report (GAR) 2009 identified ecosystems decline as one of the major drivers of risk. This conclusion echoes the internationally agreed Hyogo Framework for Action (HFA) which identified ecosystems degradation as an underlying risk factor. Degraded ecosystems can exacerbate the impacts of natural hazards

and contribute directly to disaster risk. For instance, deforested hillsides can result in flash floods and landslides. On the other hand, natural hazards can cause direct damage to the environment, preventing access to critical resources such as water, food, fuel and shelter, thus increasing vulnerability to hazard impacts.

The role of ecosystems in disaster reduction

The reduction of disaster risk is one of the most undervalued services provided by healthy, functioning ecosystems such as wetlands, forests and coral reefs. Since the South Asian earthquake and tsunami in 2004, there has been increased international awareness of the importance of ecosystem management for protecting populations and infrastructures against extreme events. Ecosystems can serve as natural buffers or protective barriers, for instance through flood abatement, slope stabilization and coastal protection against storm surges. At the same time, ecosystems increase coping capacities of communities against hazard impacts



Following the South Asian tsunami in 2004, concerted efforts, such as this UNEP project in Sri Lanka, to restore mangroves have been undertaken to provide coastal communities with additional natural buffers against small-scale tsunamis, tropical cyclones, storm surges and strong winds, as well as to support local livelihoods

by providing for basic needs and supporting livelihoods. For example, coral reefs and mangroves can reduce impact of storm surges by dissipating wave energy, while providing natural habitats for replenishing fish stocks as well as fuelwood and building materials in the case of mangroves.

Climate change

Climate change will further magnify disaster risk. There is major concern that increased frequency and intensity of extreme hydro-meteorological events will result in a corresponding increase in the number or magnitude of disasters. Over the last two decades (1988-2007), 76 percent of all disaster events were hydrological or meteorological in nature, accounting for 45 percent of the total deaths and 79 percent of total economic losses caused by natural hazards.² Moreover, climate change will affect underlying drivers of vulnerability, such as food insecurity, declining ecosystem services and new patterns of migration, and therefore increase risk.

According to the Inter-governmental Panel on Climate Change (IPCC) Fourth Assessment Report (2007), the intensity of tropical cyclones is likely to increase with climate change. Tropical cyclones generate multiple hazards, such as strong winds, coastal storm surges and heavy precipitation resulting in floods and landslides. With sea level rise, climate change will intensify storm surges and increase coastal erosion.

Small Island Developing States (SIDS) with their limited territories and low elevation are at the front line of climate change impacts. SIDS are amongst the countries most at risk from tropical cyclones.³ According to the GAR (2009), SIDS have the highest proportion of their population exposed to tropical cyclones and related hazards, experiencing a far greater relative exposure to highly destructive Category 3 and 4 storms. In terms of economic exposure, countries with the highest relative exposure are almost all SIDS, with small economies that inhibit their ability to absorb economic shocks generated by disasters including those induced by weather-related hazards.

While SIDS are not major contributors to climate change and there are limited options for them to reduce greenhouse gas emissions, they can

be much more proactive in adapting to climate change and mitigating against its impacts by addressing underlying risk factors which include environmental degradation. Ecosystems provide vital resources that SIDS depend on for basic needs, jobs and economic growth, yet many SIDS continue to experience significant ecosystems decline, especially of coral reefs, wetlands, sea grasses and forests. Ecosystems degradation is reducing SIDS' natural protective barriers and its major sources of livelihood, as they become increasingly vulnerable to hydro-meteorological hazards and sea level rise in a changing global climate.

Assessing disaster risk

International efforts, guided by the internationally agreed Hyogo Framework for Action (HFA), are working to reduce vulnerability to natural hazards through a broad range of interventions, including among others early warning systems, preparedness planning, land-use planning and better ecosystems management. Most of these efforts are guided by risk information that identifies the potential natural hazards and the extent to which lives, livelihoods and critical assets are vulnerable to the damaging impacts of those hazards.

Although numerous risk assessment methodologies are available, efforts to develop common guidelines and standards have only recently begun. Moreover, assessment methodologies do not yet adequately identify the changes to risk and vulnerability that is attributable to environmental change, including ecosystems degradation and climate change. As such, these assessments fail to identify critical aspects of risk and vulnerability, and as a result do not provide sufficient information for developing ecosystem-based risk reduction options.

The question, however, remains whether ecosystems can provide effective protection against extreme events and support adaptation to climate change. Scientific-based research that links ecosystem services with risk reduction and adaptation remain limited, yet this information is vital to inform and influence policies and decisions that affect development, the environment and risk management. Further evidence is still needed to demonstrate that better ecosystems management can reduce vulnerability through effective hazard mitigation and livelihood sustainability.



Once a small fishing village, Negril is famous for its white sand beaches and laid-back atmosphere

1.2 Purpose and scope of RiVAMP

The Risk and Vulnerability Assessment Methodology Development Project (RiVAMP) seeks to develop an assessment methodology that takes into account environmental parameters in the analysis of disaster risk and vulnerability. It is targeting national and local government policymakers and decision makers, especially land-use and spatial development planners and key actors involved in environmental management and disaster management. Specifically, RiVAMP provides national and local decision makers with an evidence-based assessment tool to help them make informed choices that reduce risk and support sustainable development through improved ecosystems management.

What is new about this assessment tool is that it takes into account environmental factors, including ecosystems degradation and climate change, as a key component in the risk assessment process. The idea is to demonstrate how ecosystems contribute towards reducing risk and vulnerability, in addition to other benefits such as supporting local livelihoods and protecting biodiversity. The information generated could then be used to advocate for the enhancement and maintenance of ecosystems for sustainable development.

As a pilot initiative, RiVAMP has developed a methodology that is applicable to SIDS or coastal environments and focuses on tropical cyclones and their secondary effects (coastal storm surges, flooding, strong winds and landslides). However, the long-term perspective is to develop related methodologies under RiVAMP which could be applied in other ecosystems, namely mountains, river basins (including low-lying deltas) and drylands.

The RiVAMP methodology combines the use of applied science and stakeholder consultation processes which allows for improved data triangulation, balancing the technical analysis with stakeholder perspectives and experiences. The technical component consisted of remote sensing analysis, Geographic Information System (GIS) mapping, and modelling the effects of coral and sea grass on the coastline under rising sea level conditions and storm surges. The science-based analysis is complemented by stakeholder interviews and consultation workshops.

This report details the findings and results of pilot-testing the RiVAMP methodology in Jamaica. A separate publication of the RiVAMP methodology which will provide detailed, step-by-step guidelines on how to apply and replicate the methodology is scheduled to be released shortly.

1.3 Jamaica as a pilot country

Jamaica was selected as the first country for the pilot for several reasons. A high coastal population density coupled with frequent meteorological hazards, particularly tropical cyclones, make the country highly exposed to disasters. As a small island state, Jamaica is also highly exposed to sea level rise which could exacerbate the secondary impacts of tropical cyclones along the coast. At the same time, Jamaica's diverse ecosystems and rich biodiversity co-exist with a dynamic international tourism industry and growing population, exerting heavy development pressures on the natural environment. In this regard, RIVAMP provides an opportunity to feed into decision-making processes at national and local levels with respect to sustainable coastal development and risk reduction. Finally, UNEP's Caribbean Environment Programme (CEP) based in Kingston and the Regional Office of Latin America and the Caribbean (ROLAC) could offer important project support and guidance on maximizing project results.

It was necessary to focus on a defined study area within Jamaica in order to limit the amount of data required for the analysis. After a consultative process with several national government agencies, Negril located in the western end of the country was selected. Like many coastal areas around Jamaica, Negril's natural environment is under threat from growing urban and tourism develop-

ment. The results of the pilot and insights gained from stakeholder consultations, therefore, also remain applicable to other coastal, tourism-based areas in Jamaica.

During the first UNEP mission in July 2009, beach erosion in Negril was highlighted by the national government as an urgent priority and hence became a major focus of the RIVAMP assessment. As a result, the project team focused on coastal ecosystems, particularly coral reefs and sea grasses. While other important ecosystems such as mangroves and peatlands (wetlands) were found in the study area, the lack of readily available data resulted in their exclusion from the technical analysis. However, some key information on mangroves and peatlands was obtained through stakeholder consultations and the few available reference materials provided by national agencies.

The project examined the impacts of tropical cyclones, particularly storm surges and flooding, as well as the potential impacts of climate change under rising sea level conditions. Environmental features were analyzed to determine the extent to which coral reefs and sea grasses serve as a natural protective barrier by protecting shorelines against storm surges and sea level rise. Satellite imagery analysis, modelling and GIS mapping supported this analysis. On the other hand, stakeholder consultations at the national and parish levels and in two selected communities focused on understanding linkages between ecosystems, drivers of ecosystem



Protruding cliffs in the West End section of Negril also attract tourists for the stunning ocean views and sunsets

degradation and socio-economic vulnerability. Annex 2 describes the pilot assessment process and Annex 3 provides further details on the methodology used for the technical analyses.

1.4 Timeline for the RiVAMP Project

The project comprised of three sequential core activities:

1. Development of the assessment tool and guidance material (February – June 2009)

To initiate the process, a brainstorming exercise within UNEP was held in February 2009 to determine the scope and approach in developing the assessment tool and guidance material. Scientific and operational partner organizations and networks were identified to provide guidance and technical inputs in project development. In May 2009, an Expert Group meeting was convened in Geneva, Switzerland, to agree on the methodological requirements (namely data sets, scale, etc.) and design a pilot study. Discussion outputs from the meeting provided the basis for drafting the assessment methodology to be pilot tested in Jamaica.

2. Pilot-testing the RiVAMP methodology (July – November 2009)

Field-testing of the RiVAMP methodology comprised two major missions to Jamaica. A scoping mission took place in July 2009 primarily to introduce the project in the country, identify an implementing partner to coordinate project activities, select a study area, and initiate data collection. Also during the scoping mission, a Project Advisory Group represented by national agencies involved in disaster management, environment and other major development sectors (water, urban development, etc.) was established to provide guidance and feedback on the pilot process and results.

A follow-up mission in October-November 2009 represented the core field component of the project. Over a three-week period, stakeholder consultations at the national and parish levels and in the selected communities of Whitehall and Little Bay in Negril were undertaken. Additional interviews and meetings with key actors including from various government agencies, the United Nations Develop-

ment Programme (UNDP) and the private sector were organized.

Results from the pilot have been consolidated into a final report which will be presented in Kingston and Negril (scheduled in March 2010). Presentation of the final report will provide a further opportunity to validate results.

3. Document finalization and next steps (March – May 2010)

Based on lessons learned from the pilot assessment, UNEP will finalize the assessment methodology into a guidance document. Both the guidance document and final report of the pilot assessment will be peer reviewed and revised accordingly.

A follow-up strategy for Jamaica will be prepared to act on proposed recommendations of the pilot assessment. Other partners in Jamaica and in the region involved in similar activities will be consulted for possible collaboration.

1.5 Partners involved

RiVAMP is a project implemented by the United Nations Environment Programme (UNEP) in collaboration with the Government of Jamaica, represented by the Planning Institute of Jamaica (PIOJ). Within UNEP, the Division of Environmental Policy Implementation (DEPI) and the Division of Early Warning and Assessment (DEWA)-GRID Europe have been the main partners involved from the outset in project formulation and implementation. The UN International Strategy for Disaster Reduction (UNISDR) Secretariat based in Geneva, Switzerland, also contributed to the conceptual development of the project. At the country-level, the Planning Institute of Jamaica (PIOJ) has been instrumental in mobilizing key national agencies to contribute to the process and coordinating stakeholder workshops and the fieldwork component of the project.

1.6 Report structure

This report is divided into four following sections:

1. An introductory section providing background information about the country;
2. Key findings based on the scientific analysis and

stakeholder consultations:

- (i) Ecosystem services and major drivers of degradation;
 - (ii) Linking ecosystems and shoreline protection; and
 - (iii) Linking ecosystems, livelihoods and vulnerability,
3. Proposed solutions describing general recommendations for Negril on how to support sustainable coastal development for disaster risk reduction and climate change adaptation;
 4. Annexes.



National consultations with government stakeholders held in Kingston (October 2009)

Section 2. Country context

2.1 National context

Jamaica is an island state located in the Caribbean Sea, between latitude 17.7° to 18.5° North and longitude 76.2° to 78.4° West. Spanning a land area of approximately 11,000 square kilometres (km²) with territorial waters of 16,000 km², Jamaica is about ten times smaller than Cuba, its nearest neighbour. It is approximately 82 km wide and 234 km long, with 1,022 km of coastline.

When Christopher Columbus landed on the island in 1494, most of it was covered with dense forests, except for scattered clearings occupied by the Taínos, an indigenous seafaring tribe who originated from South America and settled in the Bahamas and the Greater Antilles. They named the island *Xaymaca* which means the “Land of Wood and Water”.

Population

Initially a Spanish territory, Jamaica became a British colony in 1655 and finally gained full independence in 1962. It is the largest English-speaking island in the Caribbean. With approximately 2.7 million people in 2009, Jamaica is the third most populous Anglophone

country in North America, after the United States and Canada. The annual population growth has remained consistently below one percent since 1998.

The majority of Jamaica’s population are descendants of African slaves imported by the British to drive its sugarcane plantation industry. As a result of Jamaica’s colonial heritage, many Jamaicans speak an English-African creole known as *Patois*, though English remains the official language. There also remain descendants of indentured servants of Chinese and Indian origin who were also imported under British rule. Other ethnic groups include Jews, Lebanese and Syrians.

Approximately 82 percent of the population lives along the coastline, within five kilometres of the coast. The rate of urbanization is approximately 52 percent. Kingston is the country’s capital and the largest city in Jamaica, with a population of almost one million inhabitants residing in the larger Metropolitan Area.

Topography and climate

Jamaica’s topography consists mostly of mountains, surrounded by a narrow, discontinuous coastal plain. The highest point of the island is the Blue Mountain Peak at 2,256 metres above sea level.

Map 2.1 Jamaica and the wider Caribbean region





The Swamp Cabbage Palm (*Roystonea princeps*) is endemic to the island and a protected species found in the Royal Palm Reserve in Negril

The country has a tropical maritime climate. Mean daily temperature ranges from a seasonal low of 26° Celsius in February to a high of 30° in August. On average, the temperature shifts by 2° Celsius with every 300 metre change in altitude.

Precipitation regimes vary seasonally and spatially. Long-term mean annual rainfall is about 2,000 millimetres (mm). The heaviest rainfall is concentrated over the Blue Mountains which receive over 5,000 mm of rain annually, whereas Kingston receives less than 762 mm.

The country has a marked bi-modal pattern in mean annual rainfall, with the heaviest rainfall occurring from May-June and then again from October-November or December. Drier months are in January-March and in July. Kingston lies on the drier part of the island; therefore, rainfall is intermittent and usually short in duration with heavy precipitation. Tropical storms and hurricanes (tropical cyclones) usually occur between May and November.

A biodiversity hotspot

Jamaica is recognised internationally for its biodiversity and its high levels of endemism with flora and fauna species that are native or confined to the island. It ranks fifth in the world for island endemic plant species. There are more than 800 flowering plant species, over 500 species of land snails, more than 50 species of amphibians and reptiles, five bat species, 28 bird species and 19 butterfly species that are endemic to the island. Jamaica is an important contributor to biodiversity in the Caribbean Basin, which has the fifth highest concentration of endemic species out of the eight “hottest hot spots” on Conservation International’s list of biodiversity hot spots.¹ On the other hand, Jamaica ranks as number six on the International Union for the Conservation of Nature (IUCN) Red List for mammals at risk of extinction.

The following are the five main types of ecosystems found in Jamaica: coral reefs, sea grasses, mangroves, forests and wetlands (peatlands). Despite their important contribution to the local and national economy, each of these ecosystems is under threat mainly from human activities and developmental pressures as well as natural hazards (tropical cyclones), sea level rise and global warming. Ecosystems and the main drivers of ecosystem decline are discussed in greater detail in Section 3.

Table 2.1 IUCN Red List category summary for Jamaica²

Number of animal species											
EX	EW	Subtotal	CR	EN	VU	Subtotal	LR/cd	NT	DD	LC	Total
6	0	6	19	18	34	71	0	31	34	257	399
Number of plant species											
EX	EW	Subtotal	CR	EN	VU	Subtotal	LR/cd	NT	DD	LC	Total
2	0	2	40	53	116	209	0	73	5	1	501

IUCN Red List Categories: DD – Data Deficient, EX - Extinct, EW - Extinct in the Wild, CR - Critically Endangered, EN - Endangered, VU - Vulnerable, LR/cd – Lower Risk

Natural hazard profile

Natural hazards in Jamaica comprise of two following categories: *hydro-meteorological*, namely tropical cyclones or hurricanes, floods including those combined with landslides and mudflows, drought and fires; and *geological*, namely earthquakes, landslides and tsunamis.

(i) Hydro-meteorological hazards: hurricanes, floods, drought and fires

Jamaica lies in the hurricane belt of the Atlantic Ocean, and as a result, the island has suffered human losses and significant storm damage, particularly in relation to built infrastructure, the environment and agricultural sectors. The four main recent events were Hurricanes Gilbert in 1988 (category 3) and Ivan in 2004 (category 4) and tropical storms Dean and Gustav in 2007 and 2008, respectively.

Floods can occur all year round, although they are more frequent during heavy storms and the hurricane season. Lowland plains and valleys are the regions most exposed. Steep and rugged topography has meant that flash floods are common and frequently linked with landslides. Many of the disastrous flood events were in fact sediment flows as a result of heavy rainfall. For instance, Hurricane Gilbert in 1988 triggered an unprecedented num-

ber of landslides, which was also due partly to the extensive deforestation on steep slopes.

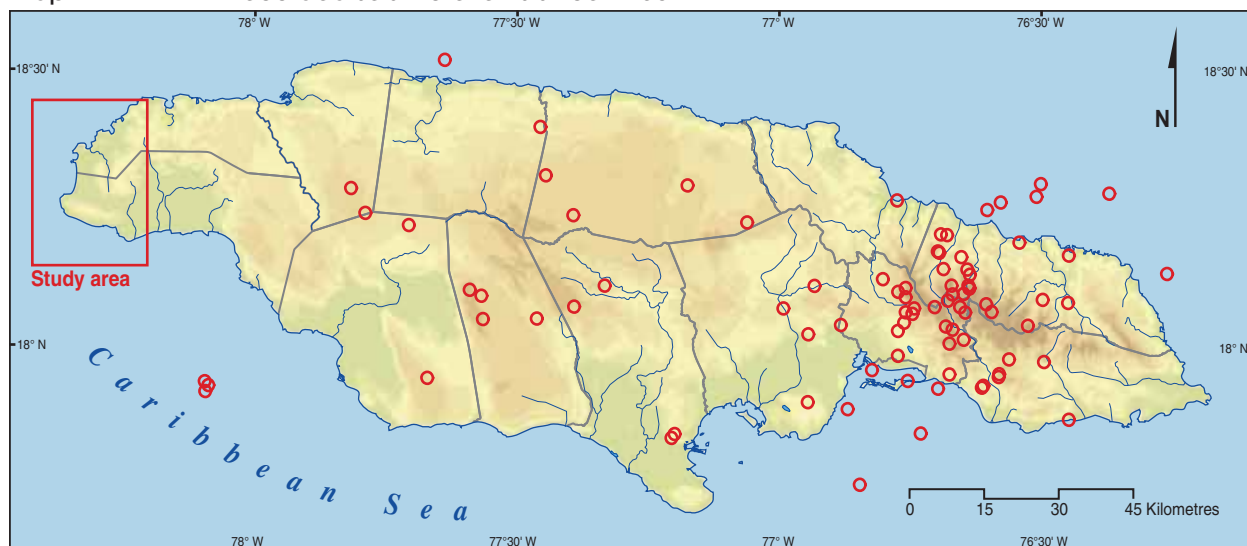
The island also experiences periodic drought, particularly in the south where there is very little rainfall and where agriculture remains dependent on underground water. In 2000, drought resulted in crop and livestock losses of approximately six million USD. Finally, Jamaica also experiences wild fires which usually occur during lightening storms or long dry spells and drought.

(ii) Geological-induced hazards: earthquakes, landslides and tsunamis

Jamaica is characterized by high seismic activity. The most seismically active areas include the Blue Mountains region in eastern Jamaica and the Montpelier-Newmarket belt in western Jamaica. Other areas of notable seismicity include the near offshore southwest of the Black River on the south coast, offshore Buff Bay on the northeast coast, and Kingston which is the most densely populated area in the country. Most earthquakes are minor, with magnitudes of less than four. Nonetheless, major earthquakes have occurred causing major damage, such as the case in Montego Bay (1958) and Kingston (1907). At the 1907 earthquake in Kingston, 800 people lost their lives and the cost of damages totalled £2,000,000.⁴

Table 2.2 All reported disasters induced by hydro-meteorological hazards since 1980³

Date	Hazard type	Name	Persons Killed	Total Affected Population	Est. Damage (US\$ Million)
28/08/2008	Tropical cyclone	Gustav	12	4,000	66.198
18/08/2008	Tropical cyclone	Fay	1		
20/08/2007	Tropical cyclone	Dean	4	33,188	300
28/10/2007	Tropical cyclone	Noel	1		
22/11/2006	General flood		1	5,000	
18/07/2005	Tropical cyclone	Emily	4	2,296	1
07/07/2005	Tropical cyclone	Dennis	1	8,000	30
19/10/2005	Tropical cyclone	Wilma	1	100	3.5
11/09/2004	Tropical cyclone	Ivan	15	350,000	595
13/08/2004	Tropical cyclone	Charley	1	126	300
23/05/2002	General flood		9	25,000	20
30/09/2002	Tropical cyclone	Lili	4	1,500	0.03
18/09/2002	Tropical cyclone	Isidore			1
06/11/2001	Tropical cyclone	Michelle	1	200	55.487
00/03/2000	Drought				6
21/11/1996	Tropical cyclone	Marco		800	3
13/11/1994	Storm	Gordon	4		1
21/05/1993	Flood		9	4,372	11
21/05/1991	Flash flood		15	551,340	30
12/09/1988	Tropical cyclone	Gilbert	49	810,000	1000
00/11/1987	General flood		9	26,000	31
15/05/1986	Flood		54	40,000	76
18/11/1985	Tropical cyclone	Kate	7	300	5.2
31/07/1980	Tropical cyclone	Allen	6	30,009	64

Map 2.2 All recorded seismic events since 1963⁵

The pronounced level of seismicity together with the steep topography and heavy precipitation events in Jamaica make the country extremely prone to land movements. Between 1667 and 1993, 13 earthquakes induced landslides. Specifically, in 1993 a 5.4 magnitude earthquake triggered approximately 40 landslides in eastern Jamaica alone.⁶ Landslide damage to infrastructure and community assets is potentially extensive, especially in the eastern region.

Large submarine earthquakes close to Jamaica have the potential to trigger tsunamis that can reach the island in a matter of minutes. For example, an earthquake that might occur in the south coast of Cuba could produce a tsunami that could reach Montego Bay area in ten minutes or less, which current regional warning systems are unable to cope with. The greatest threat of tsunamis to Jamaica is mainly of localized origin⁷, although there is also potential threat emanating from the Eastern Caribbean region, namely the Lesser Antilles, the Hispaniola and Puerto Rico trenches and Grenada.⁸

In addition to natural hazards, man-made hazards are also common. These include oil and chemical spills, accidents involving the transportation of hazardous waste material on land and sea, and aircraft accidents.

Risk and vulnerability profile

Given the country's small size, the impact of a major hazard event, such as a hurricane, can easily affect the entire country, and damage

incurred can be equal to a significant proportion of the country's gross domestic product (GDP). For example, the total economic impact of Hurricane Ivan in September 2004 is estimated at 36,931 million Jamaican dollars (J\$), which was equivalent to eight percent of the country's GDP in 2003.

Jamaica's human and economic exposure to multiple hazards and their considerable impacts on social, economic and environmental assets make the country vulnerable to disasters.

With respect to tropical cyclones, Jamaica's population exposure is high at ten percent, while seven percent of national GDP remains exposed. Since tropical cyclones generate secondary hazards (storm surges, flooding and landslides), risk is accumulated from these multiple hazards, indicating an increasing proportion of the population at risk. Given the country's limited land area, population settlement away from hazard prone areas is restricted, thus increasing exposure and risk.

Droughts exert a significant impact due to the population's heavy reliance on the agricultural sector. The effects of drought are exacerbated by increasing water stress as a result of a growing population, urbanisation, pollution, inadequate and inefficient water storage and delivery systems that result in wastage.¹⁰ Kingston is reliant on two main reservoirs, namely the Mona Reservoir and the Hermitage Dam, which are supplied by surface waters but have been severely affected by recent droughts and continuous low rainfall.

Figure 2.1 Human exposure to natural hazard (modelled number of people present in hazard zone who are thereby subject to potential losses, GAR 2009)⁹

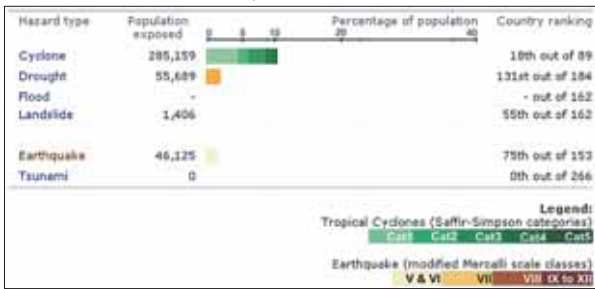


Figure 2.2 Economic exposure to natural hazard (modelled amount of GDP present in hazard zones that are thereby subject to potential losses, GAR 2009)

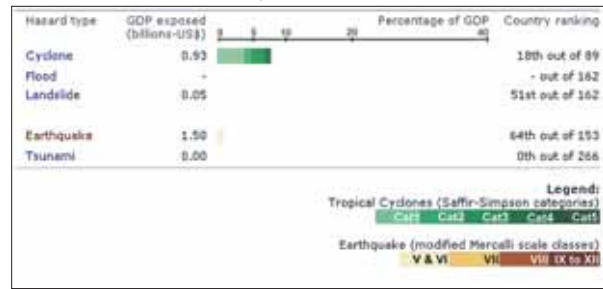
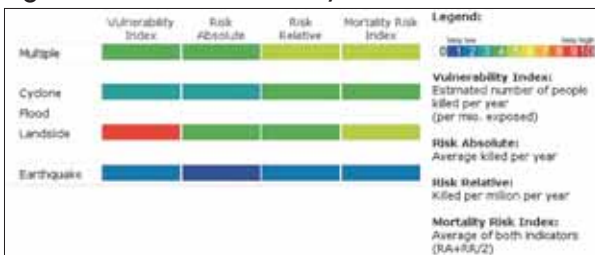


Figure 2.3 Vulnerability and risk



In the case of future earthquakes, especially in the densely populated Kingston Metropolitan Area, the impacts are likely to be comparable to or worse than the 1907 earthquake. A larger population, the low-lying topography and the weak nature of the underlying rocks are all likely to contribute to serious damage and loss of life.¹¹ Moreover, the geological configuration of the island (very close to the Cayman



Groundwater sources, such as this natural spring found in Little Bay in Negril, make up 84 percent of Jamaica's available water resources and are therefore an important source of water supply across the country



© NEGRIL ESCAPE

Tropical Storm Dean struck the Negril coast in 2007. Storm surges generated by tropical storms and cyclones potentially cause considerable economic damage especially in relation to hotel infrastructure

Ridge, a deep fracture between the Caribbean Plate and the North American Plate) and the rapid increase in population, particularly in coastal areas, make it equally likely that future tsunamis will be more destructive and fatal than historic ones.¹²

As Jamaica is highly exposed to a number of natural hazards, there is widespread public awareness about disaster risk, preparedness and response. Disaster risk reduction is now identified as a key priority in Jamaica's *Vision 2030 National Development Plan*. The country also recently completed its national review of the Hyogo Framework for Action.

Nonetheless, while extensive national-level government experience exists in conducting risk assessments and in disaster response, the National Hazard Mitigation Policy (2005) has not been translated into an Action Plan, and the National Disaster Action Plan (1997) has not yet been updated. Various initiatives related to natural hazard management, early warning and public education and awareness-raising are ongoing at the national-level, with increasing involvement by universities, civil society, the private sector and local communities.

Climate change adaptation is an emerging issue around which national government agencies (particularly the Environment Management Division under

the Office of the Prime Minister and the National Environment and Planning Agency/NEPA, National Meteorological Service and Office of Disaster Preparedness and Emergency Management/ODPEM), NGOs, funding agencies (such as the United Nations Development Programme or UNDP) are focusing their priorities and interventions. A second National Communication on Climate Change Adaptation to the United Nations Framework Convention on Climate Change (UNFCCC) is currently being finalized.

While the nexus between disaster risk reduction (DRR) and climate change adaptation (CCA) appear to be generally acknowledged at the national level, their linkage with ecosystems and ecosystems management appears less widely recognized. There are multiple initiatives related to improved environmental management (such as beach rehabilitation, coral reef protection, etc); however, based on our initial findings, these environmental initiatives do not yet integrate a DRR or CCA perspective. National policies related to disaster risk such as the National Hazard Mitigation Policy do not consider ecosystem-based approaches as a component of risk reduction strategies. As there is no National Platform on Disaster Risk Reduction, cross-sectoral collaboration or coordination on mainstreaming environment and DRR issues in national development planning remains limited.

Economy

Key economic sectors rely directly or indirectly on natural resources. The declining state of ecosystems across Jamaica, therefore, signals a major threat to economic growth and livelihoods. Major sectors of the Jamaican economy include agriculture (i.e. farming, forestry and fishing), mining, manufacturing, tourism, and financial and insurance services. The economy is heavily dependent on services, which accounted for 75.8 percent of the GDP in 2008.

Agriculture contributed 4.6 percent to the overall real GDP in 2008, but there has been a declining trend in this sector (down from 7.3 percent in 1982). Although the contribution of the agricultural sector to the GDP is small compared to other major sectors, in 2008 18.6 percent of the population was employed in the agriculture sector.¹³ Major crops include sugarcane, coconuts, oranges, coffee, vegetables and other cash crops.¹⁴ Cattle-raising constitutes a small component of farming, with chickens, goats and pigs also being reared by communities on a small scale.

The decentralized, transient and unregulated nature of wood production industries in Jamaica makes it difficult to assess trends in production. Deforestation has been partly driven by the mining industry which need to access bauxite deposits in the limestone areas. The latest data on deforestation of total forested area published by FAO revealed a loss rate of 1.74 percent over the 1990-2005 period.¹⁵

The most important metallic mineral in Jamaica's mining and quarrying sector is bauxite, the ore from which alumina and aluminium are derived. Bauxite mining comprised approximately five percent of the GDP in 2008.¹⁶ Jamaica is the world's fourth largest bauxite producer, after Australia, Brazil and Guinea. The percentage of total bauxite production has increased over the past three decades, and the sector has the highest labour productivity in the Jamaican economy due to its advanced technology and the high quality of its human capital.

Tourism, remittances and bauxite/alumina mining are the leading sources of foreign exchange. An estimated 1.3 million tourists visit Jamaica each year and most remain concentrated along the coast close to beaches, though eco-tourism in mountain areas is growing. Remittances accounted for nearly 20 percent of GDP in 2008, while tourism contributed

7.1 percent of total GDP in 2008 (slightly lower than in 2007 at 7.3 percent).¹⁷ The recent downturn in the global economy, however, would certainly have negative repercussions on these important sources of foreign exchange for Jamaica.

With one of the lowest economic growth rates in the region, Jamaica faces increasing challenges in a volatile global economy. There is large-scale unemployment at 10.6 percent in 2008 (although a major improvement from 15.4 percent in 1990). Almost ten percent of the population in 2007 was living under the poverty line and will continue to experience economic stress, with the inflation rate remaining high from 2007-2008 at 16.8 percent due mainly to increased food and energy prices. In 2009 the Human Development Index (HDI) for Jamaica was 0.766, which gives it a ranking of 100 out of 182 countries. Jamaica had a debt-to-GDP ratio of approximately 124 percent in 2008.

Governance

Jamaica is a parliamentary democracy and constitutional monarchy with the monarch represented by a Governor-General. The head of state is Queen Elizabeth II. The monarch and the Governor-General serve largely ceremonial roles, but have the reserve power to dismiss the Prime Minister or Parliament. The Parliament is bicameral, consisting of the House of Representatives whose members are directly elected and the Senate whose members are appointed jointly by the Prime Minister and the parliamentary Leader of the Opposition.

Jamaica has two levels of political governance, one at national-level and the other at the parish council-level, of which there are 14 parishes. Historically, Jamaica has functioned as a centralized political system, where power remained concentrated under the Office of the Prime Minister and across national ministries and agencies. On-going efforts, however, seek to decentralize government and aim to allocate additional power and resources towards parish councils.

Vision 2030 Jamaica National Development Plan constitutes the country's strategic road map to achieve developed country status by 2030. Approved by Cabinet in 2009, Vision 2030 seeks to achieve a development path that is environmentally sustainable, internationally competitive, and resilient to disasters and climate change.

2.2 Local Context: Focus on Negril as the RiVAMP study area

Negril is located on the west coast of Jamaica, straddling two parishes, Westmoreland to the south and Hanover to the north. Protected under the Natural Resources Conservation Act of 1991, Negril has been declared an Environmental Protection Area (EPA). Under Jamaican law, a protected area does not necessarily mean restricted access and allows for sustainable use of resources to differing degrees depending on the type of protected area. For instance, an ecosystem management area allows for wider resource use than a national park.

With a permanent population of approximately 3,000, Negril is the island's third largest tourist resort

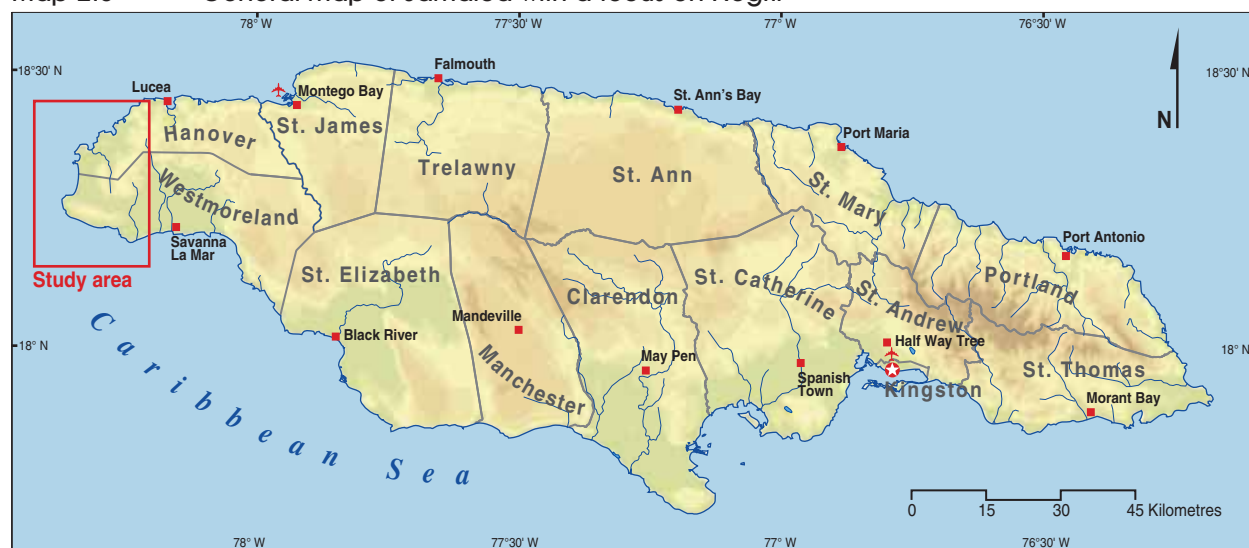
area, following Ocho Rios (117 km to the east) and Montego Bay (84 km to the north). Once a predominantly fishing community, Negril grew out of the "alternative" vacation experience of the 1960s during which hippies camped on the beach or were hosted in rustic accommodations by fisher families. The discovery of Negril as an idyllic tourist destination led to a dramatic change from a small, fishing village to a sprawling tourist resort over a period of thirty years.

Presently, one main street runs through Negril, which is divided into two segments by the South Negril River. Long Bay and its famous "seven-mile" white sand beaches lie to the north of the river and the West End to the south. The town center is Negril Village, which is located immediately south of the river and has developed around a small roundabout from which major roadways, such as the Norman Manley Boulevard and Sheffield Road, extend outwards.



Fishing boats at rest near the South Negril River

Map 2.3 General map of Jamaica with a focus on Negril





Negril's two-way main road

2.3 Regional context

The benefits of regional cooperation have long been championed by Caribbean political leaders and decision makers. Jamaica is a member of the Caribbean Community (CARICOM) which was formally established in 1973, when Commonwealth Caribbean leaders at the Seventh Heads of Government Conference decided to transform the Caribbean Free Trade Association (CARIFTA) into a Common Market and establish the Caribbean Community, of which the Common Market would be an integral part. The establishment of CARICOM was a defining moment in the history of the Commonwealth Caribbean. Unlike CARIFTA, CARICOM would establish a free-trade area which allowed for the free movement of labour and capital and the coordination of agricultural, industrial and foreign policies. Jamaica is also signatory to the Cartagena Convention (Convention for the Protection and Development of the Marine Environment of the Wider Caribbean Region). The Cartagena Convention is the only regional agreement of its kind enabling governments to work together to improve management of coastal and marine resources. UNEP's Caribbean Environment Programme (CEP) provides the programmatic framework for implementation of the Cartagena Convention in the region.

Box 1. About the Caribbean Disaster Emergency Management Agency (CDEMA)

CDEMA, formerly known as the Caribbean Disaster Emergency Response Agency (CDERA), is a regional inter-governmental agency established in September 1991 by an Agreement of the Conference of Heads of Government of CARICOM. It is primarily mandated to establish an immediate and coordinated response to any disastrous event affecting any Participating State, upon request for assistance. CDEMA is presently comprised of 16 Participating States, which includes Jamaica.

CDEMA is currently implementing a three-year project seeking to enhance regional capacity to reduce vulnerability to the effects of natural hazards. This will be done through the development of national hazard mitigation policies and implementation programmes, the promotion of the wider use of hazard information in development decisions and the strengthening of safe building practices, training and certification. Project activities are being undertaken in the four following pilot countries: Belize, British Virgin Islands, Grenada and St. Lucia.

For more information:
www.cdera.org/projects/champ

Section 3. Ecosystems and environmental change

Ecosystems are a vital component of Jamaica's economic way of life and its socio-cultural fabric. As discussed in Section 2, ecosystems directly or indirectly support people's livelihoods, fuel the tourism economy and provide important products. This section discusses the major types of ecosystems found in Jamaica and in Negril in particular, namely coral reefs, sea grass meadows, forests, mangroves and wetlands. This section also reports on stakeholder perspectives regarding the diverse range of services that ecosystems provide and the main drivers of ecosystems degradation. The tables below present actual outputs from stakeholder discussions at national, parish and community-levels.

During community consultations, residents from Whitehall and Little Bay were asked to rank the different ecosystems in order of importance. Community preferences were clearly based on the direct livelihood benefits that people derived from specific types of ecosystems. Coral reefs and beaches ranked high for both Whitehall and Little Bay residents. While residents in Little Bay also prioritized sea grasses and fisheries, Whitehall residents, on the other hand, identified the Great Morass wetland area as being important. Section 5 provides further details on results of the community consultations.

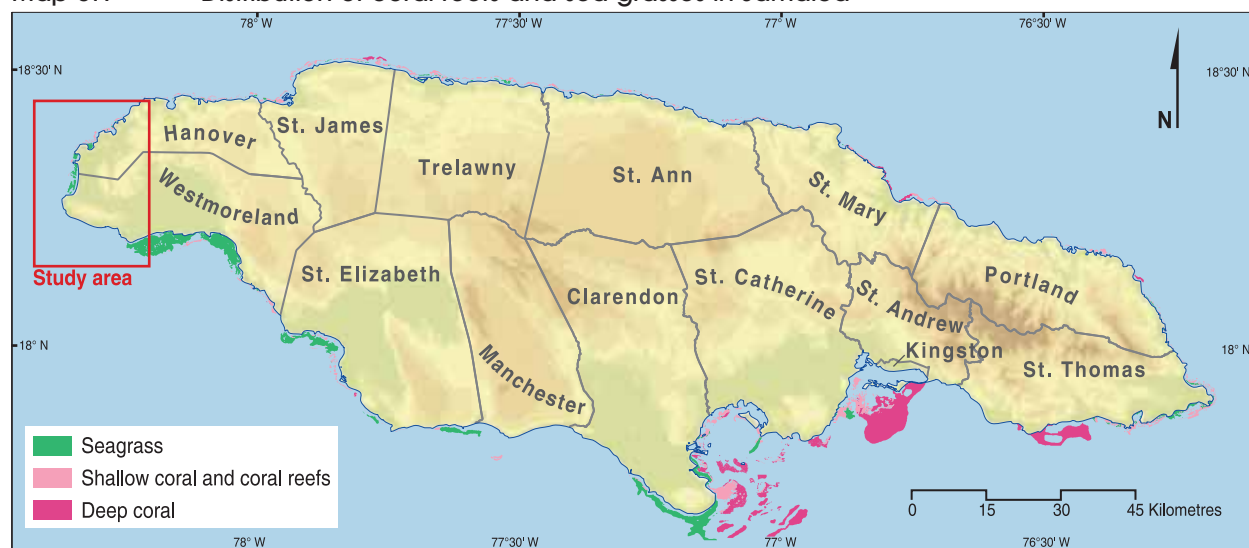
3.1 Coral reefs

Well-developed fringing reefs are found along most of the north and east coasts of Jamaica, while patchy fringing reefs grow on the broader shelf of the south coast. Coral reefs also grow on the neighbouring banks of the Pedro Cays, the Morant Cays and the Formigas.



Parish level consultations held in Negril on October 2009 included multiple stakeholders from government, civil society and the private sector. The Mayor of Westmoreland Parish (shown above, seated at center) also participated in discussions

Map 3.1 Distribution of coral reefs and sea grasses in Jamaica¹



In general, Jamaica reefs are more degraded than the rest of the Caribbean, though in 2008 specific areas were found with relatively high and stable coral cover exceeding the Caribbean average (12 of 53 sites above the regional average of 20 percent).² Overall, there has been a mix of reef decline and recovery between 2001 and 2007, during which elevated sea surface temperatures and several major hurricanes occurred. Nonetheless, average coral cover has improved threefold from the early 1990s to 2008, ranging from 5 to 15 percent respectively.

Services

Coral reefs provide important services to the Negril community and the country overall in terms of tourism revenue. Four major benefits of coral reefs include: shoreline protection, supply of beach material, tourism revenues and support to the local fishing sector.

Stakeholders at all levels recognized the importance of coral reefs in terms of providing shoreline protection. Coral reefs were viewed as natural barriers against wave surges generated by severe storms and tropical cyclones (hurricanes). (Section

4 elaborates further on the role of coral reefs with respect to shoreline protection).

Stakeholders also understood coral reefs as a key provider of beach sand material. While carbon-producing organisms living on reefs do contribute to beach sedimentation, in the case of Negril this percentage may in fact be fairly low. A 2002 study conducted by the Department of Geology and Geography at the University of the West Indies (UWI), concluded from field tests that reef-derived material (such as coral fragments and echinoid fragments) is largely lacking in the Negril’s beach sand.³ The study suggests that beach sediment is not coming from the reef, but primarily from carbonate-secreting organisms living in sea grass beds (discussed further below).

Coral reefs support the tourism industry, as they attract divers and snorkelers and support glass bottom boat operators. Many of these glass-bottom boat operators bring in extra help to act as “reef guides” who earn additional income by accompanying tourists during snorkelling trips. Finally, fishers interviewed in Little Bay and stationed at the South Negril River obviously valued coral reefs as a fish habitat and breeding ground.

Table 3.1 Important benefits and services derived from coral reefs, based on stakeholder inputs

Level of stakeholder consultation	Provisioning services	Regulating / Protection services	Socio / Cultural / Educational
National	Reef fishing for income and as a direct food source	Coastal stability / shoreline protection	Opportunities for research
	Supports tourism activities, e.g. diving		Aesthetics / recreation / sports
	Used to make ornaments and jewellery which are sold (e.g. black coral)		
	Provides white sand material to the beach		
	Habitat for many species		
	Nurseries to replenish fish and shellfish stocks		
Negril	Supports tourism, e.g. diving	Protection from storm surges	
	Provides beach material (white sand)		
	Fish sanctuary and breeding ground		
Communities	Used for ornaments / crafts	Lessens damage from storm surges if coral is healthy/intact	Aesthetics
	Provides beach material (white sand)		Educational – used for teaching school children
	Supports tourism activities		
	Serves as a fish nursery/habitat		

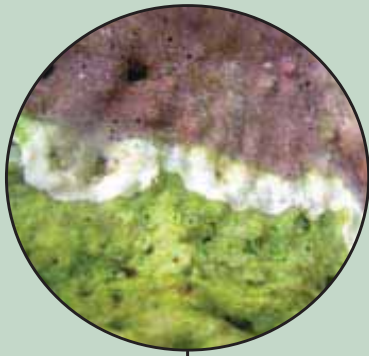
Threats

Coral reef degradation is being driven both by external phenomena and human activities. Severe storms in the region can cause significant damage to Jamaican reefs. For instance, Hurricane Ivan (2004), according to stakeholders in Negril, significantly reduced coral cover in the area which still has not fully recovered. Moreover, increased sea temperatures have resulted in coral bleaching and in some cases mortality. Mass coral bleaching in the 1980s and 1990s and again in 2005 resulted in

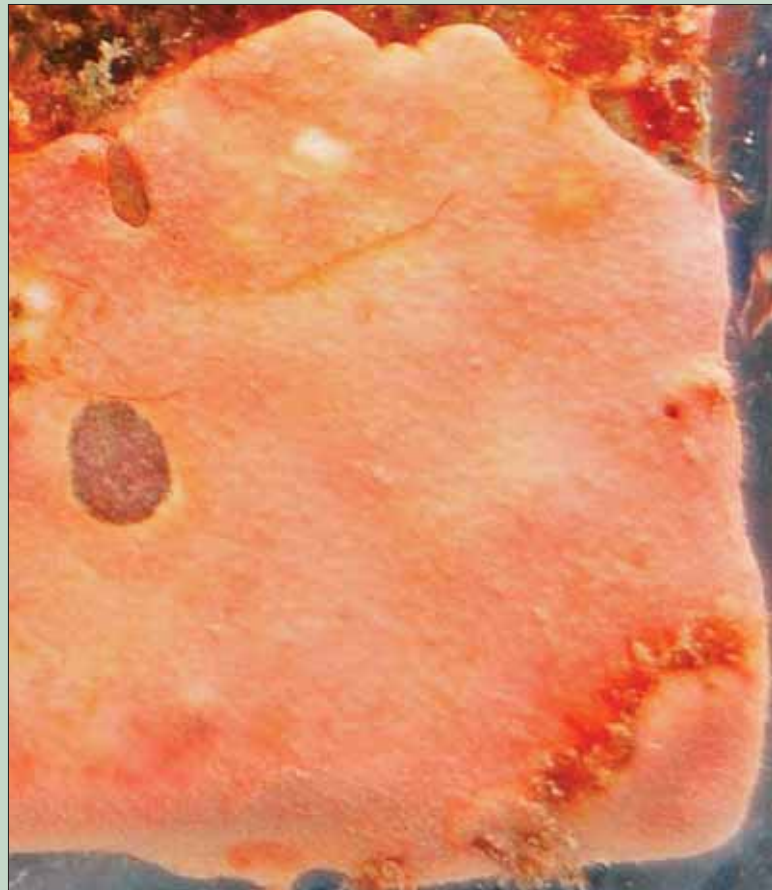
major coral losses in Jamaica, which also affected other countries in the region.⁴ In 2005, 34 percent of corals around Jamaica were bleached and half of these died, though there was evidence of coral resilience on the north coast. Studies indicate strong resilience of the fringing reefs around Discovery Bay in Jamaica.⁵ While there are encouraging signs of coral recovery especially after the 1980s and 1990s, unusually frequent and severe hurricanes as well as intense human pressures have hampered reef recovery.^{6,7}

Table 3.2 Major drivers of coral reef degradation, based on stakeholder inputs

Level of stakeholder consultation	External drivers	Local human-induced drivers
National	Impacts from storms	Destructive fishing practices: dynamite fishing, use of chemicals, over-fishing, small mesh sizes in traps and nets, reef fishing (i.e. fishing on the reef, using traditional spear fishing) and anchoring boats on reefs
	Coral diseases – white band	Land-based threats: agricultural runoff, sewage runoff, sedimentation and increased drainage of freshwater due to urbanization
	Black urchin population decline in the 1970s and 1980s	Human contact with reefs (divers, snorkelers, tour boat operators, etc.)
	Invasive species – lionfish	Ornaments /craft industry
	Indirect impacts of climate change - coral bleaching due to increased sea temperatures; increasing intensity and frequency of severe storms	
Parish	Indirect impacts of climate change – coral bleaching, ocean acidity, increase in sea level	Algal growth due to land-based pollution
	Invasive species – lionfish	Anchoring boat on reefs
		Tourists taking coral as souvenirs
		Waste – plastics, debris
		Overfishing
		Development on the shore: increased runoff (sewage, freshwater), reclamation of the Morass for buildings and farming
		Sedimentation from agricultural activities in the hillsides and the Morass
Overfishing in the reefs		
Community	Impact from hurricanes	Sewage dumping into the sea
	Climate change	Deliberate human damage to corals
		Destructive fishing practices: anchoring of boats, spear fishing
		Chemical runoff and excess nutrients from various land-based activities (e.g. farming)



Porolithon onkodes afflicted with early stages of CWBS¹³



Coralline Algae Lethal Orange Disease (CLOD)

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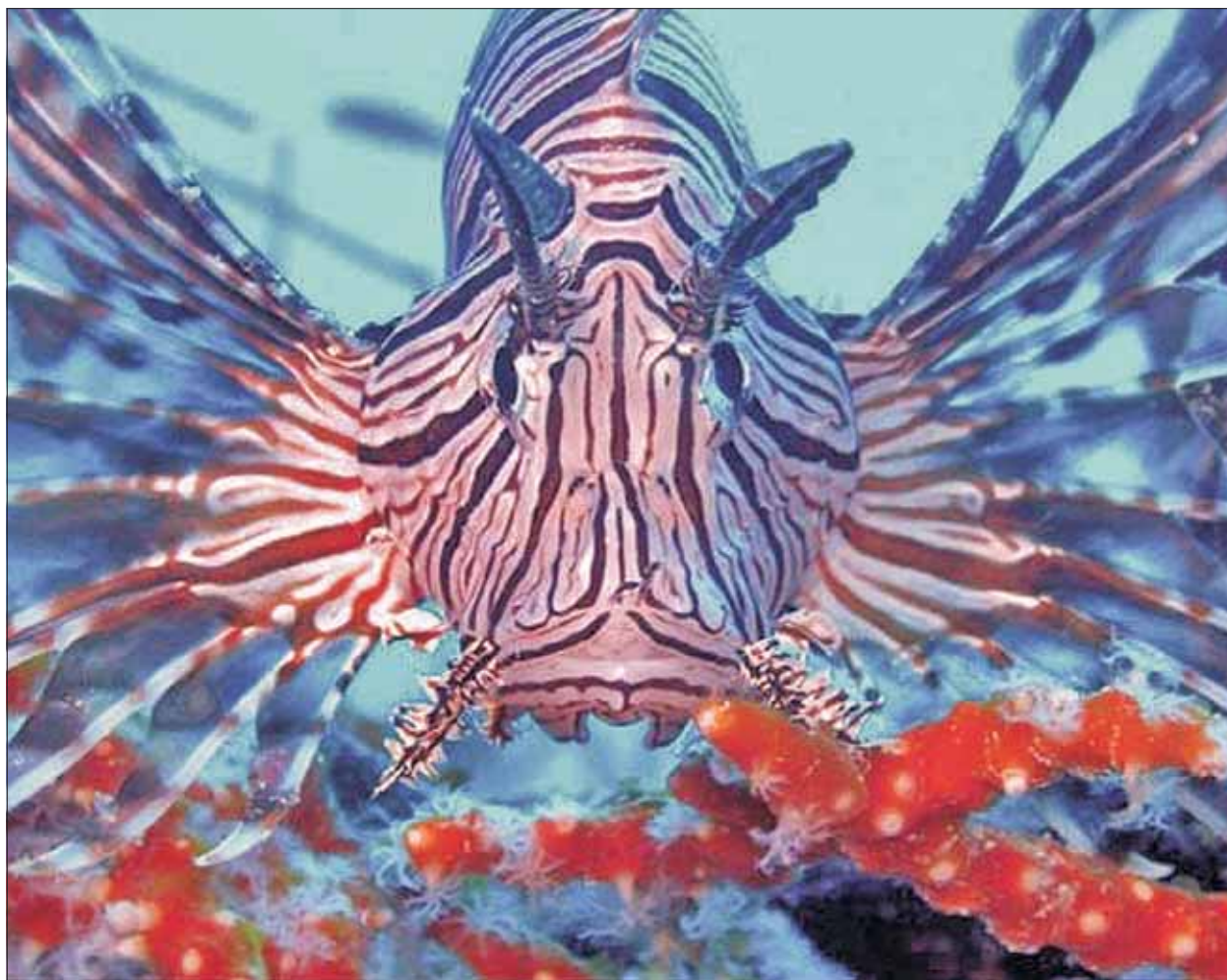
Case study 1. Coral disease threatens Caribbean reefs⁸

In the Caribbean, coral disease has caused extensive losses of living coral cover, shifts in coral community structure, and extirpations of certain key reef-building species.⁹ The Caribbean Coralline Lethal Disease, a new deadly coral reef pathogen,¹⁰ is affecting the western coast of Jamaica. The disease attacks the calcified crustose coralline algae.

Coralline algal disease is recent and rapidly expanding. Reports from the Pacific region cite orange-yellow growth of an unidentified bacteria attacking *Porolithon*¹¹ crusts with expanding circles of orange rimmed (about 1 cm wide) that result in dead skeleton. This affliction has been termed coralline algae lethal orange disease (CLOD).

In February 1996 a new condition began to kill *Porolithon* in Jamaica, starting at the water line as small spots which expanded in size, frequency, and depth distribution, killing about half of all *Porolithon* at sites on the west, east and south of the island within six months. This disease differs from CLOD, as the broad orange band is not present. Instead a thin white rim, about one to two mm wide, expands into pink *Porolithon*, with a green overgrowth composed of filamentous green algae. It is therefore known today as “Coralline White Band Syndrome” (CWBS).

This disease appears to have killed between a quarter to three quarters of *Porolithon* recently in many Caribbean sites. Microscopic examination shows that the white band is soft and can be gouged out with a needle, and the white rim spreads into normal *Porolithon*, followed by ramifying branched filamentous green algae and fungi. In all locations where it occurs, the disease is easy to identify, marked by clear expanding white-rimmed green circles. Its rapid spread has made it ubiquitous in the region. When the disease vanishes, it leaves behind an unhealthy mottled fuzzy green surface that once had been hard coral, smooth and pink. The identity of the pathogen and the filamentous algae that emerge from it are still unknown.¹²



© PICU

Case study 2. The lionfish: A threat to coral reef ecosystems in the Caribbean

The red lionfish (*Pterois volitans*) is a non-indigenous species now pervasive in the ocean waters of Jamaica and in other Caribbean countries. The lionfish's spines are extremely poisonous, making them a formidable predator that is capable of destabilizing reef fish populations.

The lionfish's natural distribution extends throughout the western Pacific from southern Japan to Micronesia, Australia, the Philippines and Sumatra. It is also naturally found throughout most of Oceania (the Marshall Islands, New Caledonia and Fiji). The arrival of the lionfish in the Atlantic region is most likely through the aquarium trade and unintentional releases into the marine environment. For example, at least six lionfish were liberated into Biscayne Bay (Florida, USA) when a beach-side aquarium broke during Hurricane Andrew in August 1992.

With few documented natural predators, the lionfish is a voracious species resulting in significant reductions of native fish in the Caribbean. Lionfish have the potential to reduce the abundance of ecologically important species such as the parrotfish and other herbivorous fish that keep seaweeds and algae from overgrowing on corals. Larger lionfish are also known to consume smaller members of their species.¹⁴

Removing lionfish from its current distribution range is very likely irreversible, but reducing its population abundance could be encouraged. For instance, the species is consumed in subsistence fisheries in the Pacific, after removing the dorsal- and anal-fin spines that contain the potent venom. An increase in outreach and education efforts may be supported to promote management and mitigation of lionfish. Additional research is also needed to better understand the potential effects of lionfish on Caribbean coastal and marine ecosystems and to identify potential predators. For example, in the Bahamas lionfish have been found in the stomachs of native groupers.¹⁵



Freshwater drainage due to urban development and tourism contributes to coral reef degradation

While external phenomena is an important factor contributing to reef degradation, human activities also play a major role, which was widely acknowledged by stakeholders at all levels. Three main causes were highlighted: land-based sources of pollution, destructive and unsustainable fishing practices and tourism-related activities.

Land-based sources of pollution include agricultural runoff (containing sedimentation, fertilizers, pesticides), sewage runoff, garbage (plastics, debris), and increased freshwater drainage due to urban development. High levels of nutrients (nitrogen and phosphorus) in Negril's coastal waters due to farming activities and sewage runoff have been well-documented in previous studies.¹⁶ Stakeholder consultations simply confirmed that people are well aware of these issues. High nutrient loads in coastal waters have been directly linked to a clear trend of algal-dominated reefs which are readily visible around the island and on Negril reefs. Algal growth suffocates coral growth and makes them less resilient to natural hazards and bleaching events.

While sanitary infrastructure in Negril has greatly improved over the past two decades, in many areas, particularly where there are informal settlements,

sanitation remains absent or poorly developed. One public health official who works in Whitehall indicated that based on her estimates, approximately 30 percent of households still do not have improved sewage systems and rely on pit latrines.

Solid waste containment, collection and disposal remain a major issue in Negril and a major source of coastal water pollution.¹⁷ Garbage finds its way into drains which feed into the South Negril River and eventually to ocean waters. In Little Bay where garbage collection is sporadic, garbage of all types (metal containers, plastics, etc.) is regularly burned, buried, thrown into coastal waters or tossed into unoccupied public spaces.

Destructive fishing practices also have a major adverse impact on reefs. Reef fishing (i.e. fishing directly on the reefs) has resulted in significant decline of fish stocks, which contributes to algal growth on reefs. The use of dynamite, chemicals, traditional spear fishing techniques as well as boat anchorage are known to cause direct reef damage.

Other than fishers, tourists (divers, snorkelers, bathers) were also known to break off coral fragments either accidentally or intentionally for souvenirs.

3.2 Coastal vegetation: Sea grasses, mangroves and beach vegetation

Little information on coastal vegetation exists in Jamaica, and much fewer time-series data to extract distribution trends. Most of the information obtained by UNEP on sea grasses and other types of beach vegetation (i.e. sand dunes) therefore remains anecdotal and locally-specific.

Four types of mangrove habitats can be found in Jamaica: silt, sand, peat and coral reefs. The four American species are all represented: *Rhizophora mangle* (red mangrove), *Laguncularia racemosa*, *Avicennia nitida* and *Conocarpus erectus*. While several national-level estimations of mangrove distribution since the 1980s have been carried out by different researchers, they do not follow a consistent measurement approach. Based on interviews with the National Environment and Planning Agency (NEPA), there is no consistent government monitoring of mangrove coverage over time and therefore only calculated estimates of trends can be derived.

Over the last 20 years, an estimated 30 percent of original mangrove forests in Jamaica have been lost. In Negril, community consultations confirmed this downward trend. For instance, Little Bay residents

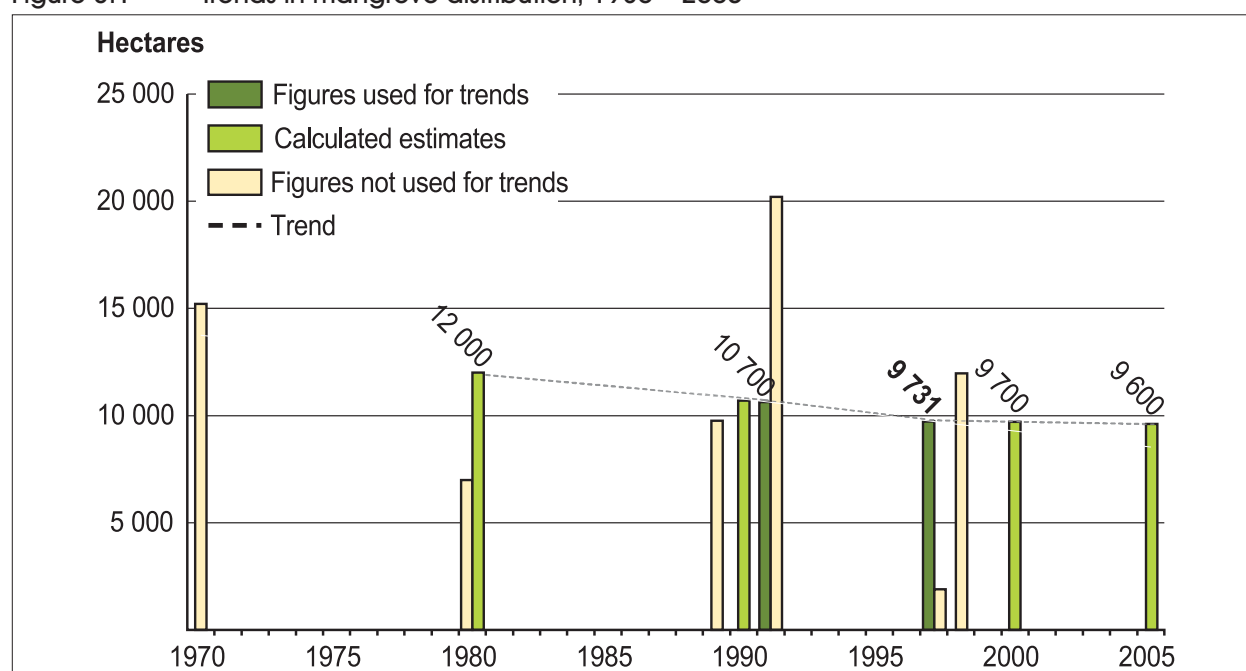
cited substantial reduction of mangroves as well as other trees (e.g. coconut, sea grape) along the coastline in their community.

The Coastal Atlas of 1990 was the last systematic, nationwide study undertaken on sea grasses.¹⁸ Since then, to UNEP's knowledge, no other study has been carried out to consistently monitor and assess the status of sea grasses as well as other types of coastal vegetation.

Satellite imagery and bathymetry data analysis help to understand and confirm that Negril sea grass patches are generally found at depths shallower than approximately 10 metres. They also benefit from small sand depressions (*cuvettes*) that can protect seeds and young shoots from currents and wave energy, allowing them to multiply.

Green algal *Halimeda* beds and branching red algae predominate Negril waters and live in a variety of habitats ranging from shallow shelf, bay, reef to fore-reef environments.¹⁹ A 2002 assessment by UWI on the sand source of Negril beaches (in Long Bay and Bloody Bay) emphasized the importance of sea grasses in the production of beach sediments: "The significant lack of coral in the beach sand indicates that algal fragments are probably not derived from the reef but rather from algae in the shallow shelf environments of the inner bay area".²⁰

Figure 3.1 Trends in mangrove distribution, 1980 – 2005*



* Mangrove area extent for the years 1980, 1990, 2000 and 2005 are based on linear regression and expert estimate (FAO 2005)

Benthic foraminifera, which are carbon-secreting living organisms, are dominated by epifaunal species that live attached to sea grasses; they contribute almost half of the identifiable beach sediment in Long Bay. However, a significant drop in the percentage of *foraminifera* and a corresponding increase in red algae between 1980 and 1999, based on UWI's study, could be attributed to the removal of sea grass beds or pollution stresses on the environment.

Least information was available for other types of beach vegetation such as sand dunes. Today, only negligible patches may be spotted in between hotel and or restaurant establishments.

Services

Despite available scientific studies on Negril linking sea grasses and beach sediment supply, this awareness was not reflected in any of the stakeholder consultations, suggesting an important knowledge gap outside the scientific and academic community. Sea grasses and mangroves were not prioritized by stakeholders at the Negril workshop.

In addition to being regarded as a fish and sea turtle sanctuary, sea grasses (red algae in particular) are harvested to prepare traditional drinks and puddings, which is a widespread practice in the

Caribbean region.²¹ In most islands, algal species used for drinks are known as sea-moss, which in Jamaica is referred to as *Irish moss*.²² Little Bay residents recalled engaging in small-scale mariculture of Irish moss, which was destroyed by Hurricane Ivan and never restarted.

Mangroves serve as an important breeding habitat for fish and shellfish and provide shelter for fishermen's boats during storms. Community residents also utilised mangroves for charcoal production and building materials.



A fisherman interviewed by UNEP recalled dunes covering wide stretches of sand in Negril about 30 years ago

Table 3.3 Important benefits and services derived from coastal vegetation (mangroves, sea grasses and beach vegetation), based on stakeholder inputs

Level of stakeholder consultation	Provisioning services	Regulating / Protecting services	Socio-cultural / educational
National *	Craft-making material for tourism	Coastal stability	Aesthetic /scenic values
	Breeding area for fish and other species (e.g. shellfish)	Reduce wind stress / wind breaker	Opportunities for research
Parish (not discussed)	N/A	N/A	N/A
Communities (with a focus on sea grasses and mangroves):			
- Sea grasses	Serve as a fish and sea turtle sanctuary	Protect the sand / minimize beach erosion	
	Used to make beverage (e.g. irish moss)		
	Supply compost / manure for farming activities		
- Mangroves	Provide natural habitat	Protective barrier against strong waves during hurricanes	
		Absorb excess rainfall	
		Act as a filter to protect beaches	

* Discussions at the national level did not include mangroves

Coastal vegetation, such as sand dunes as well as coconut and sea grape trees, provide important hazard mitigation functions by acting as a natural wind breaker and supporting coastline stability, in addition to aesthetic and material benefits.

Threats

As with coral reefs, coastal vegetation also face several threats but these are primarily due to human-induced activities. Sea grass removal is a common practice especially in the Long Bay area where many of the hotels are located. Sea grass is removed to provide tourists with clean white sand, but it is also harvested to prepare traditional drinks or used as compost for farming. Sand dunes and trees also have been uprooted to create open beach spaces for tourists and other infrastructural development, partly contributing to progressive beach erosion in Negril since the 1980s. Mangroves, on the other hand, are cut down to produce fuelwood and housing materials and to clear land for development.

Land-based sources of pollution also have a major impact. Pollution sources include garbage reaching the sea or being dumped in mangrove areas,

agricultural and industrial runoff, sewage runoff, and increased freshwater drainage from built infrastructure such as roads and hotels.



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Wave-eroded scarp demonstrates how coastal vegetation (trees and grasses) root mass can retain sand and resist the erosive effects of waves and long-shore currents

Table 3.4 Major threats to coastal vegetation, based on stakeholder inputs

Level of stakeholder consultation	External drivers	Local human-induced drivers
National (excluding mangroves)	Impacts from storms and other natural hazards	Tourism discourages vegetation growth on the coastline/beach resulting in their removal
	Fires	Land-based sources of pollution: agricultural runoff (sediments/soil, chemicals/pesticides); deforestation due to farming, intentional fires; industrial runoff (chemical, thermal), sewage runoff; increased freshwater runoff due to hard surfaces/built infrastructure
	Invasive species	
	Beach erosion	
		Coastal development Improper/inadequate waste management
Parish (not discussed)	N/A	N/A
Communities:		
- Sea grasses	Impacts of storm surges	Loss of mangroves increases pollution runoff into the sea
		Removal of sea grasses to allow for tourist recreational activities
		Harvesting
- Mangroves		Cutting down of trees Disposal of garbage in the mangroves

3.3 Wetlands / peatlands

Wetlands represent less than two percent of Jamaica's total surface. Commonly referred to as the "morass", Jamaica's wetlands consist of peat and are mostly found in two coastal areas in western Jamaica, the Lower Morass of the Black River Basin and the Great Morass in Negril, spanning 7,200 and 2,300 hectares respectively.

Wetlands are among the most biologically productive ecosystems of all Caribbean ecosystems and play an important role in maintaining coastal stability through flood mitigation and water filtration. Jamaica's coastal wetlands support a rich indigenous flora and fauna, with several endemic species. These include *Grias cauliflora*, the only native representative of the Brazil nut family Lecythidaceae, the swamp palm (*Roystonea princeps*), the thatch palm (*Sabal jamaicensis*) and the naseberry bullet (*Manilkara sideroxylon*). Wetlands support various species of birds, crabs, fish, shrimps and the American crocodile. The Black River Morass located in the southwestern coast, for example, has been described as the best area in Jamaica for water birds, and is known to be the only area where the flamingo still nests occasionally.²³ Commercially important species that use the wetland as a breeding and nursery area include snapper,

snook, tarpon, jack and several species of fresh and brackish water shrimps.

Despite its rich biodiversity and important regulatory functions, wetlands in Jamaica were initially regarded as a source of disease such as malaria. As such, extensive draining of wetlands in Jamaica, including in Negril, has taken place over the past 50 years, with the drained land then used for agricultural expansion, particularly for the cultivation of rice and other moisture-tolerant crops, as well as sugar cane. Although the first farming cycles may result in high yields largely due to rich nutrients from the peat, subsequent cropping declines substantially, requiring large fertilizer inputs or expansion into new areas. More recently, marine terminals and warehouses, freeport sites for industry and residential development have replaced coastal wetlands, particularly in estuarine locations. The greatest destruction has occurred in the larger estuaries now used for harbour facilities, such as along Hunt's Bay and the Kingston waterfront.

Covering 2,400 hectares, Negril's Great Morass is the country's second largest freshwater wetland and constitutes one-fifth of Jamaica's wetlands.²⁴ It is owned by the Government of Jamaica, with specific sections being owned or managed separately by three main agencies: the Urban Development Corporation (UDC), NEPA and the Petroleum Corporation of Jamaica (PCJ).



Dominated by sawgrass with scattered clumps of forest, the Great Morass in Negril is underlain by extensive sedge and mangrove peat

Table 3.5 Important benefits and services derived from the Great Morass, based on stakeholder inputs

Level of stakeholder consultation	Provisioning services	Regulating / Protecting services	Socio-cultural / Educational services
National	Aquaculture: shrimps	Fixes nutrients in soils	
	Harvesting of crabs	Flood protection / buffer area	
	Support tourism activities (Royal Palm Reserve)	Filters pollutants before releasing into ocean	
	Biodiversity/natural habitats		
	Source of charcoal		
Parish	Natural habitat	Protects corals from pollutants / harmful substances – closely linked to coastal ecosystems	Opportunities for research
		Water absorption / flood mitigation	Educational tours
		Carbon sink (but also releases carbon once disturbed)	Sports fishing / recreation
			Represents the identity of Negril
Whitehall community*	Habitat for fish, crabs, shrimps, local plants and wildlife		Tourist attraction
	Provides area for farming		

* Stakeholder consultations at Little Bay did not focus on the Morass

In the late 1950s, dredging in the Great Morass took place to drain water out into two canals, now known as the North and South Negril Rivers, which were subsequently straightened and widened. In the 1980s, a government proposal to mine the extensive peat deposits was abandoned, following public opposition and assessments which pointed to the potential environmental impacts on the coast. Lobbying efforts advocated for the protection of the Morass due to its rich biodiversity and important ecological functions.

The government through the PCJ then developed part of the Morass into the Royal Palm Reserve to both protect the palm forests endemic to the area, as well as promote increased appreciation of Morass ecology. In 1994, the Negril Area Environmental Protection Trust (NEPT) was established to function as a multi-sectoral organization for government agencies, civil society and communities to coordinate environmental conservation efforts and promote sustainable development in the Negril EPA. NEPT currently manages the Royal Palm Reserve. Despite local efforts to protect the Morass, major encroachment is ongoing both

within and along its boundaries due to farming activities, housing settlement and urban development.

Services

The Great Morass represents an important part of life and Negril's physical identity. Wetlands are a significant source of food and fuelwood, as well as materials for building houses. It is a natural habitat for fish, shrimp, edible frogs and crabs, but also provides additional land for farming.

While community residents placed greater emphasis on the socio-economic benefits, stakeholders at the national and parish levels recognized additional ecological values, including its contribution to biodiversity, flood control (i.e. storing rainwater and slowly releasing it to the sea), protection of reefs and sea grass beds from freshwater and other types of runoff, and prevention of inland saltwater intrusion. In addition, the Morass was also valued as a carbon sink, though with the potential of releasing significant amounts of carbon.

Threats

Major threats to the Morass are mainly driven by human activities. Although considered illegal, farming in the Morass remains common, with visible signs of intentional burning, mangrove cutting and land clearance. Local use of chemicals such as fertilizers and pesticides further contributes to degradation of the wetlands and coastal environments. However, due to the lack of systematic monitoring or recent assessment undertaken on the Morass, it is difficult to evaluate the extent of deforestation.

Drainage over the years has led to the increased state of dryness in the Morass, which stakeholders link to the greater frequency of peat fires. Fires have been known to continue burning even at sub-surface levels for weeks and months. Because peat fires are not systematically monitored or studied, it is hard to ascertain their driving causes.

3.4 Forests

Approximately 336,000 hectares (ha) or thirty percent of Jamaica is classified as forest.²⁵ Within this area, 94 percent shows evidence of human disturbance. Approximately 111,000 ha or over 10 percent of the country’s total land area have been designated as forest reserves,²⁶ but approximately one third of forests in reserves or protected areas experience human encroachment. While many studies on forest depletion in Jamaica have been undertaken, estimates of annual deforestation rates range from 0.1% to 11.3%, due to varying measurement methodologies.²⁷

Table 3.6 Major threats to coastal vegetation, based on stakeholder inputs

Level of stakeholder consultation	External drivers	Local human-induced drivers
National		Industrial pollution
		Sewage
		Road construction
		Housing development
		Storm water runoff
Parish	Wildfires	Intentional fires
		Farming activities
		Release of agricultural chemicals into the wetlands
		Drainage to dry out wetlands
		Lack of public education and awareness of the importance of the Morass
Whitehall community		Drainage of Morass for housing development, farming activities
		Agricultural runoff containing chemicals
		Removal of mangroves
		Intentional fires



Burning of vegetation in the Morass can be viewed from a hilltop in Whitehall

Most of the country's forest reserves are located in areas of rugged terrain such as the John Crow Mountains, Blue Mountains and Cockpit Country as well as the dry, hilly uplands in the south, west and northwest sections of the country. Broadleaf forests comprise the majority of forests, and other types include bamboo and natural dry open forests. The latter is often referred to as woodland or scrub, dry limestone forests that are a key component of Jamaica's forest ecology.²⁸

Services

Forests provide important products for consumption, including wild honey, fruits and wild animals, as well as medicinal ingredients. Community residents also acknowledged using forested areas for crop cultivation.

A small charcoal and firewood industry exists in the Negril Hills where hardwood is the main type of wood used.²⁹ Moreover, a small lumber industry also harvests hardwoods from both the wet and dry limestone forests. Board houses are typically found in this area, and thus lumber is in great demand (although some of it is imported). Other major uses of local woods include carving sculptures and trinket boxes for sale as souvenirs, as well as making fish traps (also locally referred to as "fish pots").

It is important to note that only national and parish-level stakeholders recognized forests' regulatory functions with respect to watershed protection, soil stabilization and local climate regulation. While there is potential to support eco-tourism in forested areas in Jamaica, this activity remains relatively undeveloped, as tourism is concentrated in coastal areas.

Table 3.7 Important benefits and services derived from forests, based on stakeholder inputs

Level of stakeholder consultation	Provisioning services	Regulating / Protection services	Social / Cultural / Educational	Other
National	Wild honey for home consumption and for sale	Regulates micro-climate	Leisure activities e.g. bird watching, hiking	Supports biodiversity
	Timber production	Carbon sequestration	Eco-tourism	
	Supports hunting activities	Watershed protection		
	Charcoal production	Soil stabilization		
Parish	Provides food products	Promotes rainfall	Opportunity for research	Genetic reserve
	Wood and lumber	Soil stabilization / mitigates against landslides	Aesthetics and recreation	
	Materials for crafts	Regulates micro-climate		
	Provides housing materials	Carbon sequestration		
Little Bay community*	Provides farmland and food		Aesthetics and recreation	
	Provides natural habitat			
	Wood used to make fish traps			
	Provides firewood for cooking			
	Provides medicinal ingredients			



Locally-sourced wood is used to make fish traps, locally referred to as “fish pots”

Table 3.8 Major drivers of forest degradation, based on stakeholder inputs

Level of stakeholder consultations	External drivers	Local human-induced drivers
National	Forest fires	Mining activities: bauxite and limestone
	Biological threats, e.g. pests, invasive species	Logging
		Agricultural activities
		Housing development: both formal and informal (squatter settlements)
		Intentional fires
	Species extinction / endangerment	
Parish	Drought	Land clearance due to farming, industry or housing development
	Wildfires	Hunting: bird shootings
	Hurricanes and other natural hazards	Overharvesting of forest materials e.g. firewood
	Invasive species	Soil erosion
	Global warming /climate change	
Little Bay community	Natural hazards: hurricanes, storms	Charcoal production
	Termite infestation	Fires

Threats

At the national-level, the main threats to forest ecosystems are mostly associated with resource extraction, specifically logging and bauxite and limestone mining. At the local-level, forest degradation in Negril is driven primarily by informal housing development, expansion of farming activities, and fuelwood and charcoal production.

Natural threats include drought, wildfires and the impact of severe storms and hurricanes. However, due to the lack of rainfall data and systematic monitoring, it is unclear whether forest fires in Negril are set intentionally to clear land for farming or caused by prolonged dry spells (or both factors).

Section 4. Linking ecosystems to shoreline protection against sea level rise and storm surges

1.1 Introduction

Coastal environments and ecosystems will be significantly affected by both climatic (long-term sea level rise and storm intensification)¹ and human-induced environmental changes. These changes will have significant impacts on the coastal communities of Small Island Developing States (SIDS).

This section elaborates on the science-based component of the RIVAMP pilot and presents the results of the spatial and statistical analyses, for which the main objectives were as follows:

- (i) Evaluate the scale of beach erosion and coastal ecosystem degradation;
- (ii) Identify the role of geomorphology (bathymetry, elevation) and natural features (coral, sea grass) in the observed erosion patterns;
- (iii) Provide a prognosis of the future impacts of the expected environmental changes such as long-term or Accelerated Sea Level Rise (ASLR) and increases in the frequency and intensity of tropical cyclones; and
- (iv) Consider solutions, together with their possible environmental impacts on the coastal ecosystems.

UNEP used data collected and generated by remote sensing to ascertain beach erosion in Negril, Jamaica. This section provides scenarios of beach erosion according to different potential increases in sea levels as well as varying intensities of storm surges due to tropical cyclones, and assesses the role of environmental features (specifically coral reefs and sea grass meadows) in mitigating beach erosion. Less focus was given to other types of coastal ecosystems, namely mangrove forests and other types of coastal vegetation and peatlands (Great Morass) due to limited data availability in the study area, though they are clearly important in the overall ecological balance of Negril.

Exposure of population and assets in the Negril area to storm surges due to tropical cyclones has been

modelled using Geographic Information System (GIS) technology and analyses. This modelling exercise serves to raise awareness of the potential impacts of storm surges, in terms of both population and affected assets, if such events were to increase in frequency and intensity. Sea level rise is factored in calculating the minimum and maximum heights of storm wave elevation, which were then used in the analyses to estimate exposure and determine future scenarios of beach erosion.

This section presents scientific-based evidence of the important protective functions of coral reefs and sea grasses to the beach. These findings should be used to inform dialogue on how to address beach erosion and reduce current and future risk as a result of sea level rise and tropical cyclones. The driving causes of beach degradation and the solutions for this have been detailed in Sections 3 and 6 of this report.

1.2 The study area

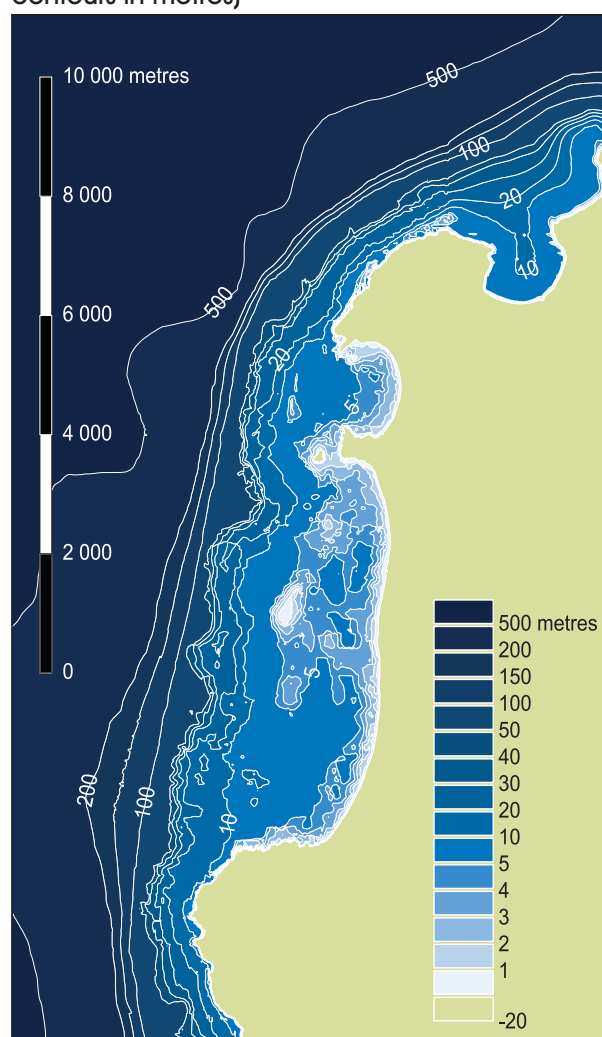
The Negril coast in western Jamaica was selected as the study area of the RIVAMP pilot (see Map 4.1). Several technical studies by the University of the West Indies (UWI) (2002) and Smith Warner International (SWI) (2007) document the increasing problem of beach erosion and coastal ecosystem degradation in the area.² The study undertaken by SWI was commissioned by the Negril Coral Reef Preservation Society (NCRPS). The pilot has drawn extensively from these previous efforts.

The coastal environment is associated with a sand barrier that form two beaches, Long Bay to the South and Bloody Bay to the North, backed by a narrow and shallow shelf exhibiting both deep and shallow coral reefs and sea grass meadows. The beaches have a total length of approximately nine kilometres (km) and comprise part of a sand barrier system fronting the Great Morass, a low-lying back-barrier wetland that terminates to the east at a steep escarpment formed along the limestone Fish River Hills. The Morass has elevations ranging between zero and three metres and is underlain for the most part by peat of varying thickness.³

Map 4.1 General map of Negril



Map 4.2 Nearshore bathymetry (down to 500 m water depth) of the Negril area (depth contours in metres)⁵



reaching 500 and 100 metres at distances less than approximately 6 and 3.5 kilometres, respectively (Map 4.2). A fringing coral reef system is found two to three kilometres from the coastline at water depths of 20-50 m, whereas in the inshore areas isolated coral reef patches are found together with sea grass meadows (Map 4.3).

Beach sands

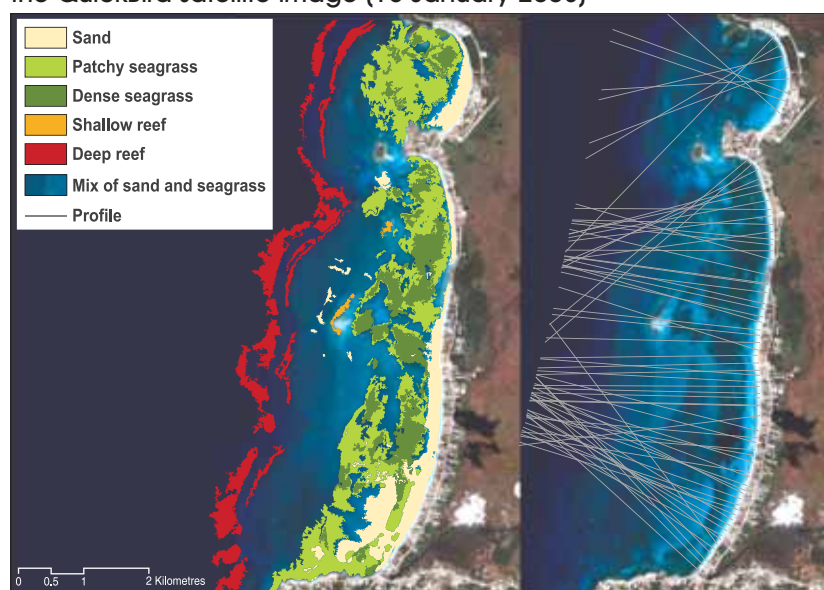
The coastal sediments of Bloody Bay and Long Bay consist almost entirely of moderately or poorly sorted, biogenic sands.⁶ The onshore sediments are generally coarser (median grain diameters or D50s ranging between 0.26 and 1.06 mm) than the shallow nearshore material (D50s between 0.25 and 0.81 mm, with most sediment samples showing D50s of 0.2 to 0.3 mm).⁷ No significant spatial trends of the grain size parameters can be discerned in the 2006 sediment samples,⁸ in contrast to earlier studies that revealed a weak coarsening trend of the sand from the middle section of the Long Bay towards the south.⁹

The beach material is composed of: biogenic material (foraminifera, *Halimeda*, bivalve, red algae, echinoderm, gastropod, serpulidae and coral fragments); amorphous and recrystallized grains, which form the dominating components (approximately 65 percent of the total) and have

The two beaches are bordered by limestone promontories (the Negril Hills, Point Pen and the North Negril Point). The southern beach (Long Bay beach) has a length of about seven kilometres, and the northern beach (Bloody Bay beach) a length of about two kilometres. The beaches are characterized by the presence of low beach ridges (rarely exceeding two metres in height) and the absence of a developed backshore dune system.⁴

The beaches are fronted by a narrow shelf, with water depths

Map 4.3 Distribution of the coastal ecosystems and locations of the profiles used for the multiple regression analysis, based on the QuickBird satellite image (16 January 2008)



been produced through geochemical alteration of the original biogenic material.¹⁰


Coral fragments, however, only form a minor component of the Negril beach sediments.¹¹ It appears that the main source of the beach sand in Negril is most probably the abundant sea grass meadows which include *Halimeda* patches.¹² Sea grasses therefore play a very important role in the long-term supply and evolution of Negril beaches.

However, biogenic sediment production rates are considered to be low in the study area, not exceeding 5,000 m³/yr.¹³ Radiocarbon dating of the beach sediments has shown that the Negril beachface still contains biogenic material produced more than 600 years ago.¹⁴ In addition, the recently observed changes in the composition of the beach biogenic material indicate a possible reduction in the areal coverage of the sea grass meadows and/or pollution stress.¹⁵ Therefore it appears that the natural sand resource of the Negril beaches is both limited and diminishing, suggesting an increased vulnerability of the beach to wave-induced erosion.¹⁶

Wave regime

The area is characterized by a generally moderate hydrodynamic or wave regime. Tidal ranges are small along the Negril coastline, not exceeding 0.6 m and 0.2 m during highs and lows respectively, whereas tidal currents have a northeast-southwest orientation, with magnitudes of up to 0.2 m per second.¹⁷ The Negril coast

is also affected by meteorological and wave-induced currents, which can dominate or even reverse the weak tidal flow. The wind and swell waves impinging onto the Negril beaches come mainly from the northwest and west. The coast is also affected by tropical storm-induced, energetic waves and sea level increases (Table 4.1). Hydrodynamic modelling has indicated that the 10-year-return-period (yrp) event can generate coastal storm surges of up to 0.3 m, whereas the 50-yrp event can bring coastal storm surges of up to 1.5 m.¹⁸



RiVAMP highlight

This study as well as previous studies in Negril have shown significant beach erosion and coastal ecosystem degradation, suggesting an increased vulnerability of the beach to potentially strong wave pressure, especially caused by tropical storms and cyclones.

Negril's sandy beaches front onto a narrow shelf composed of patchy sea grass beds, dense sea grass beds, deep reefs and shallow reefs. These ecosystems play a crucial role in providing beach material as well as dissipating nearshore waves (discussed further below).

Table 4.1 Deep water characteristics of tropical storm-generated waves and sea levels in the Negril area for several return periods (SWI, 2007). Key: Hs = significant wave height; Period = significant wave period; Max. combined sea level elevation, sum of inverse barometric pressure effects, long-term sea level rise (assumed at 5 mm/yr) and tidal effects (0.3 m above Mean Sea Level on springs)

Return period (years)	Hs (m)	Period (s)	Max. combined sea level elevation (m)	50 yrp probability (%)
5	4.7	8.7	0.45	100.0
10	6.4	10.7	0.65	99.5
25	8.2	12.4	0.74	87.0
50	9.2	13.4	0.93	63.6
100	10.2	14.3	1.25	39.5
150	10.7	14.7	1.29	28.4

4.3 Rates of beach erosion based on previous studies

Previous studies by UWI (2002) and by SWI (2007) commissioned by NCRPS indicate that over the last 40 years the Negril beaches have been experiencing severe erosion (irreversible shoreline retreat). For the period 1968-2006, average beach erosion rates have been estimated at 0.5 m per year for Bloody Bay and 1 m per year for Long Bay. These trends, however, have been observed to show large spatial and temporal variability,¹⁹ with periods of intensive erosion alternating with periods of accretion. A trend of slower beach recovery following severe storms has also been discerned since 1990.



Berm scarp along Long Bay beach (October 2009). The constrained length of scarps can indicate beach replenishment (Dean, 2002; Zarkoyiannis et al. submitted)

Negril's beaches are mostly natural, as only limited (and undocumented) beach nourishment and coastal defense schemes have been implemented mostly along the northern Long Bay section.²⁰

Wave and sediment transport observations and modelling²¹ have suggested that local wind waves are mostly accretional (i.e. they promote beach recovery). In comparison, the energetic swell waves are mostly erosional, as they may induce significant offshore sediment transport past the local closure depth and drive sediments to the deep offshore areas where they are forever lost to the beach system. Hurricanes and tropical storms that generate large swells are therefore likely to amplify beach erosion.

Although the western Jamaican coast seems to have had a relatively mild tropical storm regime during the 20th century (less than one hurricane per year and a quiet period from 1981-2000), there appears to be a recent increase in hurricane activity.²² This is in agreement with Webster et. al. (2005) who described a global increase of cyclone intensities as well as an increase in the number of cyclone events in the North Atlantic Ocean over the last decade, a trend that will have important implications for Negril beaches.

4.4 Estimation and possible drivers of beach erosion

In the RIVAMP study, the assessment of beach erosion in Negril has been undertaken by revisiting already available information and analyzing newly acquired satellite information. The collated information consisted of the following: (i) the 1968, 1980, 1991, 2003 and 2006 historical shorelines, digitized from remotely sensed information (aerial photographs and satellite images) and field surveys, and (ii) a comprehensive set of 74 beach profiles along Bloody Bay and Long Bay (acquired in November 2006).²³ New information consisted of a high resolution satellite image (0.60 m multispectral) taken by the QuickBird satellite sensor on 16 January 2008, purchased by UNEP for this study.

Although the available information can provide an estimation of the historical changes of the Negril beaches, it should be noted that such analyses carry some limitations. Remote-sensed spatial

shoreline information can be associated with various errors. Firstly, the interpretation of very high resolution satellite images of the shoreline could still give rise to errors without validation by simultaneous ground-truthing, due to beach slope or wetness effects.²⁴ Secondly, all shoreline positions had not been corrected for tidal effects. Thirdly, and most importantly, the information has been collected across different seasons and without any control for the effects of the seasonal and/or random erosion and accretion patterns. With regard to the available beach profile information, although the profiles have been tidally-corrected to Mean Sea Level (MSL),²⁵ this still represents “on-the-spot” beach morphologies but not long-term averages.

In order to acquire a more realistic (and conservative) estimation of beach erosion rates, the historical shorelines were transformed using the following procedure. First, the horizontal displacement of the shoreline due to tidal effects has been estimated for the 2006 and 2008 data sets (for which acquisition times are available), on the basis of the local tidal curves and the 2006 beach profiles. For the remainder of the data sets, the shorelines were displaced landward using the maximum horizontal landward displacement, which can be driven by a 0.3 m tidal level rise above the MSL (spring tides).

The results of the analysis (anchored on the 74 beach profiles of SWI, Map 4.4) confirm that the Negril beaches have been under severe erosion in the last 40 years, with some sites experiencing shoreline retreats of more than 55 m for the period 1968–2006. Erosion has been both temporally and spatially variable. Bloody Bay has been associated with lower erosion rates than Long Bay, whereas the highest erosion rates have been recorded after 1991, when slower beach recoveries after storms have been observed.²⁶ Erosion rates also showed a large spatial variability along the Long Bay shoreline (Map 4.4), with the beach area that fronts the north and south sides of the coral reef showing higher rates of erosion.²⁷ Analysis of the most recent, satellite image-derived information (2008) suggests continuation of the above trends.

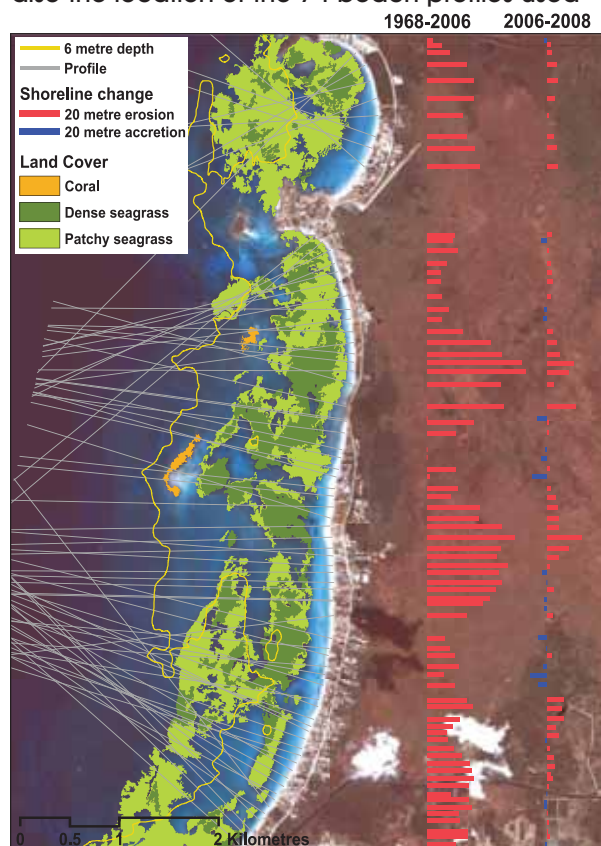
Several factors may be responsible for the observed trends, such as long-term or accelerated sea level rise (ASLR), the intensification of extreme events,²⁸ diminishing nearshore biogenic sand production

and anthropogenic impacts. Concerning ASLR, in the absence of accurate local information, the global average of the last century (3.4 mm/yr) is applied²⁹; this gives a sea level increase of 0.14 m in the last 40 years. Such an increase would give a maximum shoreline retreat of approximately six metres that may be attributed to ASLR, which in itself does not explain the observed trends of beach loss in Negril.³⁰

Storm intensification could certainly contribute to erosion, provided that there is no adequate supply of new material to replace mounting offshore losses.³¹ This is likely to be the case in Negril, which is experiencing a diminishing supply of biogenic sand production from sea grass meadows and coral reefs. While it appears that the sediment sources of Negril beaches are in depletion, more research is required in order to accurately assess the overall sediment volumes and budgets.

In addition, coastal development over the last 40 years has also contributed to the observed erosion. Sand barriers naturally tend to “roll over” or

Map 4.4 Nearshore bed cover and shoreline changes along Negril’s beaches, showing also the location of the 74 beach profiles used



self-adjust (e.g. by migrating inland) under rising sea levels and storm surges.³² However, coastal development (e.g. coastal roads and buildings) inhibits this natural process of beach adjustment and “locks” beaches at certain positions. Vertical incision (down-cutting or scouring) occurs when the beach is constrained, therefore inducing offshore material losses and beach drowning.³³

Finally, the degradation of nearshore ecosystems (sea grasses, mangroves and coral reefs) as well as over-harvesting of reef-cleaning, algae-eating animals such as the parrot fish are also likely driving causes of beach erosion.³⁴ (Ecosystems decline is discussed in greater detail in Section 3).

With respect to the observed spatial variability of beach erosion, this could be attributed to the particular long-shore distributions of the wave energy, wave-induced circulation and sediment transport patterns (discussed further in the following sub-sections).



Adequate scientific evidence shows that over the past 40 years Negril’s beaches have been experiencing severe and irreversible shoreline erosion and retreat. Erosion is variable both temporally and spatially.

Bloody Bay has experienced lower erosion rates than Long Bay, with sections of Long Bay beach that are fronting either side of coral reefs showing higher rates of erosion. In addition, the highest erosion rates have occurred after 1991, when beach recovery after storms has been slower, and these trends are likely to continue. It is expected that long-term sea level rise, a changing tropical storm and cyclone regime in the region (in terms of both frequency and intensity) as well as diminishing sand supplies due to declining nearshore ecosystems and coastal development will take an even higher toll on Negril’s beaches.

4.5 Effects of coral reefs and sea grass on beach morphodynamics

Distribution of shallow water ecosystems

Previous wave and sediment transport modelling³⁵ and *in situ* observations³⁶ in Negril suggest that the underwater ecosystems (e.g. shallow coral reefs) may perform beach protection functions, as they dissipate wave energy and reduce nearshore wave heights; and generate particular nearshore flow and sediment transport patterns that induce beach accretion at their lee (i.e. areas fronting coral reefs).

In previous studies, UNEP has already demonstrated that multiple regression analyses can highlight the linkages between environmental features and coastal protection.³⁷ Thus, the spatial distribution of the coral reefs in the Negril coastal waters (particularly that of the shallow coral reefs) may control beach erosion variability.³⁸ Moreover, as discussed previously, the nearshore sea grass meadows appear to be the most significant local source of new sand material.

In order to further study the significance of coastal ecosystems for the Negril beach morphodynamics, two different methods were used. The first method uses numerical modelling (both two dimension 2-D and one dimension 1-D) to study the coral reef impacts on nearshore dynamics. The second method employs multiple regression analysis in order to examine whether coral reefs and sea grass meadows act as a control over the observed beach erosion patterns.

4.5.1 Numerical modelling

A nearshore 2-D wave propagation model (WAVE-LS), developed by the University of the Aegean (for details see Annex 3) was used to assess the nearshore hydrodynamics under different wave regimes. The offshore bathymetry used for the model initialization was provided by the 2006 bathymetric survey.³⁹ For the RiVAMP study, this data set was extended to include onshore beach elevations of up to one metre above MSL, using the 74 beach profiles obtained at the same time.⁴⁰

With regard to model-forcing, several experiments were conducted using different offshore wave regimes, such as local wind waves, swell waves and extreme storm conditions. In all cases (for more samples of modelling results, see Annex 3), the results show considerable effects of the shallow coral reefs on the wave propagation patterns in shallow waters as well as the wave-induced current fields (Figure 4.1), as they create “shadows” at their lee that are associated with wave energy decrease.⁴¹ The modelling suggests that the beach at the lee or protected side of the shallow reefs is less likely to be eroding, which is supported by the historical beach erosion trends (Map 4.4). The model also predicts flow eddy formation⁴² in either side of the coral reefs, which intensifies under increasing wave energy and therefore induces erosion. Finally, although the above hydrodynamic features are present under all tested directions of wave approach, their aerial extent and intensity appears to be sensitive to the wave direction. These results are in broad agreement with those derived in previous studies.⁴³

In order to study further the effects of the coral reefs on beach dynamics, the cross-shore distribution of the wave-induced bed shear stress (i.e. of the force per bed unit area), which is the decisive factor for the mobilization of beach sediments,⁴⁴ has been simulated by the 1-D (one-line) cross-shore model SBEACH.⁴⁵

Experiments were run for different wave conditions and sea levels. The sea levels considered in both these and subsequent numerical experiments have been chosen to include tidal effects, storm surges and the long-term sea level rise. For the tidal effects, a SMHW (mean high water on springs) of 0.3 m higher than the MSL is used and coastal storm surge according to the SWI (2007) estimations (0.3 m and 1.5 m for the 10- and 50-year return storm, respectively). For ASLR, the minimum and maximum rates of the Rahmstorf (2007) predictions have been used (Table 4.2).

The results (Figure 4.2), which are in broad agreement with those from the regression analysis (See Section

Figure 4.1 Numerical model results for wave heights (a) and wave-induced currents (b) at the Negril coast. Conditions: Offshore wave height (H_{rms}) = 2.8 m, T_p =8.7 s. Waves approach from the northwest. Note the diminishing wave heights and changed nearshore flow patterns at the lee of the shallow coral reefs

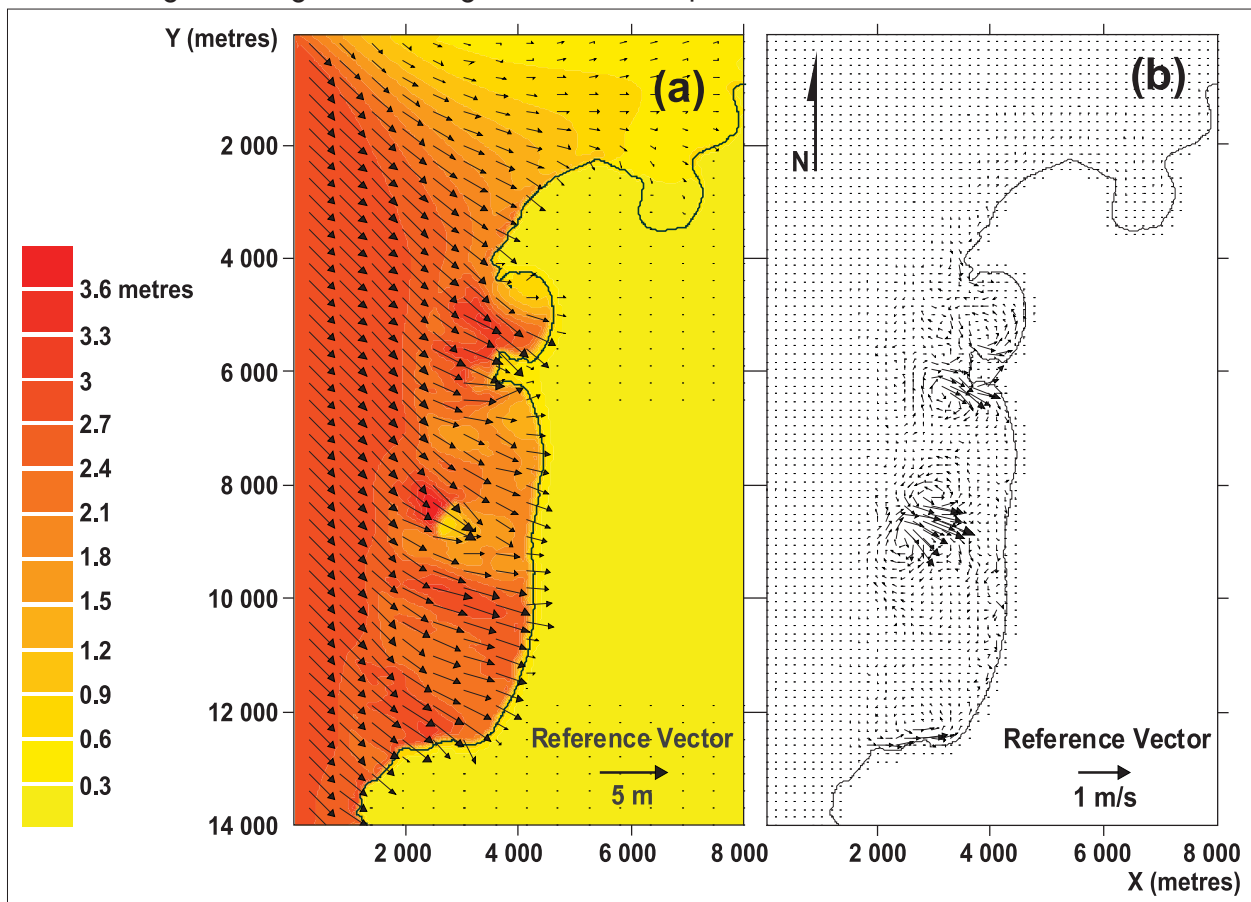
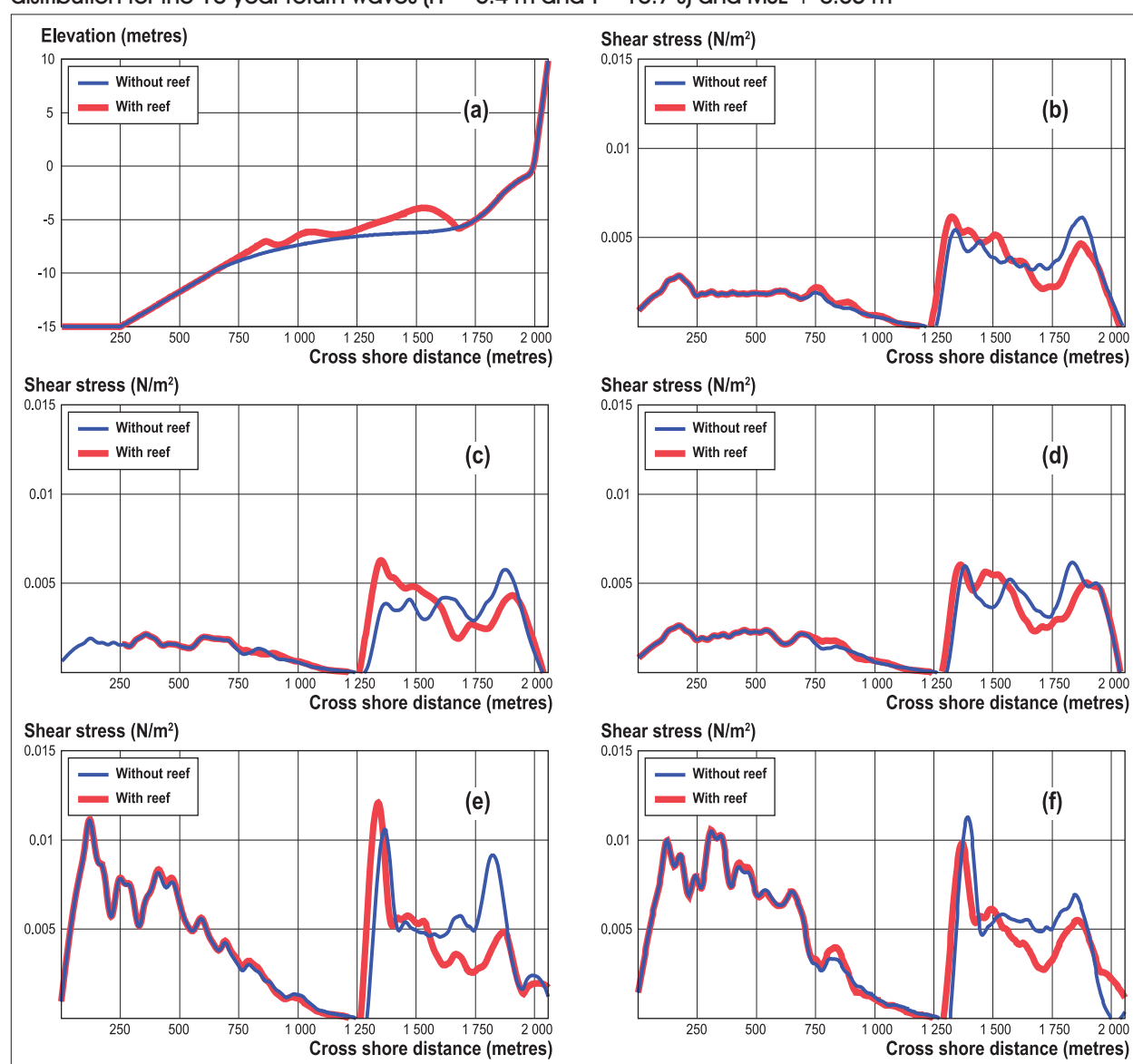


Table 4.2 Minimum and maximum levels (above MSL) used in the simulations. Long-term sea level rise is estimated on the basis of the Rahmstorf (2007) predictions and the assumption of linear increase

Return period (years)	Hs (m)	T (s)	Tidal level (m)	Coastal storm surge (m)	Min. ASLR (m)	Max. ASLR (m)	Min. combined sea level (m)	Max. combined sea level (m)
10	6.4	10.7	0.3	0.3	0.05	0.15	0.65	0.75
50	9.2	13.4	0.3	1.5	0.22	0.75	2.02	2.55

Figure 4.2 Modelled reef effects on the wave-induced shear stress by the SBEACH model (Larson and Kraus, 1989). (a) beach profile (b) cross-shore shear stress distribution for Mean Sea Level (MSL) and swell waves ($H_s = 2.8$ m and $T = 8.7$ s); (c) shear stress distribution for swell waves ($H_s = 2.8$ m and $T = 8.7$ s) and MSL + 0.52 m; (d) shear stress distribution for swell waves ($H_s = 2.8$ m and $T = 8.7$ s) and MSL + 1.05 m; (e) shear stress distribution for the 10 year return waves ($H = 6.4$ m and $T = 10.7$ s) and MSL; (f) shear stress distribution for the 10 year return waves ($H = 6.4$ m and $T = 10.7$ s) and MSL + 0.65 m



4.5.2) and the 2-D numerical models, show that the shallow coral reef functions as a natural breakwater, as the nearshore bed shear stress decreases at its lee. As expected, coral reef effects appear to be

more significant under higher wave forcing (Figure 4.2e) and less significant under increased sea levels (with the assumption that there will not be corresponding coral reef growth).

4.5.2 Applying multiple regression analyses

Selection of the variables with potential link to beach erosion

The variable to be explained is the length of beach erosion in the last 40 years. This has been estimated from the comparison of the (corrected) beach widths in 1968 (obtained through the analysis of aerial photos undertaken by SWI, 2007) and in 2008 (obtained from the QuickBird satellite image). The classification exercise shows that although there is an extensive fringing coral reef in deeper waters,⁴⁶ shallow coral reefs are particularly limited (6.4 ha). With regard to sea grasses, dense meadows are the minority (approximately 195.1 ha), with patchy sea grass meadows covering a larger surface (approximately 406.1 ha). It would have been interesting to be able to compare the recent and past seabed coverage, but such a comparison has not been possible, due to the scarcity and/or low resolution of the relevant historical information and satellite imagery. The selection of sample sites for analyses was made based on the 74 beach profiles measured in 2006,⁴⁷ which provide the slope of the beach.

Simple scatter plots of the maximum beach erosion against the cross-shore widths of the coral reefs (Figure 4.3) and sea grass meadows (Figure 4.4) along these profiles already provide clear evidence of the important role of these ecosystems. There is a general negative correlation between the area coverage of coral reefs and sea grass meadows and maximum beach erosion, indicating that they play a significant role in beach erosion mitigation.

Since other parameters, such as beach slope and the nearshore wave regime, also influence beach erosion, further analysis has been undertaken for the multiple regression. (See Annex 3 for a more detailed discussion of variables extracted for the multiple regression). GIS tools were used to estimate the cross-shore width of coral reefs and sea grass meadows at the location of the 74 beach profiles. The original short profiles were merged with bathymetric data, extrapolated offshore (see Map 4.3, right) and overlaid with land cover classification to extract width of environmental features and other morphological parameters (Map 4.4).

The length of beach erosion was computed by subtracting the beach width in 1968 (obtained

Figure 4.3 Width of coral versus beach erosion (in metres)

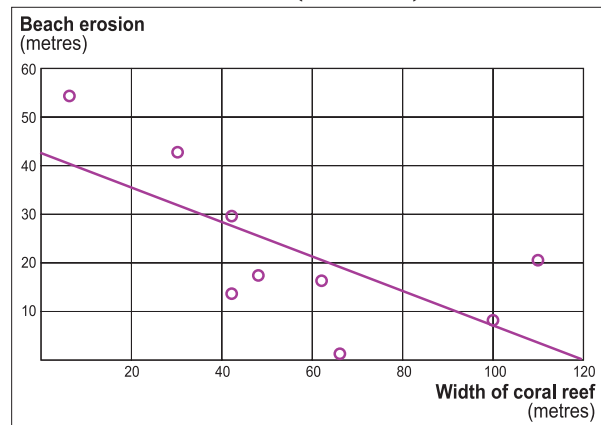
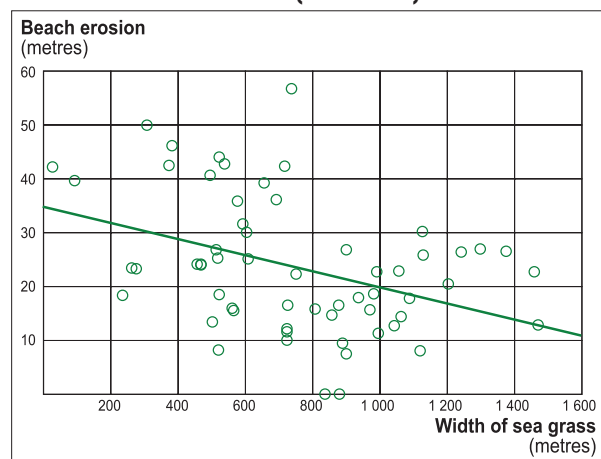


Figure 4.4 Width of sea grass versus beach erosion (in metres)



via aerial photos⁴⁸ with the beach width in 2008 (obtained from the QuickBird satellite image of January 2008). Further details in selecting the variables used for the multiple regression analysis may be found in Annex 3.

Results of the multiple regression analyses

Multiple regression analyses indicate that both the coral reef and the sea grass meadows are the main features in the model that effect a mitigating role on beach erosion, as these results confirm that the cross-shore width of these ecosystems is negatively correlated to the maximum beach erosion. However, the submarine beach slopes as well as the wave regime are also shown to have an influence on beach erosion.

On the basis of the analyses, two models were constructed. The first model (Figure 4.5) shows that

Figure 4.5 Regression for points behind shallow coral reefs (nine sites)

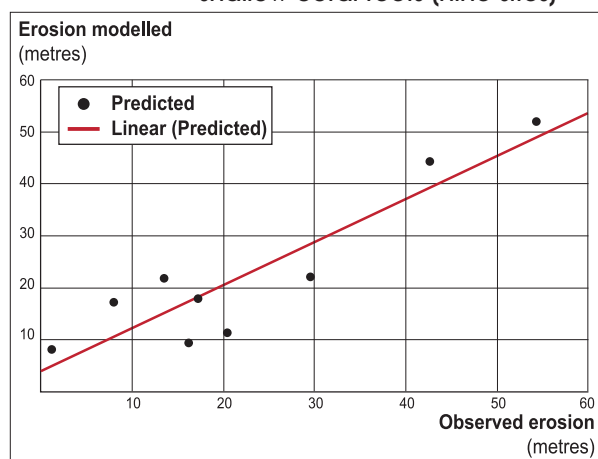
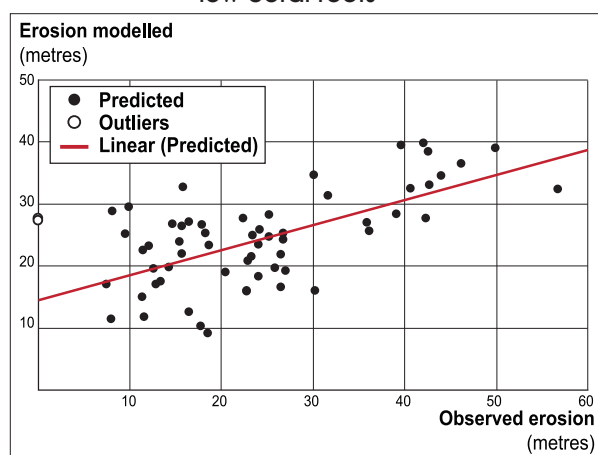


Figure 4.6 Regression line for beach points which are not protected by shallow coral reefs



beach erosion is negatively correlated with width of coral reef and slopes (Pearson coefficient of 0.91). Based on the model, coral reefs explain 83 percent of beach erosion, with the width of coral reefs playing the main role (59%) in reducing erosion. The second model (Figure 4.6) shows that beach erosion is negatively correlated with width of sea grass, slopes and Iribaren number⁴⁹ (Pearson coefficient 0.64), suggesting that the areas with steep profiles and/or less steep waves result in milder beach erosion, whereas areas behind gentle submarine slopes are susceptible to erosion. Based on the model, sea grasses explain 41 percent of beach erosion, with the width of sea grasses playing the main role (47%) in reducing erosion. In other words, areas with wider coral reefs and sea grasses experience less erosion. The regression lines of these models provided below (Figures 4.5



Significant linkages between nearshore ecosystems and beach vulnerability to erosion are demonstrated. Hydrodynamic modelling has shown that the shallow coral reefs attenuate the wave energy and promote patterns of longshore sediment transport that mitigate beach erosion to their lee (i.e. areas that directly front coral reefs).

Moreover, the observed rates of maximum beach erosion (1968-2008) have been found to be negatively correlated with the cross-shore extent (width) of coral reefs and dense sea grass meadows, suggesting also that these ecosystems provide protection to the beach.

In addition, the nearshore ecosystems, particularly the sea grass meadows, appear to be the most significant source of natural beach material for Negril's beaches. Degradation of these ecosystems will therefore result in a diminished beach sediment supply, which in turn will exacerbate beach erosion.

and 4.6) show the modelled erosion (y axis) versus observed erosion (x axis). Both models are robust. These combined results show that coral reefs and sea grasses exert a positive control on beach erosion. The extent of erosion is, however, also influenced by the characteristics of submerged beach slopes and the nearshore wave regime.

4.6 Morphodynamics under rising sea levels and storm surges

Sea level rise and storm surges are likely to have significant impacts on Negril beaches. The beaches will respond to rising sea levels with retreat, the extent and rate of which depend also upon the bed slope, the texture and budget of the coastal sediments, the wave regime as well as the health status and distribution of coastal ecosystems (coral reefs and sea grasses). In order to assess the range of shoreline retreat (i.e. the reduction of beach width) of Negril beaches under various rates of sea level rise

and storm surge, an ensemble of six coastal morphodynamic models have been used (Figure 4.7).⁵⁰ It must be noted that there are differences between the consequences of storm surges and ASLR, as the latter can result in permanent reductions of the beach width. While beaches may recover following the storm surge relaxation, in contrast ASLR results in irreversible coastal retreats.

The coastal retreat expected for the Negril beaches facing ASLR has been assessed through the application of six widely-used analytical and numerical models⁵¹ (for details see Annex 3). Experiments have been carried out for different morphological (beach slope), sedimentary (grain-size) and wave characteristics. As coastal retreat due to sea level rise is controlled by the level and distribution of the wave energy, which in turn controls not only the dynamics of the beach sediments but also the position and depth of the wave breaking, width of the surf zone as well as the sediment transport closure depth,⁵² the models were applied using varying wave conditions, i.e. wave heights (H) of 1, 2, 3, 4, 5 and 6 m and periods (T) 3, 5, 6, 7, 8, 10 and 12 seconds.

For each set of wave conditions, experiments were carried out for 5 different sediment grain sizes (D50s of 0.2, 0.33, 0.50, 0.80 and 1 mm) and 14 sea level rise rates (0.038, 0.05, 0.10, 0.15, 0.22, 0.30, 0.40, 0.50, 0.75, 1, 1.25, 1.50, 2 and 3 m). Experiments with smaller ASLR rates were also carried out, but as some models showed instabilities, their results have not been included in the estimations. All experiments concerned beaches where sediment erosion is not constrained by the sediment availability.⁵³ Regarding the beach morphology, linear profiles were used (slopes of 1/10, 1/15, 1/20, 1/25 and 1/30).

The modelling showed that positive sea level changes result in beach retreats that are also accompanied by morphological changes to the beach. The results from the different models varied for almost all the tested conditions, showing also significant ranges, due to the different morphological, hydrodynamic and sedimentological forcings employed. The Bruun model gave a relatively narrow range of coastal retreat, whereas the SBEACH and Leont'yev models produced relatively large ranges.⁵⁴ Most models (with the exception of the Bruun model) showed sensitivity to wave conditions,

with a positive correlation between wave height and beach erosion. As future sea level increases are expected to be accompanied by intensification in the mean and extreme wave conditions,⁵⁵ the positive relationship between wave height and beach erosion suggests that Negril's beaches will be increasingly vulnerable.

On the basis of the ensemble modelling results, predictions can be presented with regard to the minimum and maximum shoreline retreat (beach erosion) of Negril beaches under different combinations of sea level increases (Table 4.3). It must be noted that although the above predictions can apply to sea level increases from a combination of forcings (i.e. tidal effects, storm surges and ASLR), considerations referred to earlier should also be taken into account. Nonetheless, the most significant (and irreversible) damage to Negril beaches is going to be inflicted by ASLR.

The current spatial characteristics of the Negril beaches have been estimated through digitization of the 16 January 2008 QuickBird image, with the inshore limits of the beaches set as the seaward margin of anthropogenic structures (such as coastal seawalls and buildings). With regard to the shoreline position itself, the available satellite image was obtained during unknown wave conditions; thus, although tidal effects have been taken into account, there are uncertainties concerning the accuracy of the estimated position of the MSL shoreline, due mainly to wave run-up effects.⁵⁷

Figure 4.7 Range of results for different beach slopes (1/10, 1/15, 1/20, 1/25 and 1/30), wave conditions and sediment sizes. The means for the high and low prediction ranges of the model ensemble (brown stippled lines) are also shown.⁵⁶

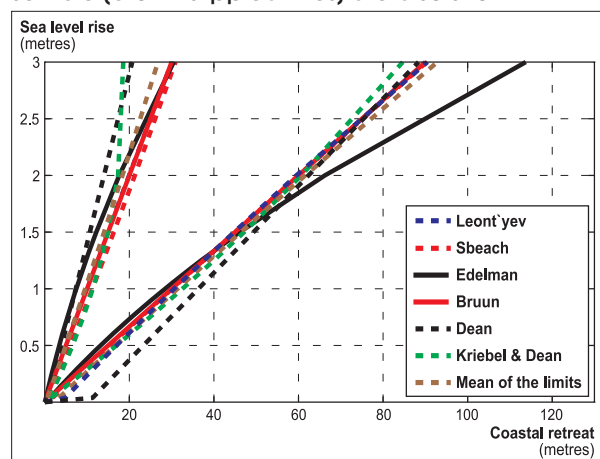
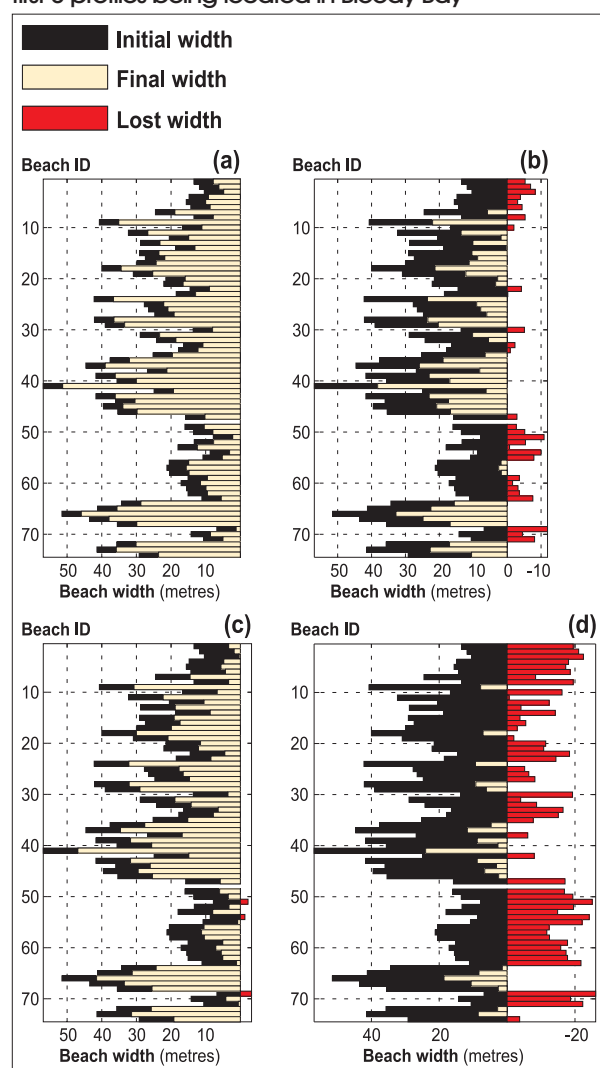


Table 4.3 Maximum and minimum beach retreats under different combinations of sea level conditions

Sea level change (m)	Minimum beach retreat (m)	Maximum beach retreat (m)
0.35	3.6	12.3
0.52	5.3	17.3
0.65	6.3	20.9
0.75	7.5	24.0
1.05	10.0	32.9
2.02	20.6	61.9
2.55	25	78.7

Figure 4.8 Minimum and maximum retreats of the Negril beaches at the location of the 74 profiles (for profile location, see Map 4.3). (a) and (b) minimum and maximum retreats for 0.52 m sea level increase (tidal effects and lowest predicted rise in 2060). (c) and (d) minimum and maximum retreats for 1.05 m sea level increase (tidal effects and highest predicted rise in 2060, see Rahmstorf, 2007). Final width values < 0 show sections of the beach which will be entirely lost. Beach ID progresses from north to south, with the first 8 profiles being located in Bloody Bay



The digitised information was then analysed through GIS tools, to estimate the widths of the Negril beaches at the location of 74 beach profiles (SWI, 2007). These widths were then compared to the minimum and maximum retreats predicted by the ensemble modelling, in the case of normal (Figure 4.8) and extreme storm surge events (Figure 4.9). The results of this rapid assessment exercise suggest very serious implications for Negril. Even in the absence of storm surges, beach erosion will be significant (Figure 4.8), particularly if the expected ASLR will be combined with a diminishing sediment supply.

In the case of extreme events (Figure 4.9), the effects will be dramatic. For example, even when the lowest range of predictions is used, there still will be no beach left as a result of an extreme storm surge in 2060 (Figure 4.9e and 4.9f). It must be noted that the modelling does not take into account the wave run-up effects, which under even moderate wave conditions will further inundate the beach, or the effects of the accumulating beach sand losses due to successive storm surges and diminishing sediment supply.⁵⁸



Cross-shore morphodynamic modelling indicates very significant risks for the beaches in Negril. Estimations based on global projections of long-term sea level rise and local predictions of extreme storm waves and surges have shown that, by 2060, the combination of ASLR and extreme wave surges will be devastating for the overall Negril beach and the coastal infrastructure behind it.

For example, even under the lowest projections of ASLR for 2060, an extreme storm event (the 50-year-return event) will result in the total loss of about 35 percent of the beach (in terms of length), while another 50 percent of the beach will lose more than half of its present width. It should be noted that these projections are based on the minimum retreat predictions of the morphodynamic model ensemble.

Moreover, as the expected climatic changes may also be linked to an intensification or change of the wave regime, the positive correlation between wave energy and beach erosion suggests the following: Even in the absence of extreme storm events, the pilot beaches will be increasingly vulnerable, particularly under conditions of rising sea levels and diminishing natural (biogenic) sediment supply.

Figure 4.9 Minimum and maximum retreats of the Negril beaches at the location of the 74 profiles (for profile location see Map 4.3). (a) and (b) minimum and maximum retreats for 0.65 m sea level increase (tidal effects, lowest predicted ASLR rise in 2020 -see Rahmstorf (2007)-and coastal storm surge of 0.3 m-10 year return storm). (c) and (d) minimum and maximum retreats for 0.75 m sea level increase (tidal effects, highest predicted ASLR rise in 2020 and coastal storm surge of 0.3 m-10 year return storm). (e) and (f) minimum and maximum retreats for 2.02 m sea level increase (tidal effects, lowest predicted ASLR rise in 2060 and coastal storm surge of 1.5 m- 50 year return storm). (g) minimum retreat for 2.55 m sea level increase (tidal effects, highest predicted ASLR rise in 2060 and coastal storm surge of 1.5 m- 50 year return storm). Under maximum retreat the Negril beaches are gone (see also Table 4.3). Final widths values < 0 show sections of the beach that will be entirely lost

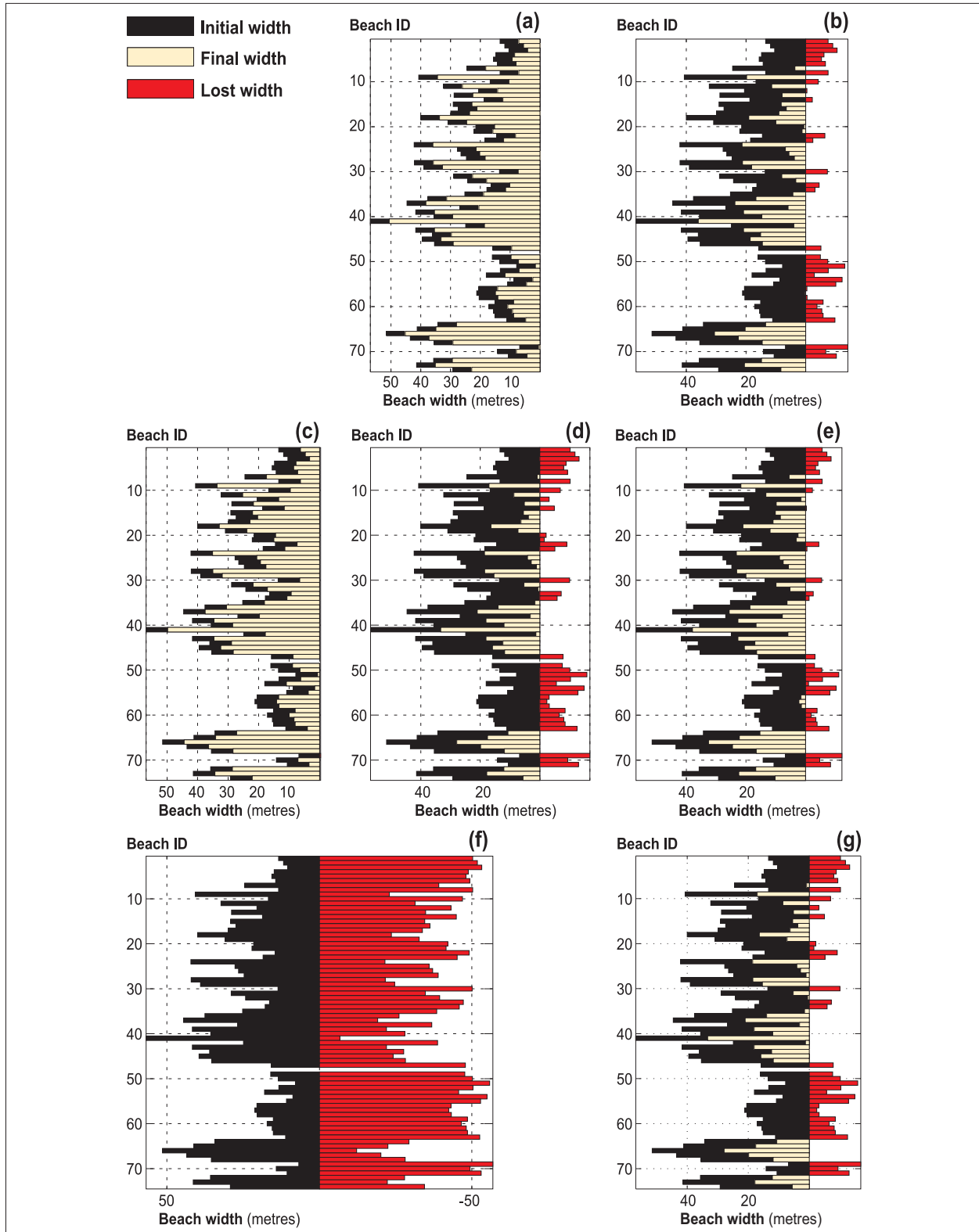


Table 4.4 Maximum and minimum beach losses under several scenarios of sea level rise and under a combination of causes (ASLR, storm surges and tidal effects). The minimum and maximum beach losses correspond to the minimum and maximum retreats predicted by the ensemble modelling (see main text). The beach sections refer to the 74 beach profiles used in the SWI (2007) study (see also Figures 4.8 and 4.9)

Scenario	Minimum losses	Maximum losses	Referenced figure
(1): (0.52 m above MSL, tidal effects + lowest predicted MSL rise in 2060).	7 sections to loose > 50% of their original width	63 sections to loose > 50% of their original width 26 sections entirely lost	Figures 4.8 (a) and (b)
(2): (1.05 m above MSL, tidal effects + highest predicted MSL rise in 2060).	31 sections to loose > 50% of their original width 4 sections entirely lost	All (74) sections to loose > 50% of their original width 53 sections entirely lost	Figures 4.8 (c) and (d)
(3): (0.65 m above MSL, tidal effects + lowest predicted ASLR rise in 2020 and coastal storm surge 0.3 m)	9 sections to loose > 50% of their original width	67 sections to loose > 50% of their original width 33 sections entirely lost	Figures 4.9 (a) and (b)
(4): (0.75 m above MSL, tidal effects + highest predicted ASLR rise in 2020 and coastal storm surge 0.3 m-10 year return storm)	14 sections to loose > 50% of their original width 1 section entirely lost	71 sections to loose > 50% of their original width 36 sections entirely lost	Figures 4.9 (c) and (d)
(5): (2.02 m above MSL, tidal effects + lowest predicted ASLR rise in 2060 + coastal storm surge of 1.5 m- 50 year return storm).	64 sections to loose > 50% of their original width 27 sections entirely lost	All (74) sections lost	Figures 4.9 (e) and (f)
(6): (2.55 m above MSL, tidal effects + highest predicted ASLR rise in 2060 + coastal storm surge of 1.5 m)	69 sections to loose > 50% of their original width 36 sections entirely lost	All (74) sections lost	Figure 4.9 (g)

4.7 Exposure to tropical cyclones

Tropical cyclones generally unfold into multiple types of hazards, namely: extremely powerful winds, torrential rains leading to floods and/or landslides, and high waves and damaging storm surge, resulting in extensive coastal flooding.

The complexity of the multiple forms of hazards triggered by tropical cyclones would normally require a more complex exposure model that factors in wind, precipitation, storm surge and landslides. However,

as landslides do not appear to be a major problem and flood data remains limited in Negril, priority has been placed on modelling potential wind and storm surge impacts.

Wind speed

The applied model consists of transforming cyclones tracks (which is derived from the eye of the cyclone location and physical characteristics of cyclones, Figure 4.10a) into mapping the area affected based on the category of the cyclone's wind speed (Figure 4.10b). Each category corresponds to a given Saffir-Simpson intensity (Table 4.5).

Figure 4.10 Tropical cyclones a) best tracks, b) Saffir-Simpson Categories (SSCat)

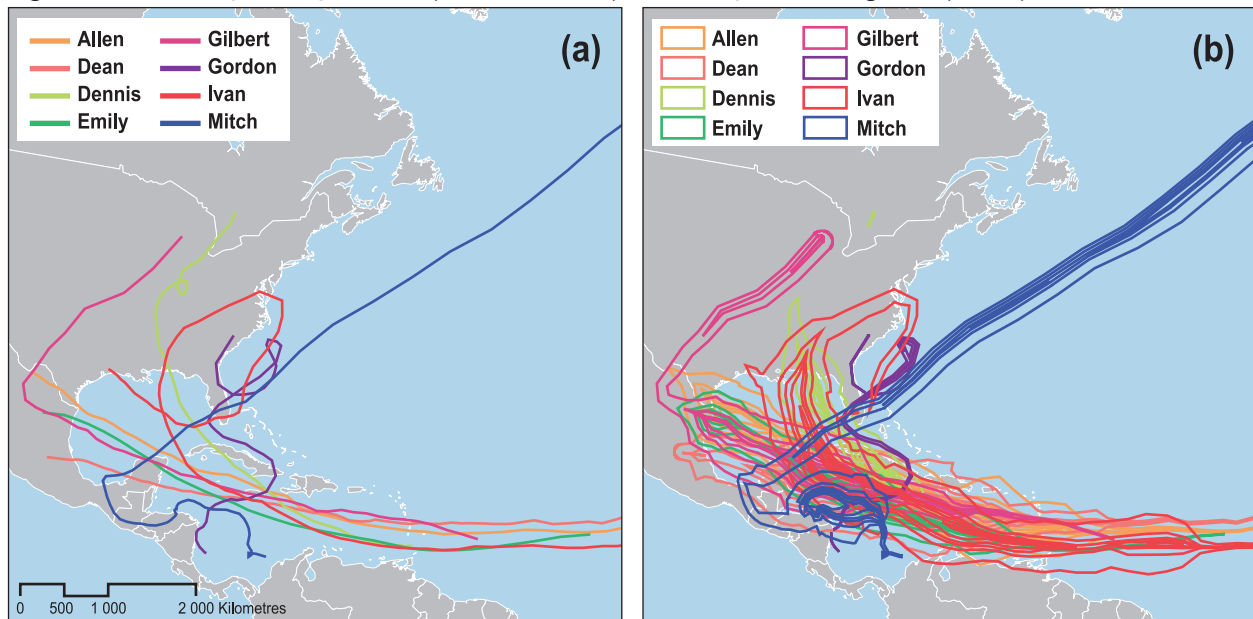


Table 4.5 Saffir-Simpson Categories (SSCat)

SSCat	Pressure (hPa)	Winds (km/h)
Tropical depression	---	---
Tropical storm	---	---
Category I	More than 980	118 – 153
Category II	965 – 980	154 – 177
Category III	945 – 965	178 – 210
Category IV	920 – 945	211 – 249
Category V	Less than 920	More than 259

Table 4.6 Tropical cyclones that reportedly have affected Jamaica

Name	Year	SSCat max event	SSCat max inland	SSCat max Negril
Charlie ⁶⁰	1951	III	II	I
Cleo	1964			
Allen	1980	V	I	I
Gilbert	1988	V	III	III
Gordon	1994	I	TS*	
Mitch	1998	V	TS	TS
Michelle	2001			
Ivan	2004	V	IV	IV
Dennis	2005	IV	I	TS
Emily	2005	V	I	TS
Dean	2007	V	IV	III
Gustav	2008	II	TS	TS

* TS = tropical storm

The model is based on an initial equation by Holland (1980), which was further modified by UNEP/GRID-Europe to take into consideration the movement of the cyclones through time and was applied at a global level over the period 1975-2008. The global dataset is made available by UNEP under PREVIEW Global Cyclones Asymmetric Wind speed profiles.⁵⁹

Table 4.6 lists the tropical cyclones that reportedly have affected Jamaica. The first two listed events are too old to be included in the PREVIEW data set, but information may be derived from other sources. The SWI (2007) report cites Hurricane Michelle in 2001 as having impacted on the island, although PREVIEW modelling does not confirm this information. While tropical storms and cyclones in the region may not produce direct wind and storm surge impacts in Jamaica, it is possible that strong waves generated from such events result in significant property damage in the country. For example, interviews with hoteliers in the West End (the cliffs) in Negril indicate that this is often the case, whereby powerful waves that smash against rock cliffs are generated by hurricanes that do not necessarily pass directly through Negril.

The PREVIEW data set shows that since 1975 eight cyclonic events have affected Jamaica with energy of at least a tropical storm, with four events with real cyclonic intensity having direct impact on Negril. The major event recorded was Hurricane Ivan in



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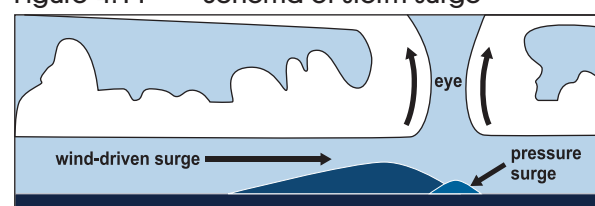
With category 4 winds, Hurricane Paloma's storm track in 2008 completely bypassed Jamaica's west coast but generated massive waves that directly impacted on hotels in the West End

2004 which registered a Saffir-Simpson category IV in Negril. To date, Negril has not directly experienced category V winds. Nevertheless, the possibility of a category V hurricane with direct impact on Negril remains real over the short-term period.

Storm surge

A storm surge is a high flood of water caused by wind and low pressure, most commonly associated with tropical cyclones. The central pressure of a tropical cyclone is so low that the relative lack of atmospheric weight above both the eye and eye wall causes a bulge in the ocean surface level (Figure 4.11) referred to as Inverse Barometric Pressure Rise (IBR). The strong winds then help push the bulging sea water towards the shore. Storm surge heights are related to the hurricane's intensity as well as with the nearshore bathymetry.

Figure 4.11 Schema of storm surge⁶¹



The total storm wave elevation depends on several factors (Table 4.7) namely, the tide, the inverse barometric pressure rise (IBR), the storm surge, the wave run-up and sea level rise. A more severe storm has a lower probability expressed in terms of its returning period. Two scenarios were considered: storms with a 10 and 50 yrp. It should be noted that a low probability event with a 50 yrp is expected to come once every 50 years; however, such an event can occur in any given year. In order to provide the minimum and maximum range of storm wave elevation, Table

Map 4.5 Flood map for two return storm periods



Figure 4.12 On-site GPS measurements taken at the Negril Escape Resort in the West End

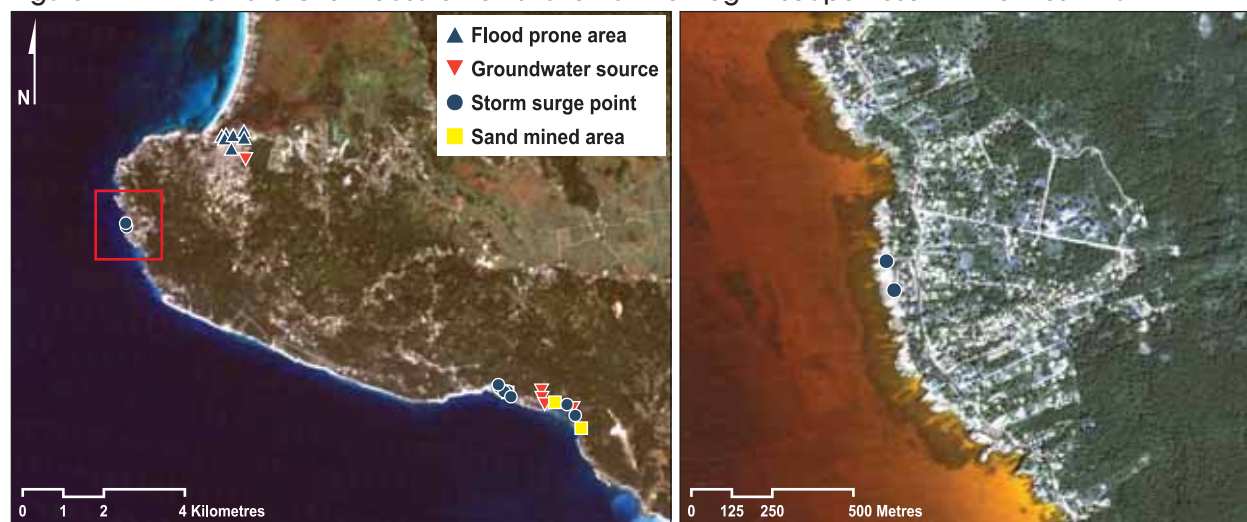


Table 4.7 Parameters used in calculating total storm wave elevation based on a 10- and 50-year return period

Return period (years)	10	50	Comments
Tide (m)	0.3	0.3	From SWI report Table 6-2
Inverse Barometric Pressure Rise (m)	0.22	0.38	From SWI report Table 6-2
Global Sea Level rise (m)	0.10	0.50	1 cm per year
Storm surge (m)	0.3	1.5	From SWI report page 60
Wave run-up (m)	2.7	4.0	RiVAMP simulation ⁶²
Total storm wave elevation	3.6 m	6.7 m	

4.7 provides the lowest and highest expected values for a 10 and 50 yrp event respectively though any combination of values within this range is possible.

Table 4.7 details the different parameters of the entire coastline that have been included, with the exception of the southwestern cliffs. With respect to the cliffs, a detailed bathymetry and wave measurements were not available to use a model and the cliff morphology might be expected to prevent the waves from flooding far inland. The only available information regarding the actual elevation of waves in the cliffs was determined based on GPS measurements taken on-site in November 2009 (see Figure 4.12), which gave a maximum affected elevation of 7.5 m above sea level for a 10 yrp, and 8.0 m above sea level (with ASLR projections added) for a 50 yrp. Storm waves generally crash against the cliffs and are “lifted” over the rocks, which could therefore reach elevated heights and potentially impact on property built on the cliffs. Differentiation with respect to exposure between the beach (or low lands) and the cliff simulation is discussed in the following sections.

The data used to map surge hazard are based on a detailed elevation model at six metre of resolution provided by PIOJ (Map 4.5). This simplified model shows flooding in all areas below the height of the storm wave. The event in which a natural barrier might exist to protect a lower-lying ground further inland from flooding is not considered, as it could be destroyed by the successive waves during a cyclonic event and a breach may be created to allow flood waters further inland.

Map 4.5 shows that flooding during a 10-year return period (dark blue) remains confined on the shoreline, especially along Long Bay, with the exception of the low area where the rivers bordering the Great Morass to its south, north and central section are located. There is also potential for major flooding in low-lying areas to the south, including Homer’s Cove in the Little Bay area. Additionally, on the cliffs, serious flooding could be expected due to wave splash; and flooding on a 50-year return period (light blue) expand into the Great Morass and the New Savannah river area.

Figure 4.13 Ten-year return period exposure for a) population, b) assets

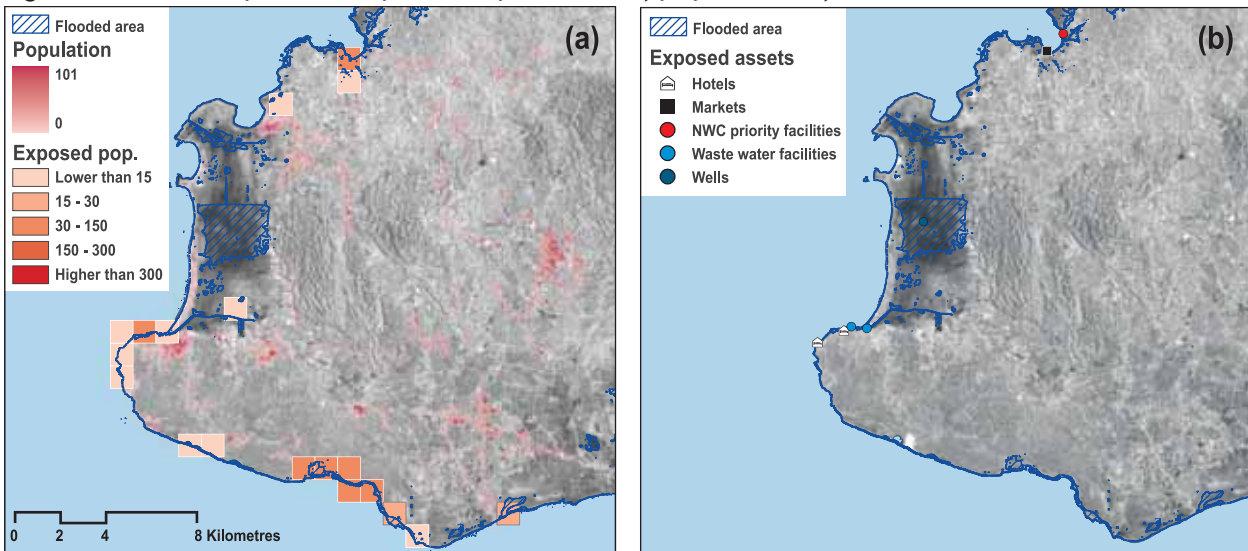
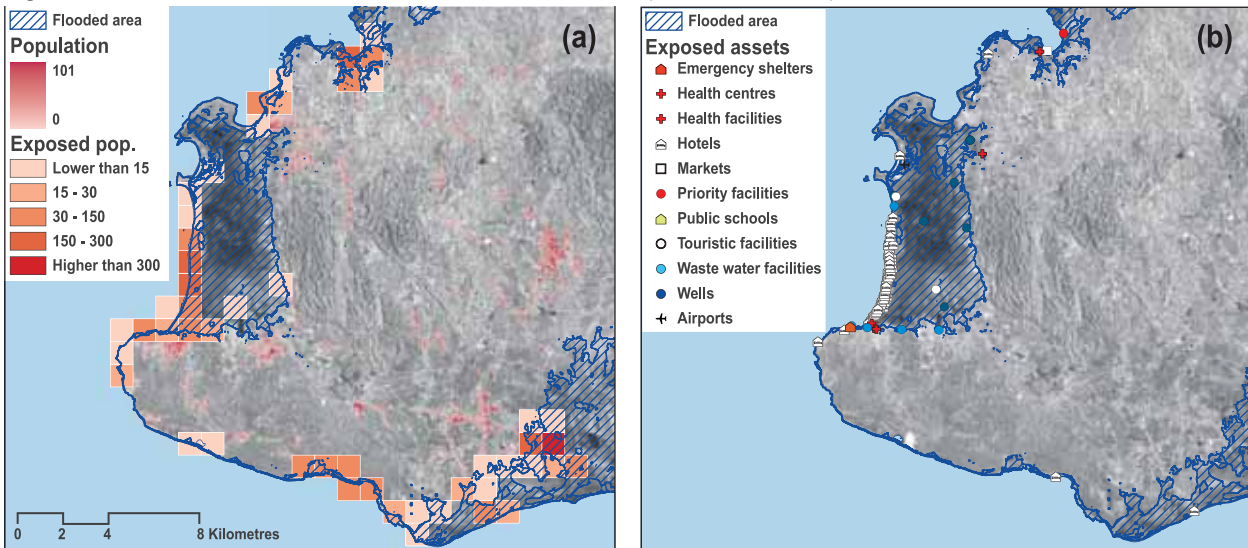


Figure 4.14 Fifty-year return period exposure for a) population, b) assets



Based on the GIS mapping results, exposure of human population and assets (infrastructure) was calculated for each return period (See Annex 3 for further details). Human population refers mainly to the residing population. However, tourist populations have not been accounted for due to the lack of local data regarding hotel room capacities. As a result, estimates of human exposure may under-calculate the potential numbers of people exposed.

In a 10-year return period, a total of 478 people could be affected by flooding due to a tropical storm (102 on the beach, 376 on the cliff) located mainly in Little Bay, Whitehall and the Green Island area. In terms of assets, the exposure is concentrated in the West End (the cliffs) affecting two hotels

and two wastewater treatment facilities and in the Green Island area.

In a 50-year return period, a total of 2,487 people could be affected by flooding due to a tropical storm (2,016 on the beach, 471 on the cliff) mainly in Long Bay, Bay Road area and Orange Bay. In terms of assets, exposure is concentrated overall in the Morass, with hotel exposure concentrated particularly on the Long Bay coastline.

In summary, over the short-term, exposure to tropical cyclones is concentrated in a few sections of the cliff (West End and Little Bay area).⁶³ However, over the long term, exposure will increase and affect the Long Bay shoreline with major impacts on hotels and the Morass environment.

Table 4.8 Assets exposure from a 10-year return period storm

Asset type	Beach	Cliff
Hotels		2
Markets	1	
NWC priority facilities	1	
Wastewater facilities		2
Wells	1	

Table 4.9 Assets exposure from a 50-year return period storm

Asset type	Beach	Cliff
Emergency shelters		1
Health centres	3	
Health facilities	2	
Hotels	61	2
Markets	1	
Nwc priority facilities	2	
Public schools		1
Touristic facilities	3	
Waste water facilities	6	2
Wells	9	
licj airport	1	



RiVAMP highlight

Given tropical cyclone history over the past 50 years and the regional trend of storm intensification, there is a high probability of a category 5 hurricane with significant direct impact on Negril's population, its beaches and coastal infrastructure.

Based on simulations of a 50-year return period event, the related storm surge and subsequent flooding could expose some 2,500 people, affecting mainly the Long Bay coastline and the Great Morass environment.

4.8 Conclusions

The results of the RiVAMP study suggest that coastal ecosystems, coral reefs and sea grass meadows in particular, are extremely important beach attributes as they protect the beach from erosive wave action and supply the beach with biogenic sand. However, this study does not preclude the importance of other types of coastal vegetation to shoreline protection, especially given the progressive removal of trees along the Negril coastline for tourism since the 1980s. In the case of Negril, due to limited availability of information, a greater focus was placed on coral reefs and sea grasses in the analysis.

Results further reveal that Negril beaches are already under very considerable erosional pressure, which will most likely intensify in the future. Possible drivers of the current beach erosion are (a) ASLR (which in itself cannot explain the observed rates of erosion); (b) recent intensification or changes in the regional storm wave and surge regime, which may have increased the offshore beach sediment losses and (c) reductions in the coastal ecosystem (shallow coral reef and sea grass meadows) area coverage, which have diminished both the natural beach protection and the biogenic sediment supply.

Under these circumstances, and taking into account the expected climatic changes, Negril beaches are not expected to recover naturally over the short or medium term. Instead, it is expected that beach erosion will further increase, putting human populations and built infrastructure on the sand barrier beach into considerable storm surge and flood risk. Critically important environmental systems, such as the Morass, are also likely to be affected. Therefore, significant correction measures are required to avert not only the destruction of these coastal ecosystems and infrastructure, but also protect a critical resource for the survival of Jamaica's tourist industry.

As a 'business as usual' approach is no longer an option given the economic importance of the beach, it is recommended that a longer-term strategy and integrated approach be considered to establish a more sustainable development course in Negril (discussed further in Section 6). Results of the quantitative assessments undertaken in this study initially point to three main courses of action to address long-term beach loss:⁶⁴

- protection and enhancement of coastal ecosystems, especially coral reefs and sea grasses;
- beach nourishment, i.e. re-supply of the beach with suitable imported sediments, preferably biogenic marine sands (marine aggregates) of suitable grading and composition; and
- construction of offshore structures (e.g. submerged breakwaters) to protect the beach from the wave action.

In considering short and long-term options to address the problem of beach erosion, the RiVAMP pilot results clearly demonstrate the critical services that coastal ecosystems provide to the Negril beach, as they are the sole natural resource of sandy material in the area and also provide the beach with considerable natural protection from the wave action. Therefore, efforts to arrest beach erosion should maximize the natural functions of coastal ecosystems, including beach nourishment, shoreline protection under a changing climate and wave regime. Protecting, rehabilitating and restoring coastal ecosystems would yield immediate as well as long-term benefits in the country, even if engineering options are pursued.

The latter two options described above related to beach replenishment will require significant financial resources and major engineering works which

would entail very careful design and detailed environmental impact studies.⁶⁵ With regard to beach nourishment, it is important that appropriate offshore resources are found,⁶⁶ to supply large quantities of material for initial nourishment as well as subsequent replenishment schemes that will most likely be required,⁶⁷ particularly under a deteriorating climate and hydrodynamic regime.

The volume of the nourishment material needed will depend on the expected outcome. An approximate estimation suggests that in order to increase the beach elevation by 1.5 m (to provide some degree of protection from flooding) and extend its width by 15 m (final expected width once the beach reaches equilibrium), the required volume (assuming nourishment material of a median grain size of 0.4 mm) would be approximately 130-200 m³ per metre of beach length (Table 4.10).

With regard to the offshore structures, these should be designed to ensure beach aesthetics remain unaltered, be both effective and safe to bathers and nearshore traffic, and minimize damage to critical coastal ecosystems. As stated previously, however, protecting and restoring coastal ecosystems will remain essential to stem beach erosion and sustain the long-term effectiveness of proposed beach nourishment schemes.

Table 4.10 Effects of beach nourishment on sediments and benthic assemblages⁶⁸

d50 (mm)	Designed bed slope	Required material (m3/m)	Initial width (m)	Final width (m)
0.4	1/6.67	145.7	34.8	15
0.8	1/6.67	87.2	23.2	15
2.0	1/6.67	62.2	17.8	15
0.4	1/3	145.7	39.5	15
0.8	1/3	87.2	26	15
2.0	1/3	62.2	21.1	15

Section 5. Local livelihoods and vulnerability

Negril's way of life is intimately tied to the natural environment in the area. The coastal environment (beaches, coral reefs, sea grasses and mangroves) is heavily influenced by the Morass and the hills located

directly behind it. These ecological systems function collectively to support people's livelihoods; provide for basic needs such as food, water, shelter and fuelwood; and give the Negril community a distinct identity.



The All Age School at Little Bay is used as a storm shelter

Box 1. General information on Little Bay

Located on the southeast coast of Negril in Westmoreland Parish, Little Bay is a small, rural community of approximately 350 residents. It is primarily residential, with no present industries or public facilities such as health centres, fire and police stations. It is a close-knit community, as many residents are family-related or are on familiar terms with one another, resulting in overall low crime rates.

Once a thriving fishing community, Little Bay has witnessed a significant decline of the fishing sector over the years, forcing residents to seek alternative employment mainly in tourism, farming and livestock-raising. Income levels, however, remain low. Available employment is generally dominated by men, while women engage in low paid service jobs in the tourism sector, small-scale farming activities or child-rearing.

Water supply is a major concern, as there is no piped water available. Potable water, which has to be purchased, is brought in by tank trucks once or twice a week from Hanover. According to a community leader, purchased water costs approximately J\$ 2.5 – 2.7 (USD 0.03) per gallon. However, most households also collect rain water in large tanks using gutter systems on their roofs or utilize groundwater sources to meet daily water requirements.

Little Bay is highly exposed to storm surge and strong winds from hurricanes (for further details on exposure, see Section 4). The Little Bay All Age School serves as the main formal community shelter, but given the strong social networks within the community, refuge is also frequently sought in houses of relatives and friends who are known to be in safe locations and have stronger housing construction. Most houses are made out of a combination of concrete and wood materials.

A good level of environmental awareness was observed, particularly among fishers who have been previously trained by the Negril Area Environmental Protection Trust (NEPT) and the Negril Coral Reef Preservation Society (NCRPS). A community-based organization (CBO) known as the Little Bay Citizens Association had once been active in promoting environmental protection. The RiVAMP consultations provided an opportunity to reactivate this CBO with the election of new representatives.



Most houses are made of concrete, with a small number of wooden board houses

Box 2. General information on Whitehall

Located in the vicinity of the Negril town centre and bordering the Great Morass, Whitehall is a growing urbanized community, with access to a range of public services including churches, a health centre, schools and fire and police stations. Over the past thirty years, there has been a ten-fold increase in the population, starting with some 500 residents in the 1970s and growing to approximately 5,000 in 2009. The rapid population growth in Whitehall is strongly associated with the expansion of tourism and the resulting employment opportunities in the area. The primary sources of employment in Whitehall are therefore tied to tourism, though farming and fishing provide additional sources of income.

Originally intended to be a planned housing development, Whitehall now has widespread squatter settlements which have contributed to the ongoing deterioration of environmental conditions in the area. The dramatic increase in unplanned housing has resulted in the deforestation of the hillsides, poor drainage and inadequate garbage disposal systems as well as sanitation facilities. While the majority of residents now have access to flush toilets, a number of houses still remain unconnected to the main sewage lines and rely on pit latrines. Almost all residents have access to piped potable water sourced from Hanover.

Since Whitehall is located away from the coastline, it is not highly exposed to storm surge but is impacted by strong winds and flooding due to heavy runoff associated with tropical storms and cyclones. Despite the risk of flooding in the area, presently there is no formal shelter in Whitehall. Residents must seek refuge in other nearby shelters or use informal shelters (e.g. churches, houses of friends and family).

A number of community organizations exist in Whitehall, which include Parent-Teacher Associations as well as religious and citizens' associations. NEPT and NCRPS have also been actively engaging in the community to promote environmental awareness and are working together with farmers to develop more sustainable cultivation practices.

Ecosystems and local livelihoods in Negril are therefore linked in two important ways. People's main livelihoods, such as fishing, farming, charcoal production and tourism, are directly or indirectly dependent on the utilization of natural resources. Environmental degradation, however, poses a serious threat to these livelihoods, as degraded ecosystems are placed under pressure to continuously provide environmental services.

In this context, natural hazards further exacerbate deteriorating environmental conditions, making ecosystems less resilient to hazard impacts. As a result, ecosystems decline has increased the vulnerability of local communities to storm surges and flooding, in addition to potentially jeopardizing the vital tourism industry upon which local livelihoods depend.

This section reports on the main findings from the community workshops held in Whitehall and Little Bay undertaken during the RIVAMP pilot (Box 1 and 2). (For locations of pilot communities, refer to Map 4.1 in Section 4). It elaborates on four key sources of livelihoods that rely on natural resources, namely fishing, farming, tourism and fuelwood production. Furthermore, the section examines how environmental degradation contributes to vulnerability. Finally, it reflects on local coping strategies to mitigate and recover from hazard impacts, highlighting the importance of environmental protection as a risk reduction measure.

5.1 Livelihoods and environmental degradation

Community participants in both Whitehall and Little Bay were asked to identify their main sources of livelihoods. Located away from the town centre of Negril and still being predominantly a fishing community, Little Bay residents identified fishing, farming and tourism as their three main sources of livelihood. Other forms of employment include among others sewing, motorbike public taxis, shopkeeping, carpentry, masons as well as professional jobs such as teaching and the medical field.

On the other hand, residents in Whitehall, a semi-urban community located in close proximity to the town centre, identified tourism, prostitution (driven mainly by tourism), retail trade and motorbike taxi transport as the community's main sources of income. Fishing was also cited as another major source of employment but to a lesser extent compared to Little Bay.

This following section focuses on the three main livelihood sources that are directly dependent on natural resources: fishing, tourism and farming. Although fuelwood production was not prioritized, it constitutes an important economic activity contributing to deforestation including mangrove depletion and is therefore discussed in this section.



Residents in Little Bay document environmental changes over the past 40 years by creating their own visual maps

Fishing

Given Negril’s beginnings as a fishing community, fishing remains an important source of livelihood that has experienced significant decline over the past two decades. Although fishing constitutes a significant portion (approximately 60 percent) of household income in Little Bay, earnings from fishing are estimated to have dropped by 85 percent.

While fishing is undertaken primarily by men, historically women also directly benefited from this activity by being actively involved in selling fish. The drastic decline in fish catches has therefore impacted on

both men and women, who have been forced to turn towards alternative livelihood sources such as farming and tourism-related services to supplement their income.

The depletion of fish stocks has been attributed to a number of factors including environmental as well as human-induced drivers. External threats include hurricanes, invasive species such as the lionfish, as well as massive die-offs of the black sea urchin populations. For instance, residents in Little Bay estimated that Hurricane Ivan in 2004 destroyed approximately 75 percent of coral in their community, which was attributed to the decline of local fish populations.

Table 5.1 Benefits derived from fisheries, based on stakeholder inputs

Level of stakeholder consultation	Provisioning services	Regulating / Protecting services	Socio-cultural / Educational purposes
National (not discussed)			
Parish	Major source of local livelihoods	Protects coral reefs against algal growth	Educational
	Supports tourism activities (diving, snorkelling, tour boat operators, etc.)		
	Provides medicinal ingredients		
Community (Little Bay only)	Food source	Sustains coral reefs	Educational
	Main livelihood source		
	Provides medicinal ingredients e.g. fish oil		



Local fishing boats anchored at Homer’s Cove in Little Bay which is vulnerable to storm surges

Table 5.2 Major threats to fisheries, based on stakeholder inputs

Level of stakeholder consultation	External drivers	Local human-induced drivers
National (not discussed)		
Parish	Hurricane damage to coral reefs	Destructive fishing practices: over-fishing, dynamite fishing, spear fishing, use of small net sizes
		Higher demands for fish consumption due to tourism
		Economic crisis: People turn to fishing due to unemployment or underemployment
		Poor enforcement of laws due to limited resources for monitoring and enforcement and low political will
		Lack of understanding and awareness of issues
		Coastal development: destruction of fish reproduction areas, habitat degradation (wetlands, mangrove destruction), sewage runoff, oil spills (jet skis, boats, mega-liners off of Kingston Harbour)
		Agricultural runoff and sedimentation
Community (Little Bay only)	Invasive species: Lionfish	Destructive practices: Chemical use, dynamite fishing, small net sizes, spear fishing, night-diving
	Hurricane damage to coral reefs	Disposal of garbage into the sea
		Removal of mangroves

Lionfish was also regarded by Negril-based stakeholders as a significant problem, as they are known to be voracious predators. Moreover, significant reduction of the black sea urchin population that controls algal growth on reefs was also cited as a factor contributing to fish stock decline, although the cause of their disappearance is not fully understood.

Nonetheless, unsustainable fishing practices play a significant role in the depletion especially of near-shore fishing stocks. As a result of increased tourism demand, over-fishing remains a major problem and is linked to destructive practices, such as the use of small net sizes, dynamite and spear fishing, and violation of seasonal bans for specific species (e.g. lobster). In addition, local food preferences heavily favour reef fishes, encouraging fishing activities directly on the reefs. Parrot fishes, king fishes, snappers, lobsters and crabs are among the most popular catches that are either consumed directly or sold to hotels and restaurants. Low fish densities in turn contribute to algal growth on the reefs, which are compounded by land-based sources of pollution (discussed earlier in Section 3).

Tourism

The tourism industry in Negril provides an important income source to local residents and represents **the** main employment alternative or supplement

to fishing and farming. In Whitehall especially, over 80 percent of the population derived income directly or indirectly from tourism. Tourism-related employment includes hotels, bars and restaurants; water sports activities (e.g. diving, snorkelling, paragliding, jet skis, etc.); glass bottom boat operators; tour operators; dance clubs; handicrafts, among others. While tourism in Negril is a major economic sector, local residents also associated the sector with low wages.

Prostitution associated with the tourism sector was also identified as a significant income source, involving approximately ten percent of Whitehall residents (both men and women). As a result of limited employment opportunities, young girls are increasingly drawn towards prostitution as a means of sustaining themselves and their families. Stakeholders pointed out that individuals involved in the sex trade – unlike most working in other tourism-related sectors – are able to acquire material wealth, including buying cars and building their own houses.

Finally, an indirect benefit from tourism is increased investment in other local sectors (Table 5.3). For instance, one former fisherman in Little Bay started a small chicken farm to meet consumption demand of hotels and restaurants.



Using an image of their community from Google Earth, residents in Whitehall document the rapid expansion of their community

Table 5.3 Tourism benefits and threats, based on consultations in Whitehall

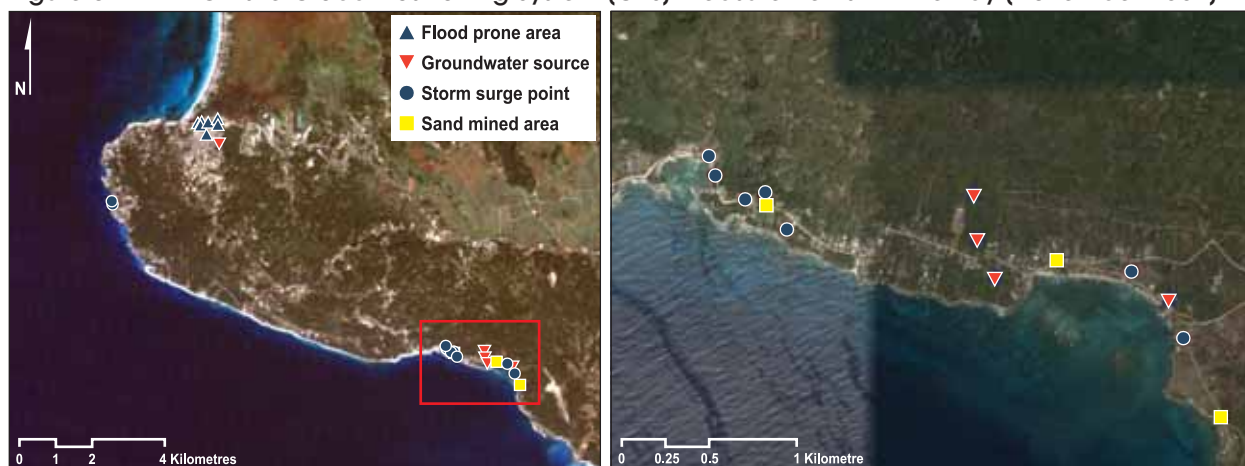
Benefits	Threats
<ul style="list-style-type: none"> • Employment opportunities • Provides foreign exchange • Increase consumption of rural food products • Improved infrastructure e.g. Highway 2000 • Promotes investment in other sectors • Provides returns from taxation 	<ul style="list-style-type: none"> • Crime and violence • Environmental degradation (deforestation due to development expansion) • Increase in prostitution • Natural hazards • Overpopulation

Major threats to tourism, as identified through stakeholder consultations, include environmental degradation and natural hazards. Beach erosion in particular was widely acknowledged as a major threat to tourism. Residents in Little Bay linked beach loss to rising sea levels and the erosive effects of hurricanes, but a community leader also cited illegal sand mining as a major factor contributing to beach loss, with sand reportedly extracted from Little Bay to replenish beaches in Montego Bay. Figure 5.1 shows the reported locations of sand mining in Little Bay (discussed further under Section 5.2).



According to a local fisherman in Little Bay, the beach used to extend further out, reaching the rear of the fishing boats shown above

Figure 5.1 On-site Global Positioning System (GPS) measurements in Little Bay (November 2009)



It should be noted, however, that during community consultations, it was observed that some residents from both Whitehall and Little Bay did not fully understand the link between beach loss and coastal ecosystem degradation, and the potential negative impacts on tourism-related jobs and fishing.

Hurricanes and peat fires were also viewed to adversely affect tourism. Hurricane season (from May to November) obviously discourages visitors to Negril, with peak tourism season corresponding with the winter months in North America and Europe. Moreover, damage to infrastructure as a result of hurricanes can also make it difficult for local business investors to repeatedly undertake damage repairs and recover from serious losses, as many hoteliers and restaurant owners in Negril do not have insurance. According to the President of the Negril Chamber of Commerce, many small and medium-sized hotel operators self-pay for damages due to high costs of purchasing insurance.

With regard to peat fires, the heavy smoke they generate can cause health problems and result in the evacuation of tourists from affected hotels. Presently, there appears to be no systematic monitoring and assessment of peat fires, their causes and specific locations (discussed further under Section 5.2).

Farming

Although comprising a smaller economic sector than fishing and tourism, farming still constitutes a major source of livelihood particularly in Little Bay. Farming usually involves crop production, such as yams, onions, tomatoes, peppers and other types

of cash crops, but can also include livestock-raising, such as chickens and goats. In Little Bay, approximately 20 to 30 percent of people's income is derived from farming. While farming was not regarded as a key livelihood in Whitehall, there was clear evidence of crop cultivation in the Morass which lies directly adjacent to the community. According to one local source, many of those who farm in the Morass reside in Whitehall.

There is very little systematic monitoring or studies on crop cultivation in the Negril area. Farming is not commonly undertaken on a full-time basis, but instead it contributes to household subsistence and or provides supplementary income to other existing means of employment such as fishing or tourism. Exceptional cases may be residents who have invested financially in livestock-rearing or cash crop production to service the hotel and restaurant sectors.

During consultations, Little Bay residents indicated that overall farming in the community is in decline, as younger generations prefer to work in other sectors, especially in tourism, motorbike public transport and fishing. Nonetheless, older generations still rely on farming to provide subsistence and additional household income. Farming also represents a vital "fall-back" employment option for many who are forced to abandon fishing or have lost jobs in the tourism sector. One female resident recalled that many fishers turned to farming cash crops following the devastation of nearshore fisheries by Hurricane Ivan.

Farming practices utilize basic, non-mechanized tools but rely heavily on fertilizers and pesticides to augment production. While more systematic

assessments are warranted, soil erosion and agricultural runoff are likely to contribute to high levels of nutrients and turbidity in coastal waters which have been documented by previous studies.¹ The Negril Area Environmental Protection Trust (NEPT) is presently embarking on a project to promote better farming practices in the Morass. While NEPT is not seeking to legalize farming in the Morass, the project promotes conservation agriculture based on combined techniques of promoting organic cultivation and soil conservation. It further aims to educate farmers of the importance of the Morass with regards to biodiversity and the coastal environment.

Fuelwood production

Although stakeholders did not consider fuelwood production as a main livelihood source, individuals clearly rely on this activity for household energy and to supplement incomes. While to UNEP's knowledge there are no official statistics on fuelwood-use in Negril, community residents confirmed that fuelwood collection and charcoal production are prevalent, contributing to deforestation in the hillsides, the Morass and coastal areas. Hardwood trees that produce slow-burning, high quality char-

coal are especially targeted, which includes the harvesting of mangroves.

5.2 Local vulnerability to natural hazards

During community consultations, residents also identified the main natural hazards that affect their respective communities and the subsequent impacts on human well-being and livelihoods. For the purpose of the RiVAMP pilot, this sub-section places greater attention to hurricanes (tropical cyclones) and their secondary impacts (storm surges and flooding). Whitehall does not experience storm surges, as it is located further inland than Little Bay. However, flooding due to heavy precipitation events represent a major problem in Whitehall and is therefore highlighted in this section.

In addition, fire hazards are considered as they appear to be an increasing phenomenon in Negril, especially affecting the Morass. While earthquakes and drought occur periodically, they have not had major adverse impacts on the population, according to the residents.²



Crop cultivation in the Great Morass is easily observed, which often entails illegal clearance of vegetation

Figure 5.2 On-site GPS measurements in Whitehall (November 2009)

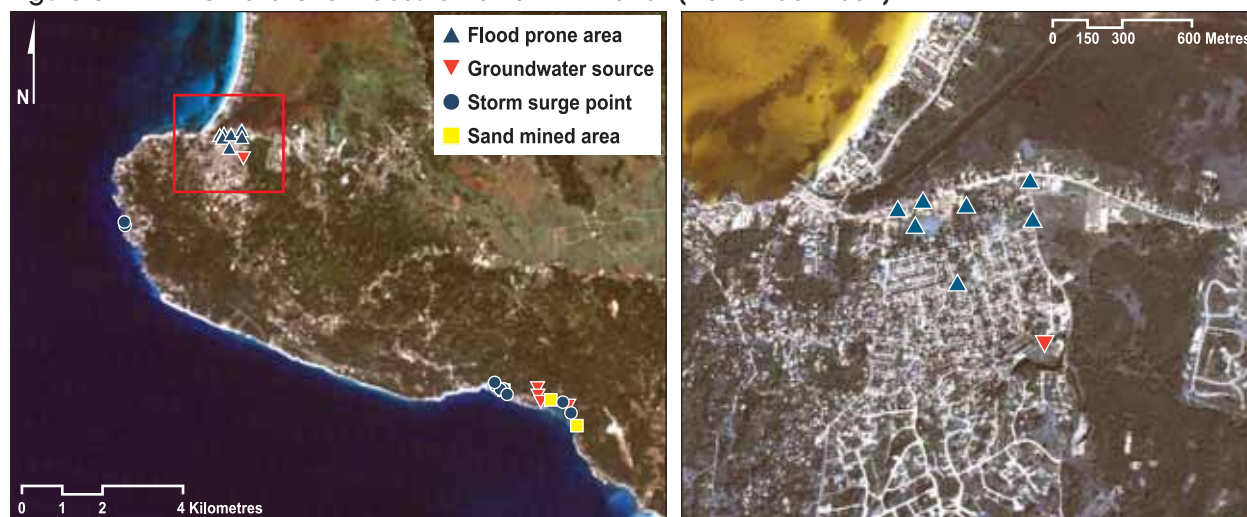


Table 5.4 Major natural hazards that threaten Negril communities, as identified by stakeholders

Whitehall	Little Bay
Hurricanes – strong winds, flooding	Hurricanes – storm surges, strong winds
Flooding from storms	Earthquakes
Fires	Fires
	Drought

Impacts from tropical cyclones and heavy precipitation events

Overall, residents from both communities appear most exposed to the impacts of flooding due to heavy precipitation events and hurricanes. For both Whitehall and Little Bay, however, mortality risk appears low, as residents did not recall deaths associated with hurricanes or flooding.

According to Whitehall residents, flooding due to hurricanes and heavy storms causes the most damage to their community. Figure 5.2 illustrates flood-prone areas in Whitehall. Flood waters can reach up to two metres and last for up to a week, especially affecting housing and other built infrastructure located downhill towards the Negril town centre. Other impacts due to hurricanes cited by community workshop participants include: damage to roads, lack of clean water supplies, fallen trees and outbreaks of waterborne diseases (e.g. gastroenteritis).

In Little Bay, the most significant impacts from hurricanes are storm surges and wind damage. Figure

5.1 illustrates storm surge points in Little Bay. Based on stakeholder input, structures closest to the sea are severely affected by both strong winds and surges, while structures located towards the hillsides (across the main road) are affected only by winds. Strong winds cause significant damage to roofing material of homes in Little Bay, as in Whitehall. Flooding, on the other hand, occurs primarily as a result of storm surges which affect low-lying areas along the coast. Residents in surge prone areas are forced to relocate to neighbouring houses or with relatives, as sea water can remain for up to a week.

The storm surge usually cuts off Little Bay's only main road into town which is vital for receiving water supplies. Major hurricanes can disrupt water delivery into Little Bay for up to two weeks, with residents forced to rely on unprotected groundwater systems. In addition, downed power lines are also common, as was the case after Hurricane Gilbert in 1988 which left residents without electricity for a month.



As groundwater springs in Little Bay remain brackish, residents import almost all of their potable water supply on a weekly basis, which is brought in by tank trucks from Hanover

Map 5.1 Hazard map of Whitehall indicating flood-prone areas due to tropical storms and hurricanes



Map 5.2 Hazard map of Little Bay illustrating areas in the community prone to storm surges and wind damage as a result of hurricanes



Impacts from fires

Although fires usually do not cause widespread damage, residents cited an increase in the incidence of fires in the hills and the Morass. However, it is difficult to confirm whether there has been a real increase in fire incidents over time. The Negril Fire Department provided figures of fire events from 2007-2009, but comprehensive time-series data or detailed assessments concerning the main causes and precise location of fires are unavailable.

Based on stakeholder feedback, fires can sometimes coincide with prolonged droughts, but residents generally cite human activities as the primary cause. Cultivators who wish to clear land often burn vegetation. This is particularly a major problem in the Morass which contains highly combustible peat. As a result, fires in the Morass can burn uncontrollably for weeks and months producing thick smoke, which

poses a public health hazard and impacts on tourism. For instance, several fire incidents in the Morass in 2008 and 2009 forced tourists to evacuate and some hotels to temporarily shut down.

Underlying vulnerability factors

(i) Environmental degradation as a contributing factor to local vulnerability

Environmental degradation has contributed to increasing people's exposure and vulnerability to natural hazards, in particular flooding and storm surge. In Whitehall, for instance, urbanization and the subsequent deforestation of the area have rendered certain parts of the community prone to flooding. Community mapping exercises revealed that flooding only became a problem starting from the late 1980s with accelerated urban and housing development (case study 1).



Debris from runoff often clog drainage ways, and natural catchment areas have been partly reclaimed, which exacerbate flooding

Case study 1. An historical perspective of flooding in Whitehall

In the 1960s, Whitehall had fewer homes with the original settlers residing downhill closer to the main road and town centre. It had less paved roads and more ground tree cover on slopes and hillsides as well as extensive natural "pools" (ponds) which collected storm water runoff.

As urbanization in Whitehall took place in the late 1980s and 1990s, housing development expanded on the hills, but without proper drainage systems in place. Trees on hillsides were cut down to build roads and houses. With fewer trees on hillsides and more paved roads to hasten storm runoff, flooding has become a common occurrence especially affecting the original settlers residing downhill.



According to residents in Little Bay, more trees and thick patches of vegetation used to line their coastline, serving as a natural protective barrier against storm surges

Case study 2. An historical perspective of storm surge impacts in Little Bay

Located directly on the coast, Little Bay has always been vulnerable to flooding due to storm surges. However, based on community mapping exercises and interviews with community leaders, flooding due to surges now reaches further inland than in the past and affects larger sections of the community. One long-term resident pointed out that thick vegetation (i.e. comprised of seagrape, coconut and banana trees, vines and bushes) previously dotted the coast which formed a natural protective barrier for the community. As a result, the main road would rarely remain flooded from the surge.

Presently, much of the tree vegetation along the coastline has disappeared for various reasons (being washed out to the sea, cut down for fuelwood or housing material, disease, etc). Coupled with beach erosion, Little Bay's natural tree protection against storm surge has been substantially reduced. Consequently, the present main road and low-lying areas in the community can remain inundated for several days and weeks. Given the community's dependence on external potable water supplies, remaining isolated has forced people to use untreated groundwater sources, which could make them susceptible to waterborne diseases.

In order to minimize surge impact, several guesthouses located on the waterfront have submerged large boulders to act as groynes to dissipate wave energy. These boulders in effect simulate the natural functions of reefs and sea grass beds. It is not certain whether technical assessments were undertaken to determine the appropriate placement of the groynes and the consequences that such efforts may have on the adjacent coastline.

According to residents in Little Bay, beach erosion has resulted in increased storm surge flooding inland over the past two decades, which has been validated by the modelling work undertaken for this study. Structures including several guesthouses, private homes and small fishing docks located on the coast and in low-lying wetland areas are most vulnerable. According to seasoned fishers, major hurricanes can wash out significant volumes of sand, only a portion of which is eventually returned to shore, which validates RiVAMP's scientific assessment of the beach erosion problem in Negril (see Section 4). Storm surge is likely exacerbated by coral reef degradation and removal of coastal vegetation, such as mangroves, fruit trees and sea grasses (Section 4). As discussed previously, beach erosion has been also linked to illegal sand mining.

(ii) Limited economic options contribute to local vulnerability

As discussed, the main sources of livelihoods such as fishing, farming and tourism are heavily dependent on natural resources and the continuous provision of these services. Given the reality of declining ecosystems in the area, as well as the increased frequency and intensity of hydro-meteorological hazards (hurricanes, tropical storms, and possibly fires), the livelihoods of the selected communities are therefore highly vulnerable and face increasing challenges to maintain economic sustainability over the long term.

Traditional livelihoods such as fishing and farming, in most cases, can no longer provide sufficient income to individuals and their families, who are then forced to rely on alternate livelihoods such as in tourism that are equally vulnerable to adverse environmental conditions. Other employment options such as in retail trade, bike taxi transportation or professional trade exist, but these often require financial resources or specific skills that the majority of the population do not possess.

Ecosystems degradation and the increasing impacts of natural hazards may over time undermine these nature-based livelihood options that communities rely on to sustain themselves and recover from extreme events or shocks. For instance, declining fish stocks in Little Bay over the past decade have forced many women out of the fish sector, contributing to unemployment or underemployment and

thus a reduction in household income. Residents from Little Bay have therefore identified skills training and alternative employment opportunities as a priority need within their community.

5.3 Local strategies to cope with and recover from hurricane impacts

Despite local exposure and vulnerability to tropical cyclones, Whitehall and Little Bay residents did not recall serious injuries or casualties in recent memory as a result of hurricanes. It should be noted, however, accelerated beach erosion, long-term sea level rise and the increased frequency and intensity of tropical storms and cyclones in the region pose a real threat to the safety and well-being of local communities (see Section 4).

Residents rely on a range of assets, namely local knowledge, stock piles and social networks, to manage risk associated with hurricanes. For instance, in Little Bay, incoming storms are detected based on a local assessment of wind and sea waves, which are validated with official public broadcasts. Since both communities have relatively easy access to supplies, residents also stock pile basic items such as food, fuel and water in case of an emergency.

Social networks also provide another critical form of support for people to "ride out" the storm. Strong social ties appear to be much stronger in Little Bay as it remains a relatively more close knit community than the larger, more urbanized settlement of Whitehall. Little Bay residents often rely on their relatives and neighbours to provide safe housing and share essential goods such as fuel, water and food.

Residents did not appear to rely heavily on the natural environment for meeting basic needs before or during hurricanes or severe storms. However, depending on the aftermath of hurricanes, residents occasionally are forced to rely on unprotected groundwater systems for drinking as well as wood sources for fuel and building materials to undertake structural repairs. Local reliance on the natural environment in post-hazard contexts therefore highlights the importance of protecting local ecosystems (especially related to groundwater and fuelwood sources) to ensure continued supply of these critical services.

Section 6. Priority issues and proposed recommendations

This section identifies several options for reducing and managing risk. It expands on a “no regret” option that is based on improving ecosystems management as a critical component of disaster risk reduction and development planning. The no regret option advocates for the establishment of a comprehensive Negril Development and Management Plan to integrate ecosystems management as part of land-use planning, disaster risk management, climate change adaptation and livelihood development.

Proposed recommendations are based on the results of the RiVAMP pilot which include the technical findings as well as inputs from stakeholders who participated in national, parish-level and community workshops held in October-November 2009. Suggested recommendations should be regarded only as a starting point to establish meaningful dialogue between relevant stakeholders at all levels. Identifying appropriate interventions should be based on a systemic view of human and ecological interactions, balance stakeholder interests, and utilize cost-benefit analyses.

6.1 “Change nothing”

The “change nothing” option simply means “business as usual”. In this scenario, priority issues elaborated in this report would remain unaddressed, and local communities would face the consequences of ecosystems decline, thereby increasing exposure and vulnerability to the impacts of natural hazards.

As discussed in Section 4, the growing frequency and intensity of tropical cyclones in the region, sea level rise, reduction of sea grass beds and coral reef degradation have resulted in beach loss, exacerbating Negril’s vulnerability to storm surges and flooding. Beach erosion is a real threat to the Negril environment, people’s way of life and long-term economic development. Without addressing coastal ecosystem degradation as a contributing factor to beach erosion, the beach will continue

to erode, and subsequently the economy of the area will suffer.

6.2 “Managed retreat”

“Managed retreat” suggests the relocation of inhabitants and infrastructure that are located in flood and storm surge prone areas (refer to GIS storm surge maps in Section 4). However, this option may no longer offer a practicable or politically feasible alternative.

Once covered with dunes, the Negril coastline is now dotted with housing and tourism-related infrastructure and one long main road. Built infrastructure compacts the sand and creates a barrier, making the beach more susceptible to erosion and therefore increasing community exposure to hurricane and storm surge impacts. However, reversing the trend of urban and coastal development would be a major challenge, as it requires the relocation of people, physical assets and established infrastructure.



Hotel infrastructure built close to the shoreline and the cliff edge is highly vulnerable to storm surges and wind damage associated with hurricanes

Box 1. Reasons why solutions to environmental problems have not worked in the past, as discussed by stakeholders at the national workshop (without any order of priority)

- Ignorance or disregard for environment regulations and laws;
- Lack of monitoring for enforcement and compliance;
- Established marine parks only provide a limited, demarcated area for environmental protection but do not address the wider human-ecological system. Jurisdiction of marine park ends at the high water mark in some areas;
- Lack of political willingness to enforce rules and regulations;
- Difficulty in maintaining data to inform policies and regulations;
- Lack of coordination and duplication of efforts between agencies, resulting in the division of already scarce resources;
- Legislation is non-existent or too permissive;
- Overlapping or conflicting mandates between different levels of authority;
- Powerful lobbying groups influence decision-making process and law enforcement;
- Corruption; and
- Lack of adequate human and financial resources.

6.3 “No regret” option

The “no regret” solution maximizes the multiple benefits of restoring and maintaining healthy ecosystems for risk reduction and sustainable development. For instance, to stabilize a slope against landslides, the two main choices would be to either build a hard wall structure or replant vegetation. Both options would most likely stabilize the slope and reduce the occurrence of landslides. However, if a hazardous event does not strike, the investment in building the wall accrues no value, while regular maintenance of the wall will be required and incur an extra cost. On the other hand, replanted vegetation continues to provide services whether or not hazards occur, which include: water resources, soil retention, support to biodiversity, products for

human use and consumption (i.e. fuelwood, fruits, etc.), recreation and aesthetic values, *in addition* to slope stabilization.

Investing in ecosystems is therefore a “no regret” option, which provides multiple benefits in support of human development and risk reduction. The key is in harnessing applied science and local knowledge to determine appropriate policies and interventions that maximize the risk reduction functions of healthy ecosystems. It means promoting ecosystems-based approaches as a critical component of risk management, climate change adaptation and development planning.

6.4 Establishment of an integrated Negril Development and Management Plan

Establishment of a comprehensive, cross-sectoral Negril Development and Management Plan is central to the proposed “no regret” strategy. Presently, there is no integrated land-use and development plan in Negril, and an institutional mechanism for managing the beach as a common resource is absent. A comprehensive plan is needed to guide the development of the area and take into account disaster risk, by incorporating information on all potential hazards including seismic and tsunami risks and climate change and how these could impact critical sectors including the environment in Negril. The plan would inform land-use and the future development of infrastructure, human habitation and commercial buildings including hotels, thereby mainstreaming ecosystem and disaster risk management into local development planning.

The basis in formulating such a plan should be determined through an **integrated strategic environmental assessment (SEA)** process and framework. Based on a comprehensive understanding of the current status of ecosystems as well as disaster risk patterns and trends (including climate-related risk), the SEA would then establish a framework for evaluating development options (plans, programmes, and investment projects) in a way that supports sustainable livelihoods, green economic growth, disaster risk reduction and climate change adaptation. Moreover, the SEA would create a

process for engaging multiple stakeholders encompassing national and local-level actors to better coordinate and implement development plans. It should involve national and local governments (e.g. the National Environment and Planning Agency or NEPA, Westmoreland and Hanover parish councils and the Negril Green Island Area Land Planning Authority or NGIALPA) as well as non-government actors (i.e. NGOs, academe and the private sector such as hoteliers, construction firms, etc.).

The Negril Development and Management Plan is intended to optimize natural resources for sustainable development and improve the quality of life in the community. Stakeholder consultations identified three main pillars for engagement:

- strengthening environmental governance;
- identifying eco-solutions for risk reduction; and
- promoting environmental education for effecting behavioural change and local action.

Strengthening environmental governance

Ecosystem degradation in Negril was strongly attributed by stakeholders to poor governance. Given the complexity of environmental governance systems, laws and policies in Jamaica, it is clear that a more comprehensive assessment of governance policy and legal frameworks, systems (mechanisms and structures) and capacities is needed to better understand challenges to environmental management in Negril. A full governance assessment is therefore warranted as a follow up to RiVAMP to be able to maximize available instruments and support greater linkages between resource management and risk reduction strategies.

Five key areas for improvement are highlighted in this section: (i) policy and legal frameworks, (ii) land planning and zoning, (iii) overlapping institutional mandates, (iv) reforming local governance and (v) mechanisms for cross-sectoral, multi-stakeholder collaboration and coordination.

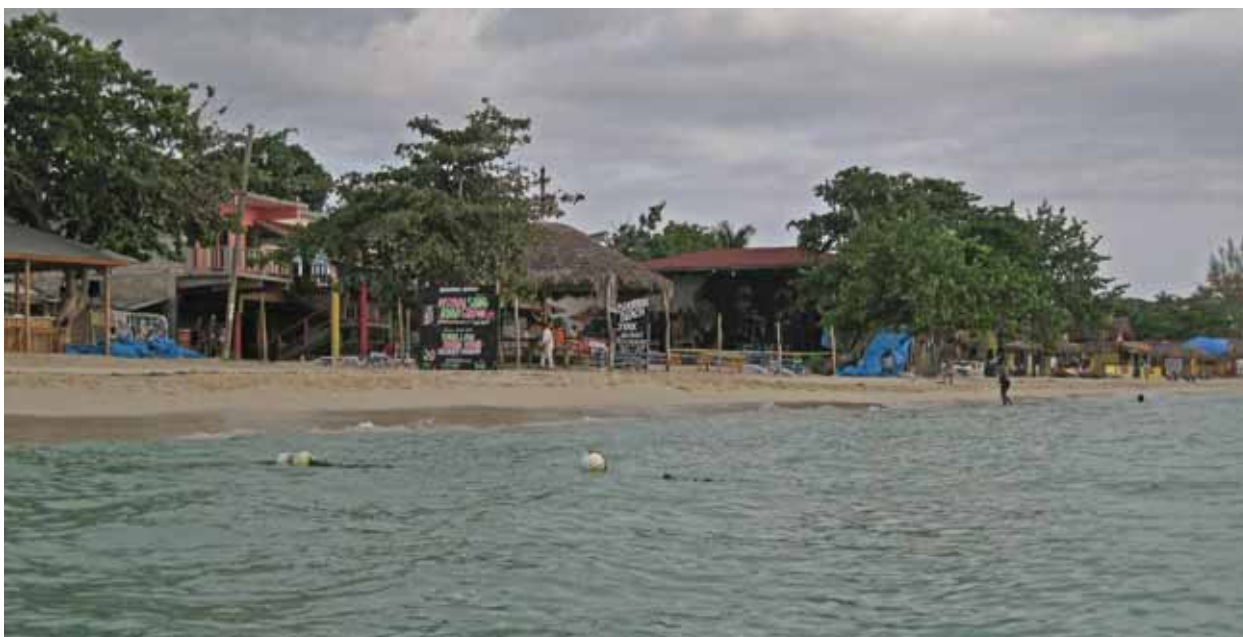
(i) Policies and legislation

While environmental policies and laws are well-established in Jamaica, stakeholders cited the need to re-examine, update and revise policy and

legislative frameworks to make them more current and effective. For instance, numerous policies that affect critical ecosystems, such as the Mangrove and Coastal Wetland Protection Policy (1996), Coral Reefs Protection and Preservation Policy (1996) and Protected Areas Policy (1997), remain in draft form and are more than a decade old, while there is currently no policy or law to protect sea grass. In addition, monetary fines imposed on violators were no longer viewed as an effective deterrent. For example, the fine for removing trees from a forest is J\$100.00 or approximately USD 1.22. Moreover, the lack of human and financial resources has hampered enforcement of existing laws. To address these challenges, one proposal put forward by national stakeholders is the development of positive incentives (e.g. tax breaks, rewards) which could be combined together with law enforcement to achieve greater local support and compliance.

Policy and legal frameworks for conducting environmental impact assessments (EIAs) also need to be revisited. While EIAs are required and implemented for development projects, they were considered by national stakeholders to be inadequate and ineffective in protecting ecological services. For instance, at present, EIAs do not incorporate the assessment of multiple hazards, which could potentially be exacerbated by the environmental impacts of a development project, and therefore natural hazard assessments should be incorporated into EIAs. In addition, EIA recommendations should be legally binding and monitored by NEPA to ensure full compliance. There was a general perception, however, that EIAs were simply a “rubber-stamped” process and their approval remained biased towards economic gains rather than environmental considerations. Workshop participants at the national-level pointed out that there is a conflict of interest in allowing potential developers to hire their own consultants to conduct the EIA. Instead, NEPA should be able to directly contract out the EIA on behalf of the developer, monitor the process and enforce recommendations accordingly.

Additionally, post-disaster impact assessments need to incorporate environmental damages and costs, which to date is not systematically undertaken after major storm events. Authorities both at the national and local levels will need an enabling policy environment to ensure that environmental recovery is considered in overall post-disaster reconstruction plans.



Many hotels and restaurants on Long Bay build directly on the beach close to the high water mark

(ii) Land-use planning and zoning

Improved spatial planning remains essential in determining appropriate land-use activities and zoning of houses, hotels, roads, public buildings and other critical infrastructure. To minimize potential hazard damage to critical infrastructure and assets, multiple hazard assessments that take into account environmental conditions as well as climate change projections need to be fully integrated into land-use planning.

Present land-use in Negril does not reflect strategic planning which takes into account potential storm surge, flooding and beach erosion due to tropical cyclones and sea level rise. Hotels along the Negril coastline are built on the beach in close proximity to the high water mark, as there are no clearly defined setbacks that establish an adequate buffer zone. Current setbacks are based on outdated 30-year mean rainfall data and should be reviewed to forecast the future high water mark based on current rainfall patterns and sea level rise projections. In the West End, hotels are perched on cliff edges which periodically experience significant storm surges even from hurricanes that do not directly impact Jamaica.

Moreover, the building of new hotels often results in nearby illegal settlements established by hotel workers, with limited access to critical facilities such as water, sanitation and waste disposal and thus contributing to coastal pollution. National and

parish-level stakeholders pointed out that greater political will is needed to better monitor and enforce land use regulations, as politicians sometimes condone illegal settlements to develop their own political constituencies.

While parish development plans do exist, most are out of date and generally do not define the carrying capacity¹ of the natural environment nor incorporate analysis of potential hazards and impacts of climate change, which are key to establish limits on human activities and resource use. Negril is currently updating its own local development plan led by the NGIALPA. However, the current Negril Development Plan does not reflect spatial planning or zoning that takes into account hazard and risk information including climate change projections.

At the national-level, NEPA is the primary government agency responsible for approving major development projects in Negril and the country in general. ODPEM reviews development projects under approval by NEPA to assess potential hazard impacts; however, this review is not a legal requirement and thus only undertaken on an ad hoc basis. Local projects approved by NEPA go directly to local planning authorities at the parish-level (in Negril's case to NGIALPA) for final building permits, which are readily given without further technical review. Buildings in Negril are therefore sometimes established, without planning for potential hazard risks and environmental costs.

Table 6.1 Results of workshop group exercise at the national-level, comparing government entities with potential overlapping roles and responsibilities in relation to environmental management, disaster risk reduction and development planning

Specific responsibilities	Gaps / limitations
National Environment and Planning Agency (NEPA)	
<ul style="list-style-type: none"> • Environmental / ecosystems management • Development control • Delegating the management of national parks to non-governmental organizations (that usually have limited funding) • Planning and mitigation • Environmental impact assessments and development approvals are processed through NEPA • Disaster risk reduction 	<ul style="list-style-type: none"> • Ecosystems are not managed for disaster risk reduction • Economic and financial short-term gains take precedence over long-term environmental impacts in development proposals • Environmental managers and ecologists are unable to communicate in economic or financial terms – there is thus a need for professionally trained environmental economists in NEPA and other environmental agencies to ascribe the financial value to ecosystem services.
Parish councils / Local authorities*	
<ul style="list-style-type: none"> • Disaster risk management through the Parish Disaster Coordinator • Regulation of building projects and construction • Infrastructure planning • Roads and works – e.g. clearing drainage systems 	<ul style="list-style-type: none"> • Lack of financial resources to implement effective solutions • Location and resources are dismal for emergency operation centres • Technical skills lacking in disaster risk reduction, hazard/risk assessments • Political biases / persuasions affect Parish Council decisions • Ineffective use of resources that exist • Lack of transparency and communication with communities – no effort to actively engage community members and leaders • Lack of access to scientific data for decision-making • Political autonomy is limited.
Urban Development Corporation	
<ul style="list-style-type: none"> • Infrastructure development • Focuses primarily on achieving economic benefits • Shift in thinking towards sustainable development slowly emerging 	<ul style="list-style-type: none"> • Focus on short-term economic gains • Need for increased integration of sustainable development principles in proposed projects • UDC shares similar roles and responsibilities with NEPA which require clarification.

* Information listed reflects results from both national and parish-level workshops

The absence of a comprehensive zoning plan in Negril is further magnified by the absence of a disaster plan at the local level. Disaster plans of both the Westmoreland and Hanover parishes do exist, but it is unclear how both plans are applied over the entire Negril Environmental Protection Area (EPA). Disaster plans that affect the Negril area should be folded into local land-use planning processes.

(iii) Potential for overlapping institutional mandates

The protected area management system in Negril is complex, as it involves local authorities from two parishes, a local planning authority (NGIALPA), a multi-stakeholder organization (the Negril Area Environmental Protection Trust or NEPT), a local non-government organization (the Negril Coral Reef Preservation Society or NCPRS)² as well as numerous national agencies or bodies with direct decision-making power over land-use.

Varying perceptions on how the multiple entities manage the area suggest lack of clarity of governance mechanisms and institutional mandates. Workshop group discussions on governance, for instance, revealed that there was a lack of understanding amongst national agencies regarding their respective mandates. In break-out group discussions at the national level, stakeholders pointed out that there was potential for institutional overlap between the Urban Development Corporation (UDC) and NEPA, as the country’s leading development planning and environmental protection agency (Table 6.1). This is a potential reality in Negril, where UDC has legal jurisdiction over parts of the Great Morass, while NEPA maintains management responsibility over the entire Negril EPA. There is thus a strong need to identify interdependence and gaps in specific functions between government entities at both national and parish-levels.

(iv) Reforming local governance

While local authorities were recognized as critical players in environmental management, development planning and disaster risk reduction, their autonomy and power remain limited. Presently, the NGIALPA only has the power to monitor and regulate but no power of enforcement, which is assigned to NEPA. The NGIALPA reviews development projects approved by NEPA and provides endorsement but has no real power to oppose NEPA approved projects. Parish council authorities, on the other hand, only have the power to issue building permits, but the ultimate power of approving major development initiatives, such as demarcating large housing subdivisions,³ lies with NEPA. While clearly NEPA has a powerful mandate, at the sub-national level the organization lacks adequate human resources. For instance, only one officer is assigned to Negril and Lucea (the main town in Hanover Parish), covering an area of approximately 48 km², which was considered by national-level stakeholders a challenging task for one person.

According to stakeholders at the national and parish-levels, decisions made by local government authorities and even national technical agencies could be overturned by higher-level government officials. The need to strengthen the decision-making power of local authorities was one



According to stakeholders, the protection of coastal ecosystems should be financed in large part by users of the beach and the marine environment, for example hoteliers, tourists and water sports operators

of the key messages to come out of stakeholder consultations. The rationale is that locally-based government officials would possess a better understanding of local conditions and therefore be able to make more responsive and effective decisions. In addition, local constituencies may find it easier to hold locally-elected officials more accountable. One workshop participant remarked that he would rather vote for a parish councillor than a national public official.

It was viewed that parish councils needed greater political and financial authority in local development planning, including critical aspects such as land-use and zoning. Furthermore, they should be empowered to enforce environmental laws and environmental mitigation requirements of approved development projects. However, it was acknowledged that local authorities require additional human and technical resources to undertake their work more effectively. Generally, they do not have access to scientific data or specialized training, for instance in hazard and risk assessments and environmental management. It is therefore crucial to balance support from national government with needs and capacities of local authorities.

Jamaica is presently deliberating on local governance reform which would redefine the scope, structure and functions of local governments, by giving them a greater role in local development planning, legislation, law enforcement and financial management. However, while governance reform deliberations remain ongoing, many stakeholders at both national and parish-levels were unclear and held conflicting views about the reform. In the context of Negril, it is unclear how local governance reform would affect area management responsibilities ascribed to the two parishes, national agencies and the NGIALPA.

Nonetheless, local governance reform will most likely present important opportunities to mainstream ecosystems management as an integral part of local development planning, while pointing to human and financial resource challenges that will need to be addressed. A mechanism should be established to ensure that a portion of the tourism revenue is used for ecosystem maintenance and support of sustainable livelihood activities. It was proposed that use of the Tourism Enhancement Fund (TEF) be explored as one option.

Strengthening local governments, however, needs to be balanced by establishing strong government accountability mechanisms through greater community and civil society participation in decision-making processes. Communities should be engaged more to maximize local knowledge as well as achieve greater local ownership and support of local development plans. Community-based organisations (CBOs) and local NGOs should be strengthened to implement community-level actions which contribute towards Negril-wide efforts to better manage ecosystems and protect livelihoods.

(v) Mechanisms for collaboration and coordination

Establishing and implementing a comprehensive development plan for Negril will require strong institutional mechanisms to represent overall public interest and ensure long-term ecosystem sustainability. A common institutional platform would need to bring together multiple stakeholders at all levels (national, parishes and communities) and work

across sectors (e.g. agriculture, fishing, tourism). National agencies with key area management responsibilities in Negril, such as NEPA and UDC, remain essential actors, especially in further developing governance capacities of local authorities.

As a multi-stakeholder organization, NEPT is an ideal entity with the mandate to manage the Negril EPA and has the potential to bring together local authorities from both parishes, private sector and civil society. Working in collaboration with NEPT, NCRPS is also a critical player with management jurisdiction over Negril’s marine environment.⁴ However, both NEPT and NCRPS have been considerably limited due to financial and staffing constraints and have lacked recognizable convening power. Over the years, NEPT has mainly operated as an NGO that works directly with communities to implement environment and livelihood-related projects. In the context of local governance reform, consideration should be given on how to strengthen existing multi-stakeholder mechanisms, such as NEPT.

Table 6.2 Proposed solutions per ecosystem that relate to governance, based on national and parish-level stakeholders inputs

Ecosystem	Proposed governance-related solutions
Coral reefs	<ul style="list-style-type: none"> • Improve regulation of fisheries sector through policy and legislation • Assess NEPA regulations governing discharge into the sea and other water bodies • Improve monitoring and enforcement • Enforce fishing ban during closed seasons
Fisheries	<ul style="list-style-type: none"> • Improve monitoring and enforcement of fisheries policy and legislation • Increase legal authority of marine park officials to enforce fines on violators even if they leave marine park boundaries (presently, park officials are unable to fine violators once outside park boundaries) • Greater power given to parish authorities to manage fisheries • Prohibit sale of small mesh sizes (size to be determined) • Improved definition and management of the Exclusive Economic Zone
Coastal vegetation (sea grass, beach vegetation but not including mangroves)	<ul style="list-style-type: none"> • Improve NEPA regulations with respect to beach control and setbacks • Environmental requirements to obtain permits should be enforced. For instance, removal of sea grass beds due to construction or development must be offset by the cultivation of new sea grass elsewhere, but monitoring and enforcement rarely take place • Local authorities need to be empowered by giving them sufficient resources to monitor compliance of ecological regulations • Provide resources needed for monitoring enforcement as well as for acquiring and maintaining data • Expand Green Globe and Blue Flag certification schemes to other hotels and beaches • Apply an environment tax or use the current environmental levy to support environmental protection activities (i.e. rather than just for garbage collection, as it is presently).
Forest	<ul style="list-style-type: none"> • Update environmental laws and regulations with regard to logging and mining, including review of fines and penalties for environmental breaches • Address corruption • Implement proper and comprehensive zoning laws • Increase the number and coverage of protected areas (to go with proper zoning and planning) • Apply “polluter pays” principles • Better regulation and importation of plant and animal species to limit introduction of invasive species • Enforce Forest Act to curb deforestation • NEPA to establish adequate system for environmental law enforcement and follow-up to ensure compliance with permit requirements, e.g. reforestation • Reduce wood imports to reduce disease outbreaks • Strengthen and empower local and national authorities
Wetlands	<ul style="list-style-type: none"> • Enforcement of existing laws and policies (fire control and prohibition of farming in the Morass) • Development of more stringent legislation (e.g. a USD 200 fine is not a sufficient deterrent) • Address potential inter-agency conflicts over jurisdiction and management



To combat beach loss on their property, hoteliers have reportedly resorted to occasional beach replenishment with sand material sourced elsewhere

Identifying eco-solutions for risk reduction

A package of ecosystems-based solutions needs to be developed as part of Negril's development and risk management strategy, grounded in a systemic understanding of human and ecological interactions. Three key principles should be adopted in identifying effective solutions: (i) a "hills-to-oceans" approach, (ii) science-based decision making and (iii) balancing competing priorities.

A hills-to-oceans approach takes a comprehensive view of the root causes of ecosystem degradation to develop integrated solutions. Such an approach is not new to Jamaica with ridge-to-reef, watershed projects implemented in Montego Bay and Portland by NEPA in partnership with the United States Agency for International Development (USAID) (2000-2005), and the Global Environment Facility (GEF)-funded Integrated Watershed and Coastal Areas Management (IWCAM) (2005-2010). However, to ensure that such efforts are institutionally mainstreamed, they should be undertaken within the larger context of land-use and development planning.

As discussed previously, coastal degradation in Negril has been linked to multiple sources, including urban development and tourism, fishing practices, drainage and farming in the Morass, as well as

deforestation and agricultural runoff from the hills. Therefore, improvements to coastal and marine ecosystems would need to tackle human activities across a wide geographic space cutting across multiple sectors. For instance, addressing threats to coastal resources would need to reduce land-based sources of pollution (i.e. agricultural runoff including soil and chemicals, sewage, solid waste, industrial runoff including chemical and thermal discharge, deforestation, increased fresh water runoff due to hard surfaces and built infrastructure).

Furthermore, better management of Negril's environmental resources will require improving access to data and applying this information to guide development planning. Science-based models and assessments should be utilized to provide trends regarding emerging threats to the environment such as climate change and sea level rise. Available instruments, such as environmental vulnerability assessments that are designed to assess the vulnerability of ecosystems to specific stress factors, may be used.

By using evidence-based information, policymakers can make better informed decisions and develop more effective policies and interventions based on sound science. Scientific information should then be weighed against local knowledge and priorities to design appropriate interventions.

Box 2. Data management and application

Existing data should be centralized and digitized to facilitate distribution and access especially by planning authorities and managers. One major challenge identified by stakeholders is the difficulty of developing and maintaining research data to inform policies. For instance, environmental data in relation to beach erosion and water quality in Negril already exists, but data is scattered within and outside the country across various institutions, thus limiting data accessibility. It is therefore necessary to compile, collate and centralize information and place it on a GIS format server with open access.

It is recommended that the following tasks be undertaken with respect to improving data management:

- create an inventory of baseline studies undertaken in the past (by internal or external actors);
- digitize documents and record meta data;
- analyze data quantitatively and qualitatively;
- maintain data sets; and
- train users in data application.

The RiVAMP pilot in Negril illustrates the potential of applying science for decision-making purposes. With regard to the problem of beach erosion, the national government is seriously considering beach replenishment as a key solution to protect its beaches and the tourism economy. However, beach replenishment would require major engineering works (e.g. sand harvesting and transport, establishment of groynes to protect the newly replenished beach from being washed out, etc.). More detailed assessments, including environmental impact assessments, are required to determine the feasibility of beach nourishment.

Regardless of the options pursued, the protection and restoration of coral reefs, sea grass meadows and other types of coastal vegetation should still be viewed as an essential component of Negril's beach protection strategy. As demonstrated by the findings of the RiVAMP pilot, reefs reduce and spread out wave energy and can therefore provide natural beach protection. Sea grasses, on the other hand, are the main providers of beach sediments, while also contributing to storm surge mitigation. Unless these natural systems are protected, the cost of maintaining replenished beaches will be much higher without viable ecosystems in place.

Scientific analysis must be utilized to maximize coastal ecosystem services for beach protection. Ecosystems provide different services in terms of modifying vulnerability for different types of events. Sea grass is better

for sand production, while coral mitigates normal wave action on the beach. However, for instance in the event of a tsunami which generates long waves that pass through coral more easily, corals may offer limited buffering value or may even cause the tsunami to "lift" and reach further inland. Hence, in the event of a tsunami, sea grass meadows may be more effective than coral in dissipating wave energy. In the context of Negril, it will be important to assess different types of hazards including from climate change and evaluate how coastal ecosystems can be improved and designed to better mitigate and reduce potential hazard impacts.

Finally, balancing competing interests will be essential to develop appropriate and realistic solutions, based on detailed cost-benefit analyses that take into account how different components within the Negril human-ecological system interact and impact on each other. For example, since Negril functions as a single beach system, individual activities by beachfront hotel owners, such as establishment of groynes, to conserve or replenish the beach may adversely affect other beachfront owners. This particular example highlights the importance of coordinating efforts through a single overall development framework and plan. A mechanism for representing the common interests of stakeholders in Negril is required to ensure that management of the entire system takes place, and well-meaning individual efforts do not create adverse or irreversible damage.

Table 6.3 Proposed list of technical solutions identified during stakeholder workshops at the national and parish-levels

Ecosystem	Potential solutions to ecosystem degradation and threats
Coral reefs	<ul style="list-style-type: none"> • Establishment / enhancement of marine parks and fish sanctuaries or fish spawn areas (e.g. mangroves, coral) • Acquire and build new mooring buoys and anchor them in strategic places (determine with fishers and dive centres for the appropriate number and locations) • Develop more sustainable fishing practices • Identify alternative livelihood options to fishing • Review and determine effective closed seasons for certain species, e.g. lobster, conch, parrotfish • Exploration of non-traditional fish stocks and other fishing grounds • Assess economic and environmental viability of aquaculture • Extraction of water hyacinth (an invasive species) from rivers and placed in filtration ponds to enhance the current sewage treatment system. Plants could be collected, turned into fertilizer and sold to local farmers.
Fisheries	<ul style="list-style-type: none"> • Establish artificial reefs • Provide better fishing equipment, e.g. larger engines, to fish further out • Upgrade the existing sewage treatment plant to a tertiary treatment level in order to reduce nutrient runoff into coastal waters. Runoff could be redirected into the Morass, which would solve another problem of the Morass drying out and peat fires • Better soil conservation techniques, e.g. bench terracing, to reduce sedimentation of coastal waters • Aquaculture in fresh or saltwater (e.g. breeding parrotfish) (although potential environmental impacts should be assessed) • Eliminate invasive species such as lionfish⁵ - Fishers, NGOs, marine park staff should be trained and encouraged to harvest the fish (e.g. through financial incentives). Because lionfish is edible, people could be trained on how to prepare it for consumption and thus create a market demand
Forests	<ul style="list-style-type: none"> • Reforestation using local, indigenous species. Local experts should advise on what trees are appropriate, as planting non-indigenous trees could have a negative impact (e.g. soil acidity near agricultural areas, reduction of water tables) • Re-establishment of a green belt of trees to serve as a buffer area between houses and the Morass to minimize encroachment as well as spread of fires • Further scientific research on invasive species. For instance, “piano” grass, which was introduced in the late 1960s to protect pianos during shipment, is said to facilitate the spread of fires in the Morass
Wetlands (Morass)	<ul style="list-style-type: none"> • Improve farming practices, e.g. reducing use of chemicals • Increase agricultural yields to minimize encroachment into the Morass • Identify alternative land for farmers who are cultivating in the Morass • Explore viability of greenhouse farming to increase yields and reduce land demand • Raise sewage treatment to the tertiary level and redirect runoff into the Morass instead of coastal waters • Establish mechanisms, e.g. dams, to keep the water in the Morass instead of draining into the North and South Negril Rivers • Undertake research on the causes of peatland fires, better detection and solutions • Establish a fire warden system: train people from the communities and work through active CBOs; furnish wardens with protective gear and communication equipment



Concrete groynes on Long Bay beach are used to trap sand and prevent the long shore drift of sediment, but they can result in sediment starvation of down-current sections of the beach

Overlapping priorities across sectors should be the main starting point of discussion to identify coordination efforts. Since many key issues identified are cross-cutting, they will require cross-sectoral support from stakeholders to implement solutions. Livelihood and environmental concerns in particular need to be jointly tackled. For instance, overfishing, a key environmental issue, is in part driven by the lack of alternative sources of income available to fishers. Hence, efforts to protect coral reefs and fish stocks will simultaneously need to provide fishers with alternate skills to gain access to other employment opportunities in other sectors, for instance in tourism as boat operators, snorkelling guides or marine park guards.

Promoting environmental education for effecting behavioural change and local action

A public education campaign is needed to raise local understanding and awareness of beach dynamics and the critical role of ecosystems in protecting against beach erosion, reducing impacts of natural hazards and sustaining resource-dependent livelihoods. Most importantly, however, is the translation of environmental awareness into concrete actions and initiatives that contribute towards better ecosystem management. A more educated public is viewed as an important prerequisite to also ensure greater public accountability of government decisions.⁵

During stakeholder consultations at the national and parish-levels, participants pointed out the need to help sensitize Jamaicans to environmental issues, especially the risk reduction functions of ecosystems. For instance, it was acknowledged that community residents and hotel owners actively remove sea grasses without fully understanding their role in protecting and maintaining the beach. Communities expressed interest in learning more about human-ecological interactions, ecosystem benefits for hazard mitigation as well as best practices for ecosystem protection and recovery.

Such an educational campaign should target different sectors or groups to more effectively disseminate information and mobilize action. Target groups identified include the following: fishers, hoteliers, water sports and dive operators, farmers, students and youth, as well as local government technical units/agencies.

Communities vulnerable to natural hazards, such as Little Bay and Whitehall, should also be targeted, by strengthening capacities of existing CBOs. As part of capacity development efforts, community members would be able to identify specific actions to protect the environment, for instance with respect to beach protection. Not only would such activities help bring about improved environmental management, but this would also empower community members to focus on problem areas within their control and area of responsibility.

While NCRPS and NEPT have been implementing educational campaigns, especially among fishers, with good results, lack of funding has limited their geographical coverage and the scaling-up of efforts. Environmental education initiatives should therefore be integrated into the Negril Development and Management Plan in order to provide more secured financing drawn from tourism revenue.

Multiple forms of media should be utilized to reach a wider audience. These include use of local or popular artists, sports personalities and other local cultural icons, who traditionally have not been tapped for environmental advocacy campaigns. NGOs on the ground can play an effective role in developing appropriate communication and education materials.



The Negril Royal Palm Reserve, which is a special demarcated area being managed by NEPT within the Great Morass, seeks to both protect the endemic palm forests and promote public appreciation of morass ecology

Section 7. Next steps

7.1 Learning from the process: A preliminary review

A formal evaluation of RIVAMP has been scheduled in May 2010 and will invite key contributors and experts who have been involved in the project, including selected Jamaican counterparts. The following presents initial reflections of UNEP on lessons learned from the process.

As the first pilot assessment of RIVAMP, the case of Jamaica provided excellent opportunities to field-test and improve the methodology. Key factors that facilitated successful pilot implementation included strong project support from national-level counterparts, especially from key government agencies, such as the Planning Institute of Jamaica (PIOJ), the National Environment and Planning Agency (NEPA), the National Spatial Data Management Division under the Office of the Prime Minister, the Office of Disaster Preparedness and Emergency Management (ODPEM), among others. (see List of Contributors).

PIOJ as a convening national development planning agency served as an excellent partner to facilitate inter-agency coordination and field implementation. It maintains a strategic role in ensuring that RIVAMP findings are communicated to policy and decision makers and are translated into concrete actions across relevant sectors.

Additionally, it was particularly important to have been able to adjust the methodology according to the local context and priorities. In the case of Negril, beach erosion was identified as a major risk factor and threat to the vital tourism industry. To address this concern, UNEP enlisted a beach erosion expert to focus on the problem and used the issue as the key basis for demonstrating linkages between coastal ecosystems, hazard mitigation and climate change adaptation. Future efforts to replicate RIVAMP should ensure that the process is demand-driven and tailor made to address priorities at the country level.

Another key success factor was the very high level of technical capacity and data availability at the national-level. GIS-based data sources on population distribution, infrastructure and other types of assets

provided critical information to support storm surge risk analysis. In addition, previous technical studies on Negril's beaches undertaken by the University of the West Indies (2002) and Smith Warner International (2007) offered significant baseline data to run additional modelling and statistical analysis. Data was made easily accessible to UNEP, including critical information on shoreline erosion trends and contextual features (bathymetry, elevation, coral reefs and sea grasses). Such information may be less readily available in other SIDS and would have to be generated.

Finally, UNEP presence in the country was also instrumental in gaining local support from the outset and greatly facilitated meetings with government, civil society and academia. In order to maximize and follow-up on the RIVAMP pilot assessment results, it will be important to capitalize on UNEP's presence in Jamaica and collaborate with other international partners in the country and within the region.

Nonetheless, RIVAMP also faced several challenges. Despite the wealth of information available on Negril, the lack of post-hazard impact assessments in the study area represented a major data gap for the risk assessment. Post-hazard impact information is critical in order to "ground-truth" or test the tropical cyclone model developed by UNEP against reality based on actual impacts, and therefore more precisely estimate risk based on past exposure to hazard events. As a result, it was not possible to verify RIVAMP's model of storm surge impact (refer to Map 4.5 and Figures 4.13 and 4.14 in Section 4); therefore, the model remains theoretical. If this data had been available, UNEP would be able to compute human exposure to storm surges with greater precision. On-site GPS measurements collected in November 2009 provided rough estimates on the actual elevation of waves due to surge, which were then used in the model. Moreover, limited information on other types of coastal ecosystems, such as mangroves, sand dunes and the peatlands, excluded them from the scientific modelling and regression analysis.

The limited timeframe for the pilot further posed a challenge. In the future, more time should be allocated to thoroughly evaluate and select appropriate study areas based on data requirements. Future pilot efforts will need to consider the required timeframe and resources for generating data that may not be

available in the selected study area. In addition, a more comprehensive assessment of governance capacities especially in relation to development planning, environmental management and risk reduction may be needed to add further insight on opportunities and challenges of transforming RiVAMP findings into tangible outcomes. Nevertheless, the stakeholder consultation process at the national and parish-levels provided a good starting point to collectively reflect on key governance-related concerns.

Finally, UNEP from the outset sought to establish a hands-on learning process which would develop in-country capacity to apply the RiVAMP methodology in other parts of Jamaica. However, time proved limited in maximizing the RiVAMP Technical Working Group for undertaking collaborative data analysis. While it was possible to train and involve PIOJ staff, Negril-based NGOs and community-based facilitators in conducting community-level workshops, the science-based component (involving GIS mapping, satellite imagery analysis, statistical analyses and modelling) was carried out entirely by UNEP. A follow-up training on the RiVAMP methodology has been therefore proposed to develop national and regional capacity to be able to replicate similar processes in other locations in Jamaica and in the Caribbean region.

7.2 Proposed follow-up actions in Jamaica

To sustain the momentum generated by the RiVAMP process and maximize results, it will be critical to identify immediate next steps in consultation with national stakeholders. Two main activities have been discussed previously at the national-level: training on the RiVAMP methodology, and potential application of RiVAMP in other coastal areas of Jamaica.

Hands-on training

A proposed training on the RiVAMP methodology would include technical staff from relevant national agencies and parish councils, as well as other stakeholders from academe and civil society. However, the training will be geared towards government as the primary end users. It will elaborate on the approach, tools and process used in pilot-testing RiVAMP in Negril and enable users to apply the methodology in other locations. Specifically, the training will enable participants to undertake change detection using recent high resolution satellite images and aerial photos. Participants will learn how to measure

shoreline changes through time and detect changes in environmental features, such as coral, sea grass, mangroves and forests, based on remote sensing techniques. The training will also develop capacities for carrying out stakeholder consultations, including strengthening workshop facilitation skills and applying participatory methods.

The final version of the RiVAMP methodology will be provided, and complete data sets generated from the pilot will be handed over to PIOJ or another designated agency responsible for maintaining the RiVAMP database.

Potential replication in Jamaica

The potential for application in other coastal areas has also been discussed with PIOJ, which would serve as a complementary component to the training described above. A suggestion was made during consultations to compare healthy and degraded ecosystems as another means of examining their role in hazard mitigation. As beach erosion is a major threat in many parts of the island, replication of future beach loss scenarios in different areas could also be initiated. Additional resources, however, will need to be mobilized to apply RiVAMP in other parts of Jamaica.

7.3 Planning for RiVAMP Phase 2

At present, the RiVAMP methodology focuses on an island context geared especially towards SIDS, and the potential for replicating in other SIDS is high. The coastal-based aspects of RiVAMP are, however, also readily transferable to other coastal zones and therefore could be applied to non-SIDS islands as well as non-island coastal areas. The long-term vision for RiVAMP is to develop a range of methodologies which could be applied in other types of ecosystems, including mountains, river basins and drylands, but only after the coastal-based methodology has been thoroughly field-tested.

RiVAMP Phase 2 will look towards other SIDS in either the Caribbean and or Asia-Pacific regions, depending on capacity to mobilize additional resources. Special regard will be placed on countries where UNEP has country presence and ongoing programmes as well as where strong UNEP partners are operational. Countries with limited data will be targeted to test the practicability of the RiVAMP methodology in locations where data needs to be generated.

Endnotes

Section 1.

1. These figures have been taken directly from the Global Assessment Report 2009 which used the latest data available from the Centre for Research on the Epidemiology of Disasters (CRED) International Emergency Disasters Database EM-DAT.
2. Centre for Research on the Epidemiology of Disasters (CRED) cited in UN International Strategy for Disaster Reduction (2008).
3. UNISDR *Global Assessment Report* (2009): pp. 26-31.

Section 2.

1. Conservation International. *Biodiversity Hotspots*: www.biodiversityhotspots.org
2. See "The IUCN Red List of Threatened Species" at www.redlist.org
3. Emergency Events Database (EM-DAT) (www.emdat.be)
4. Jamaica Gleaner. *Disaster – The Earthquake of 1907*: www.jamaica-gleaner.com/pages/history/story0017.html
5. Advanced National Seismic System - Northern California Earthquake Data Center global earthquake catalog. Downloaded at <http://quake.geo.berkeley.edu/cnss/catalog-search.html>
6. Ahmad R., Miller D.J et al. (2006).
7. Prof. Edward Robinson, Marine Geology Unit, Department of Geography and Geology, University of the West Indies (personal communication, 30 March 2010).
8. United States Geological Survey (2006); Poncelot, J.L. (1997).
9. The Global Assessment Report on Disaster Risk Reduction risk profile is an analysis of the mortality and economic loss risk for three weather-related hazards: tropical cyclones, floods and landslides. In addition, new insights have been gained into other hazards such as earthquakes, tsunami and drought. See <http://preventionweb.net/english/hyogo/gar>.
10. The National Water Commission, the national water supplier, loses approximately 60 percent of their water supply to leakage (PIOJ, personal communication, 11 February 2010).
11. American Geographical Society (1907).
12. Grindlay, N.R, Hearne, M & Mann, P. (2005).
13. See "Jamaica country profile", UN Data at <http://data.un.org/CountryProfile.aspx?crName=Jamaica>
14. See "Jamaica Top Production", FAOSTAT at <http://faostat.fao.org/DesktopDefault.aspx?PageID=339&lang=en&country=109>
15. Food and Agriculture Organization (2005).
16. Planning Institute of Jamaica (2009a).
17. Data on tourism share of GDP was provided by Ms. Carel Coy, Director of Economic Accounting at STATIN (personal communication, 23 November 2009).

Section 3.

1. United Nations Environment Programme / World Conservation Monitoring Centre. "World Atlas of Coral Reefs" (2001) at: www.unep-wcmc.org/marine/coralatlas/contents.htm

2. Wilkinson, C. (2008).
3. See also Mitchell et al. (2002).
4. Coral bleaching is a phenomenon linked to global warming, whereby temperature increases of as little as 1° Celsius above average during the warmest month of the year causes coral animals to expel their zooxanthellae-unicellular algae which symbiotically provide corals with food. After losing their algal pigments, corals turn pale or “bleached” white. Once they are bleached, corals starve, become less resistant to damage (i.e. due to strong surges, sedimentation or algal over-growth due to excess nutrient runoff) and die. Bleached corals can recover slowly if temperatures do not remain elevated for prolonged periods of time.
5. Wilkinson, C. (2008).
6. Nyström M, Folke C. and Moberg F. (2000).
7. T. P. Hughes and J. H. Connell (1999).
8. Weil and Hooten (2008).
9. Woodley, C.M., Bruckner, A.W. et al. (2008).
10. A pathogen is biological agent that causes disease to its host.
11. Coralline algae in the Family Corallinaceae of the order Corallinales. They are characterized by a thallus that is hard because of calcareous deposits contained within the cell walls. The colors of these algae are most typically pink, or some other shade of red, but some species can be purple, yellow, blue, white or gray-green. Coralline algae play an important role in the ecology of coral reefs. Sea urchins, parrot fish and molluscs feed on coralline algae.
12. Goreau T.J., Cervino J., Goreau M. et al. (1998). For more information on Caribbean coral diseases, consult: www.gefcoral.org/Portals/53/downloads/disease_products/0807%20Caribbean%20Underwater%20ID%20Cards.pdf
13. See “Coralline White Band Disease” at the Florida Museum of Natural History at : <http://www.flmnh.ufl.edu/malacology/cwbs.htm>
14. Fishelson (1997).
15. Maljkovicæ et al. (2008).
16. Forrest, D. (1999).
17. Ibid.
18. The Coastal Atlas (1990) also provides information on coral reefs.
19. University of the West Indies (2002).
20. Ibid: p. 9.
21. Smith, A.H. (1992).
22. Breton, Y, Brown D. et al. (2006).
23. National Environment and Planning Agency. (2006). “Draft Policy & Regulation for Mangrove & Coastal Wetlands Protection”, NEPA, www.nepa.gov.jm/policies/Draft-Policy-mangrove-costal-protection.pdf
24. Ibid.
25. National Forest Management and Conservation Plan (“Forest Plan”), www.forestry.gov.jm/PDF_files/ForestPlan.pdf
26. There exist discrepancies with respect to forestry data in the country. The Forestry Department has initiated a programme of surveying forest reserve boundaries and digitizing surveyed data which will produce more accurate maps.
27. Evelyn, O. and Camirand, R. (2000).
28. Official classification of forest types include swamps and mangroves, and they are likely counted in national statistics of total forest coverage.
29. Otuokon S. (2001).

Section 4.

1. Richardson et.al. (2009)
2. UWI (2002); SWI (2007).
3. Bjork (1984).
4. UWI (2002). A fisherman interviewed in Negril recalls wide stretches of sand dunes on the beach when he was a child (over three decades ago), but dunes can no longer be observed in Negril.
5. Extracted from SWI (2007).
6. UWI (2002).
7. SWI (2007).
8. Ibid.
9. UWI (2002).
10. See UWI (2002). Biogenic sand contains the skeletal remains of plants and animals, most of which are made of calcium carbonate. Biogenic (organic) sands form from the skeletal fragments of corals, coralline algae, mollusks, sea urchins, fish, etc. Biogenic sand is easily distinguished from abiogenic sand which is made of eroded pieces of rock. As the rocks of the continental and oceanic crust break down through the process of weathering, abiogenic or inorganic mineral sands are formed.
11. UWI (2002); Mitchell et al (2002).
12. See also Rees et al. (2007).
13. SWI (2007).
14. UWI (2002).
15. Ibid.
16. Velegrakis et al. (2008).
17. SWI (2007).
18. Ibid.
19. Ibid.
20. Ibid.
21. Ibid.
22. Ibid.
23. Ibid.
24. BEACHMED (2008).
25. SWI (2007).
26. Ibid.
27. See also SWI (2007).
28. Webster et. al. (2005).
29. Rahmstorf (2007).
30. See also Brunel and Sabatier (2009).
31. Duke et. al. (1991); Komar (1998).
32. For example, Komar (1998).

33. Nicholls et. al. (2007); see also UWI (2002).
34. UWI (2002).
35. SWI (2007).
36. UWI (2002).
37. Chatenoux and Peduzzi (2005 and 2007); Peduzzi (2010).
38. See also SWI (2007).
39. SWI (2007).
40. Ibid.
41. See also SWI (2007).
42. An eddy is a circular movement of water causing a small whirlpool.
43. SWI (2007).
44. For example, Paphitis et. al. (2001).
45. Larson and Kraus (1989).
46. Coral reefs in deeper waters possibly span more than 200 ha, but it is difficult to confirm this without on-site measurements at such water depths as the satellite image signal is poor.
47. SWI (2007).
48. Ibid.
49. The Irribaren number represents the relationship between the beach slope and the wave characteristics/steepness and provides an indication of the beach vulnerability to the wave energy.
50. See also Velegrakis et. al. (2009).
51. Edelman (1972); Kriebel and Dean (1985); Bruun (1988); Dean (1991); Larson and Kraus (1989); Leont'yev (1996).
52. Komar (1998).
53. Vousdoukas et. al. (2009).
54. See also Velegrakis et. al. (2009).
55. Richardson et. al. (2009); Steffen (2009).
56. The low prediction mean (i.e. the best fit of the lowest predictions from all models) is given by $S = 0.22 \alpha^2 + 9.5 \alpha + 0.28$ ($R^2 = 0.99$) and the high prediction mean by $S = 0.52 \alpha^2 + 28.6 \alpha + 2.24$ ($R^2 = 0.99$), where S is the shoreline retreat and α the sea level rise.
57. BEACHMED (2008).
58. See Brunel and Sabatier (2009).
59. See <http://preview.grid.unep.ch/>
60. Information on Hurricane Charlie was obtained from the National Oceanic and Atmospheric Association (NOAA) Hurricane Center All Atlantic Hurricane Track shapefile (<http://csc-s-maps-q.csc.noaa.gov/hurricanes/download.jsp>
61. Simmon, R. (2007). Downloaded at: http://earthobservatory.nasa.gov/Features/Hurricanes/Images/storm_surge.gif
62. See wave run-up model in Annex 3
63. For an account of hazards along the coast between West End and Little Bay, see Rowe et al. (2009).
64. See also SWI (2007).

65. Colosio et. al. (2007).
66. See Velegrakis et. al. (2010).
67. Dean (2002).
68. Colosio et. al. (2007).

Section 5.

1. UWI (2002). See also Forrest (1999).
2. However, in light of the earthquake in Haiti and the scale of destruction, Jamaica may have to reassess its geological (i.e. seismic, landslide and tsunami) risks across the country.

Section 6.

1. Carrying capacity refers to the number of individuals (or any given species) who can be indefinitely supported in a given area within its natural resource limits. As the natural environment is degraded, carrying capacity shrinks, leaving the environment no longer able to support the number of people who could formerly live in the area on a sustainable basis.
2. Since 2002, the NCRPS has been directly responsible for the management of the Negril Marine Park. The Negril Marine Park falls within the boundaries of the Negril Environmental Protection Area (EPA) and spans a total area of approximately 160 km², extending from Davis Cove in the north of the EPA to St. John's Point in the south. The boundaries of the Park begin at the high water mark along the coast to approximately 3.2 km seaward.
3. Housing subdivisions with greater than ten lots of more than five acres.
4. Presently, NCRPS has signed a Memorandum of Understanding with NEPT to facilitate collaboration in the overall management of the Negril EPA.
5. The red lionfish *Pterois volitans* has few natural predators in the Caribbean. It is a venomous and voracious predator with high reproductive capacity. Having spread quickly across the Caribbean Sea, this invasive fish species poses a significant threat to coral ecosystems by contributing to declining fish stocks in Jamaican waters.
6. The current delay in bauxite mining in the cockpit country was one example cited at national-level consultations to demonstrate how public advocacy has been used to protect a valuable mountain ecosystem.

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ANNEXES

Annex 1. List of criteria and indicators

The following lists the four main components and indicators used to guide the RiVAMP pilot assessment. However, this list very much remains a work-in-progress, as the RiVAMP methodology continues to be pilot tested, adapted and refined. While the RiVAMP pilot in Jamaica attempted to cover all four key areas, not all of the indicators were applied for a number of reasons, including among others: lack of or limited data in the study area, limited timeframe to fully assess and test the indicators, and the more focused assessment on beach erosion which prioritized other informational requirements.

In Jamaica, at the request of the Government, UNEP focused on assessing the risk of beach erosion. The hazards considered were sea level rise and storm waves (with a specific return period of 10 and 50 years). Vulnerability was measured based on contextual parameters (slopes, bathymetry) and environmental features, specifically coral reefs and sea grasses. Exposure was calculated based on the width of the beach. Overall results presented the risk of losing the beach according to several future scenarios of sea level rise and probability of storms with 10 and 50 year return periods.

An estimation of coastal storm surges was also undertaken, but the modelling work was limited due to the lack of post-hazard impact information. As a result, the model of storm surge exposure remains theoretical.

Criteria 1: Ecosystems and ecosystem services

Set of indicators #1: Types of ecosystems, their current status and types of services provided

Indicator #2: Identification of services provided by each major type of ecosystem, specifically their protection and mitigation services

Indicator 2.1: *At the community level*, extent of household incomes that are derived from or remain dependent on nature-based livelihoods (e.g. fishing, farming, tourism, forestry, mining and quarrying) and evolution over a ten to twenty year period

Indicator 2.2: Based on the current status of selected ecosystems, it may be possible to perform simulation exercises of the effects of ecosystems on hazard conditions and impacts. For instance, a comparison could be undertaken between Category 3 and 5 storms, their potential damage, and the influencing role of environmental features.

Criteria 2: Human induced land-use change and climate change factors

Indicator 3: Major causes of ecosystem degradation

Indicator 4: Assess exposure to secondary hazards. Understand and compare the role of natural triggering factors (i.e. tropical cyclones) versus human triggers (i.e. changes in land-use).

Indicator 5: Kilometres of coastline, the percentage of (total) coastline length, the land area (in square kilometres) and the percentage of a community's area that is less than 2 metres above sea level.

Criteria 3: Vulnerability

Indicator 6: Percentage of impacts versus exposure. To be computed for human vulnerability and for the three main sectors that affect livelihoods and human well-being (e.g. tourism, agriculture, fisheries, housing, water supply, health and sanitation).

Indicator 7: Types of nature-based livelihoods (already measured as Indicator 2.1) and natural resource management practices at the household / community level.

Indicator 8: Local coping strategies that enable households/communities to absorb and recover from hazard impacts and/or reduce future risk

Criteria 4: Environmental governance

Indicator 9: Does the country have (i) a National Adaptation Programme of Action (NAPA), as part of the UNFCCC-endorsed process for Least Developed Countries (LDCs), or if not an LDC, a similar climate change adaptation programme; (ii) a national agency dealing with disasters; (iii) a national agency dealing with disaster risk reduction; (iv) climate change incorporated into the national agency dealing with disaster risk reduction; (v) a national strategy for dealing with disasters and for disaster risk reduction (both are essential); (vi) a national agency, policy or strategy for protected areas on both land and sea?; (vii) strategic environmental assessments of national policies (any one of these would be acceptable)

Indicator 10: Presence of a community-based mechanism (formal and informal) for dealing with potentially damaging phenomena, risk reduction and/or natural resource management, e.g. teams or committees.

Indicator 11: Natural resource management, and ecosystems management in particular (including protected areas), are explicitly integrated or mainstreamed in a mandatory manner into development and disaster risk management policies and planning processes. Integrated planning across sectors should also be noted. Constraints to integration should be identified.

Annex 2. Assessment Process and Methodology

2.1 Assessment approach

RiVAMP developed a two-pronged assessment approach. In order to provide convincing evidence of the role of ecosystems in hazard mitigation, a science-based, quantitative approach was applied, drawing on GIS mapping and analysis, remote-sensing and satellite imagery analysis, modelling of beach erosion under conditions of sea level rise and storm surges, and statistical analysis. To validate and complement the scientific assessment, stakeholder consultations were undertaken at multiple levels (national, parish and communities). These consultations helped to address critical data gaps and provided an in-depth understanding of the local context. This combination of quantitative and qualitative (contextualized) analyses is the fundamental basis of the RiVAMP methodology.

The RiVAMP Project Team comprised of UNEP staff from the Divisions of Environmental Policy Implementation (DEPI) and Early Warning and Assessment (DEWA) based in Geneva to capitalize on the range of expertise needed to undertake the assessment. As beach loss emerged as a major issue in Negril (the study area), a coastal beach erosion expert based in the University of the Aegean in Greece was enlisted to provide technical guidance and undertake statistical and spatial analyses.

2.2 Assessment process

The full timeline of the overall RiVAMP project has been discussed in Section 1. The actual pilot assessment in Jamaica was undertaken in July-December 2009. The major elements of the process are described in more detail below. These activities do not necessarily follow a linear sequence and often overlapped in the process:

- desk study on Jamaica with a focus on Negril;
- initial scoping mission;
- GIS mapping and analysis;
- remote sensing analysis;
- analysis of the effects of ecosystems on the beach;
- estimation of beach erosion under sea level rise and storm surges;
- stakeholder consultations and fieldwork;
- write-up and peer reviews;
- reporting and data transfer.

Desk study

In June-July 2009, DEWA carried out a desk study on Jamaica with a focus on Negril as the pilot area. The purpose was to provide baseline information and enable the project team to focus its investigation and data collection during the initial scoping mission in Jamaica. It surveyed the available literature and scientific studies and summarized general information related to geography, hazards, risk and vulnerability profiles, status

of the environment and key players and institutions. The desk study provided substantive content for writing up the country context (Section 2) of the RiVAMP report.

Initial scoping mission

From 13-22 July 2009, the RiVAMP project team conducted its first visit to Jamaica which was primarily an exploratory and fact-finding mission. It aimed to gain political support for the project from key government agencies and determine data availability.

Gaining national ownership and support

The Planning Institute of Jamaica (PIOJ) was selected as the most appropriate implementing partner for the pilot. As the leading planning agency of the government, PIOJ has the mandate to strengthen the planning capabilities of the government as well as coordinate the development of policies, plans and programmes across all sectors. In addition, they manage external cooperation agreements and have experience collaborating with external funding agencies.

A RiVAMP Advisory Group coordinated by PIOJ was established to provide guidance and support towards the implementation of the RiVAMP pilot. The rationale was to establish and sustain national ownership of the entire process. The Advisory Group comprises senior level representatives from key agencies namely: National Environment and Planning Agency (NEPA), Office of Disaster Preparedness and Emergency Management (ODPEM), National Spatial Data Management Division, Urban Development Corporation (UDC), the Ministry of Agriculture and Fisheries, the Forestry Division, the Water Resources Authority, among others (see Annex 4). The University of the West Indies (UWI) is also represented.

Under the Advisory Group, a Technical Working Group was established to provide technical guidance to the UNEP project team and also learn from the pilot exercise. The Technical Working Group consists of technical staff from the key agencies represented in the Advisory Group.

In practice, UNEP maintained close consultations with the Advisory Group during pilot implementation as well as in reviewing results, but the limited timeframe constrained opportunities for hands-on training and learning together with the Technical Working Group. Nonetheless, these two entities have great potential for sustaining the RiVAMP process and applying report findings to influence planning decisions across sectors.

Selection of study area

In order to select the study area for the pilot, an inter-agency committee was established to identify potential sites and rank them based on pre-determined selection criteria. The committee comprised of representatives from ODPEM, PIOJ, NEPA, and National Spatial Data Management Division. Table 1 presents the results of the site selection ranking exercise.

Table 1. Results of the site selection ranking exercise

Selection criteria by order of importance	Negril		Treasure Beach		Trelawny to Discovery Bay		Montego Bay		Portland and St. Thomas		Portland Cottage to Portland Bight	
	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score	Rating	Score
8. physical vulnerability to natural hazards	2	16	3	24	1	8	1	8	3	24	3	24
7. coastal tourism	3	21	2	14	2	14	3	21	1	7	0	0
6. data availability	3	18	3	18	3	18	3	18	3	18	3	18
5. development pressure	3	15	1	5	3	15	3	15	2	10	0	0
4. ecosystem diversity (based number of different types of ecosystems)	2	8	1	4	3	12	2	8	3	12	3	12
3. socio-economic vulnerability	2	6	2	6	2	6	2	6	3	9	3	9
2. level of degradation	2	4	1	2	3	6	2	4	3	6	3	6
1. willingness of local communities to participate in pilot	3	3	3	3	2	2	3	3	2	2	2	2
Total score	91		76		81		83		88		71	
Ranking	1		5		4		3		2		6	

* Rating: 0 = none; 1 = least; 2 = mid; 3 = most

Located at the western end of the island, Negril was finally selected after intensive discussions. The study area for the RiVAMP pilot was defined based on Negril's watershed boundaries and limits of the surrounding marine environment.

Assessment of data availability and preliminary data gathering

The project team also conducted initial data collection on ecosystems, physical infrastructure, socio-economic trends, disaster reduction and environment-related policies, hazard and disaster impact assessments. The National Spatial Data Management Division as well as Mona GeoInformatics Institute based in UWI provided GIS-referenced information.

GIS Mapping and Analysis

Computation of exposure to storm surge and flooding associated with tropical cyclones was based on GIS mapping and analysis. Data used included an accurate digital elevation model (DEM) with a six metre resolution, the population distribution and infrastructure or assets in the study area. Maps of previously exposed areas to storm surge and flooding (i.e. past hazard impact assessments) would have greatly improved estimations of exposure. However, in the case of Negril, post-hazard impact information was not readily available especially for the Long Bay area; thus, RiVAMP's model for storm surge exposure remains at a theoretical level.

Remote sensing analysis

Remote sensing used high resolution QuickBird satellite images purchased by UNEP and aerial photographs from 1968 taken from the study by Smith Warner International (2007). The purpose was to determine the types and distribution of environmental features, specifically coral and sea grasses, which would later be used to inform the analysis of coastline erosion due to tropical cyclones and sea level rise. Aerial photographs compared with the recent satellite data helped estimate changes in the coastline over the past four decades.

Analysis of the effects of ecosystems on beach morphodynamics

In order to study the interaction of the coastal ecosystems in relation to the Negril beach morphodynamics, two different methods were applied. The first method used numerical modelling (both two dimension/2-D and one dimension/1-D wave propagation models) to study coral reef impacts on nearshore dynamics. The second method employed multiple regression analysis in order to identify the positive influence of coral reefs and sea grass meadows on the observed beach erosion patterns along the Negril coastline. These two methods and their results are described fully in Section 4. (Annex 3 provides further details on the hydrodynamic modelling and multiple regression analysis).

Estimation of beach erosion under sea level rise and storm surges

In order to assess the range of shoreline retreat of Negril beaches under various rates of sea level rise and storm surges, an ensemble of six widely-used, numerical models were applied. (For further discussion on the morphodynamic model ensemble, see Annex 3). Experiments were carried out for different morphological (beach slope), sedimentary (grain-size) and wave characteristics. As coastal retreat due to sea level rise is controlled by the level and distribution of the wave energy, which in turn controls not only the dynamics of the beach sediments but also the position and depth of the wave breaking, width of the surf zone as well as the sediment transport closure depth, the models were applied using varying wave conditions, i.e. wave heights (H) of 1, 2, 3, 4, 5 and 6 m and periods (T) 3, 5, 6, 7, 8, 10 and 12 seconds.

For each set of wave conditions, experiments were carried out for 5 different sediment grain sizes (D50s of 0.2, 0.33, 0.50, 0.80 and 1 mm) and 14 sea level rise rates (0.038, 0.05, 0.10, 0.15, 0.22, 0.30, 0.40, 0.50, 0.75, 1, 1.25, 1.50, 2 and 3 m). Experiments with smaller ASLR rates were also carried out, but as some models showed instabilities, their results have not been included in the estimations. All experiments concerned beaches where sediment erosion is not constrained by the sediment availability. Regarding the beach morphology, linear profiles were used (slopes of 1/10, 1/15, 1/20, 1/25 and 1/30).

Stakeholder consultations and fieldwork

Stakeholder consultations and fieldwork were carried out from 26 October-03 November 2009. Consultations involved two-day workshops at the national, parish and community levels as well as individual interviews. National facilitators were engaged to lead group discussions, as they are better informed than UNEP counterparts concerning local perceptions and behaviour.

The stakeholder consultations aimed to develop a more in-depth understanding of ecosystems which could further inform as well as validate the scientific analysis and findings. For instance, stakeholder inputs on the major drivers of ecosystems degradation provided additional insight into the problem of beach erosion. At the community level, consultations also helped develop a fuller understanding of local reliance on ecosystems and local vulnerability to tropical cyclones. Local residents also provided critical information concerning storm surge points in their area, which were used by UNEP to calculate the maximum elevation affected by storm surge in the GIS modelling of exposure.

National and parish level workshops

Workshops at the national and parish-levels were held in Kingston and Negril, respectively. The main target audience consisted of representatives of government agencies or divisions, civil society and academia. National and parish-level workshops followed the same structure and format, combining UNEP presentations with break-out group sessions designed to encourage discussions amongst participants.

UNEP prepared formal presentations on the following topics: (i) overview of the RiVAMP project and methodology; (ii) the role of ecosystems in risk and vulnerability reduction; (iii) preliminary results of the GIS analysis and mapping of storm surge and flood risk in Negril; (iv) an overview of shoreline retreat and coastal ecosystems; and (v) understanding governance in the context of environmental management, disaster risk reduction and development.

Break-out group sessions addressed the following themes: (i) identifying the main types of ecosystems in Jamaica and in Negril, types of services provided by each ecosystem and major drivers of ecosystem degradation; (ii) institutional mapping and analysis to assess governance in the context of environmental management, disaster risk reduction and development; and (iii) key issues and potential solutions for risk management and environmental protection.

Community workshops

Stakeholder consultations also involved two-day workshops at the community-level. UNEP selected the communities of Whitehall and Little Bay following consultations with PIOJ and Board Members of the Negril Green Island Area Planning Authority (NGIAPA) represented by Negril-based NGOs and parish council members from Westmoreland and Hanover. The main criteria for community selection included: high vulnerability to natural hazards, receptiveness to the pilot process and on-going or previous environment and or DRR-related initiatives in the area. It was also important to have a representative sample of communities found in Negril: Little Bay characterized a predominantly fishing and coastal community, while Whitehall represented a semi-urban, tourism-dependent community.

Community workshops included informal leaders in the community as well as people from various sectors (e.g. fishers, farmers, health workers, etc.) and established a balance between gender and age groups (elders and youth). While there was certainly good overall representation, the fact that workshops took place during the day in the middle of the week resulted in greater participation of women and youth (males and females).

Community workshops were structured differently from the national and parish-level consultations. More interactive, hands-on methods were applied, for instance the use of community mapping exercises and seasonal calendars. Greater focus was placed on understanding local vulnerability which involved stakeholder analysis of hazards and hazard impacts, local livelihoods, livelihood practices and coping strategies. Participants also examined the main causes of ecosystems degradation and their impact on livelihoods.

Due to time constraints, it was not possible to evaluate existing community-based organizations nor discuss at length potential solutions. Nonetheless, the community-level information provided sufficient material for understanding local vulnerability and reliance on ecosystems.

Write-up and peer reviews

PIOJ coordinated the preparation of the stakeholder workshop reports at the different levels, which were commissioned to the workshop facilitators. UNEP then reviewed these workshop reports together with the on-site GPS measurements, satellite imagery, GIS mapping products, spatial modelling and statistical analyses. A comprehensive draft report synthesizing the main results and recommendations was drafted and circulated for review.

The draft report was circulated for internal peer review within UNEP as well as shared with local counterparts in Kingston and Negril through PIOJ. Several members of the Experts Group who were involved in the conceptual development of RiVAMP (see Section 1) also provided comments on the draft report.

Reporting and data transfer

The RiVAMP pilot assessment report will be presented in mid-March 2010 in Kingston and Negril, respectively. The objective is to communicate and validate key findings and results of the pilot assessment. It is hoped that RiVAMP could serve as an impetus to attract political attention and support across key national agencies for promoting ecosystems-based approaches to risk reduction and climate change adaptation.

The report will be finalized at the end of March and submitted to the Government of Jamaica through PIOJ, along with all scientific results as well as the GIS-referenced data collected and generated.

Annex 3. Details of the Scientific Analyses

3.1. Key steps in calculating exposure to storm surges

Step 1: Digital elevation model

The minimum data needed when simulating flooding due to storm surge is an accurate Digital Elevation Model (DEM). In the pilot, UNEP used a six metre resolution elevation grid (Figure 1) provided by the Government of Jamaica. The RiVAMP pilot is fortunate to access such high resolution DEM, which may not always be readily available in other SIDS or developing countries.

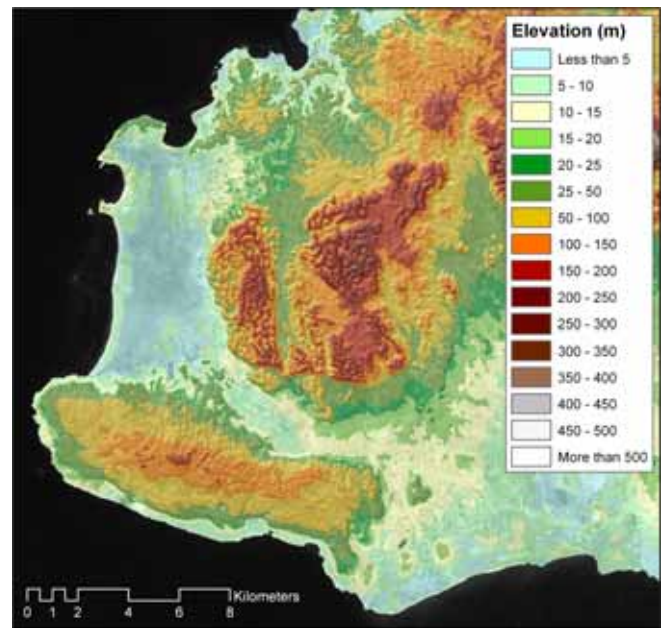


Figure 1. Six metre Digital Elevation Model

Step 2: Population distribution

In order to calculate population exposure to winds and storm surges associated with tropical cyclones, a new digital population map was created by UNEP using the last population census (2001) and building locations purchased from the Mona GeoInformatics Institute.

The process involved spreading the 2001 population census of each administrative unit to match the building density grid (on a 50 metre resolution) based on building locations. The rationale for doing so was to estimate more accurately the numbers of persons exposed per given unit. A key assumption made was that people would be most concentrated in areas where buildings or infrastructures are located.

The number of persons within each grid or pixel has been estimated using the formula below:

$$poppix = buildpix \times popunit / buildunit$$

With:

poppix: population on a pixel,

buildpix: number of buildings on a pixel,

popunit: population on an administrative unit,

buildunit: number of buildings on an administrative unit.

Figure 2 shows the raw data used for processing, while Figure 4 indicates the results of spreading the population according to building density.

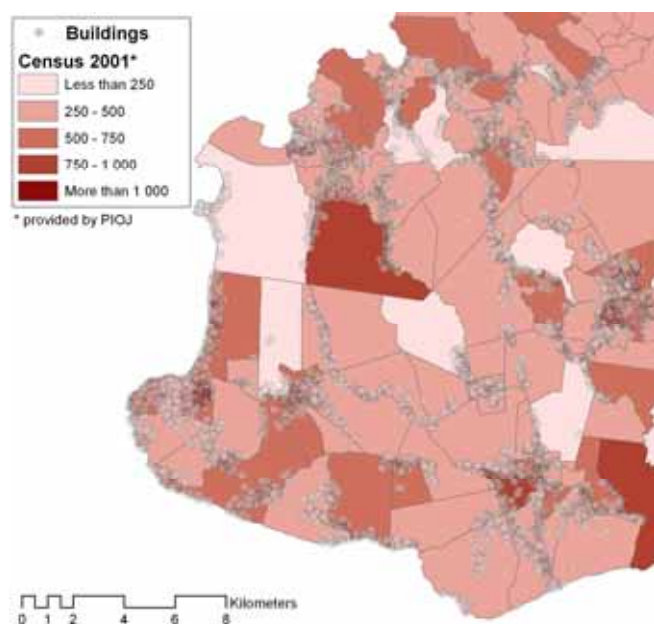


Figure 2. Raw population data

A correction factor was applied to all pixels of each administrative unit in order to guarantee that the sum of the pixels would match the 2001 census value (Figure 3).

The final grid in Figure 4 has accuracy per administrative unit of -5% and $+12\%$.

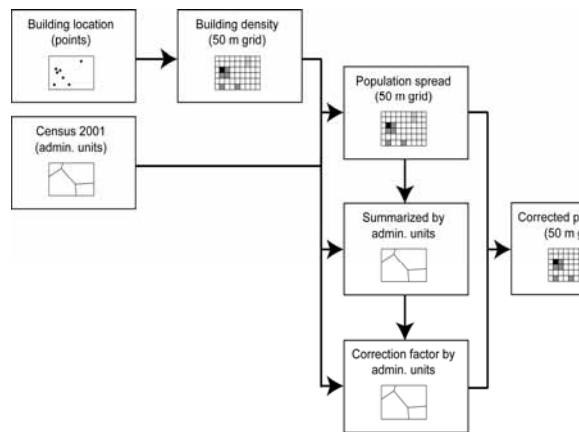


Figure 3. Process for correcting the population grid

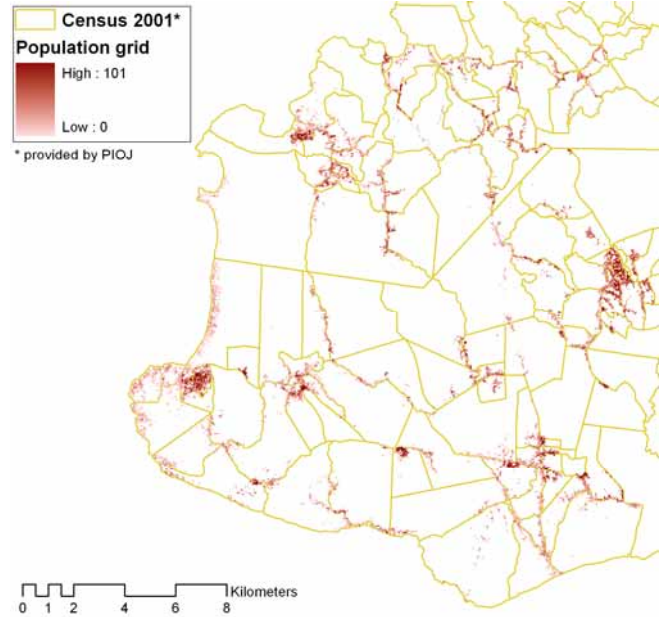


Figure 4. 50 metre population grid

In the absence of a precise population model, an identification of urban and housing areas could also be undertaken using high resolution satellite sensors to map housing footprints. The population at a given location could then be re-distributed over the detected housing settlements.

Step 3: Assets distribution

PIOJ provided UNEP with GIS-referenced data detailing a list of assets, namely: hospitals, health centres, health facilities, day care facilities, emergency shelters, fire stations, police stations, public schools, hotels, markets, National Water Commission priority facilities, waste water facilities, wells and JPS substations.

However, the total guest capacity of hotels in the Negril area was not readily available which prevented a more accurate calculation of the total number of people exposed to storm surges. The model therefore only calculated exposure of visiting populations based on the total number of exposed hotels.

Step 4: Computation of exposure

Since the 2001 census was based on formal administrative units with varying geographic sizes, an arbitrary 1 km grid has been overlaid on the study area to achieve standardized spatial limits to map population exposure (Figure 5).

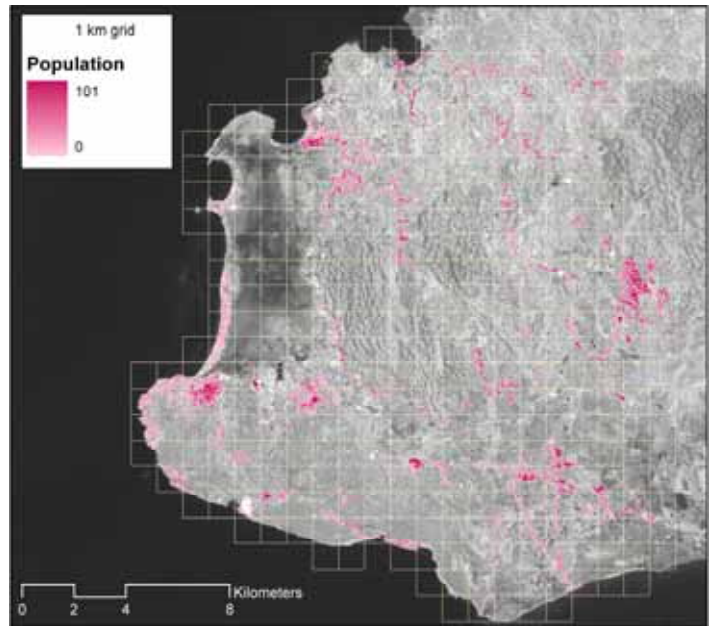


Figure 5. Population exposure units (1 km grid)

The population and assets exposure has been processed in two ways.

As population distribution has now been established based on the 50 metre resolution grid, exposure was calculated by aggregating information in potentially flooded areas using the one km grid (Figure 6).

The assets located in the potentially flooded areas have simply been counted and summarized (refer to Tables 8 and 9 in Section 4).

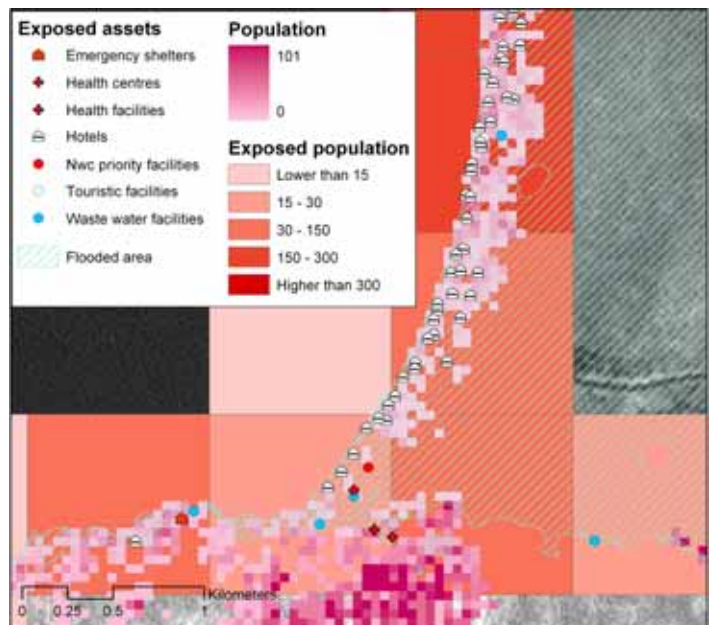


Figure 6. Exposure extraction

3.2 Satellite imagery analysis to determine distribution of coral reefs and sea grasses

Negril coast benthic habitat classification

High resolution QuickBird satellite images were processed using object-based analysis to map the spatial structure of the current coastline as well as underwater sea-bed cover. The sea-bed differentiation was broken into the following categories: shallow sand, sandy bottom, sea grass bottom, coral and deep coral. The benthic habitat classification involved three steps: model description and treatment, classification of features and segmentation.

(i) Model description and treatment

High-resolution pan-sharpened QuickBird images of the Negril study area were obtained from DigitalGlobe[®]. QuickBird pan-sharpened imagery is the highest-resolution colour satellite imagery commercially available, which was a prerequisite for analyzing underwater features.



Figure 7. QuickBird satellite image of the Negril area taken in January 2008

The 4-band (1-blue, 2-green, 3-red and 4-NIR) Quickbird image was acquired on 17 January 2008, 16:15:36, and has a spatial resolution of approximately 60 cm. For many multispectral analysis techniques such as band ratios or Normalized Difference Vegetation Index (NDVI), a common practice is to convert multispectral digital number (DN) data into radiance and reflectance before running the algorithms and developing the classification method.

Top-of-atmosphere spectral radiance is defined as the spectral radiance entering the telescope aperture at the QuickBird altitude of 450 km. The Negril QuickBird image is an 8-bits image, generated after 6 June 2003 and is therefore defined as:

$$L_{\lambda \text{Pixel, Band}} = \frac{K_{\text{Band}} \cdot q_{\text{Pixel, Band}}}{\Delta\lambda_{\text{Band}}}$$

Where:

$L_{\lambda \text{Pixel, Band}}$ is top-of-atmosphere band-integrated radiance image pixels, K_{Band} is the absolute radiometric calibration factor for a given band, $q_{\text{Pixel, Band}}$ are radiometrically corrected image pixels [counts] and $\Delta\lambda_{\text{Band}}$ is the effective bandwidth for a given band.

Similarly, the equation to obtain band-averaged reflectance equation for a QuickBird image band is:

$$\rho_{\lambda \text{Pixel, Band}} = \frac{L_{\lambda \text{Pixel, Band}} \cdot d_{\text{ES}}^2 \cdot \pi}{E_{\text{sun} \lambda \text{Band}} \cdot \cos(\theta_s)}$$

Where:

$\rho_{\lambda \text{Pixel, Band}}$ is the target diffuse spectral reflectance, $L_{\lambda \text{Pixel, Band}}$ is the top-of-atmosphere band-integrated radiance (calculated above), d_{ES} is the Earth-sun distance, $E_{\text{sun} \lambda \text{Band}}$ is the band-averaged solar spectral irradiance normal to the surface being illuminated and θ_s is the solar zenith angle.

Before developing the classification, two additional steps were taken. Band reflectances were used to calculate the Normalized Difference Vegetation Index (NDVI) following this formula:

$$\text{NDVI} = \frac{(\text{NIR} - \text{RED})}{(\text{NIR} + \text{RED})}$$

The NDVI is not a good indicator for submerged aquatic vegetation (SAV) (i.e. vegetation that is adapted to live underwater or other aquatic plants that are submerged during flood events even at shallow depths (30 cm)¹.

The four image bands as well as the NDVI were then converted to 16bit unsigned integer and resampled (multiplying the original cell-size by six using the nearest neighbour algorithm) to make classification calculation faster. All the steps mentioned in this section were made possible using the ERDAS IMAGINE 9.2[®] software.

(ii) Classification of features

An object-oriented approach to image analysis is based on objects defined as a group of pixels reflecting real-world features². The objects can be extracted from multi-spectral images based on their internal homogeneity and spectral separability. In order to perform object-based analysis and classification, appropriate software is necessary. For the RiVAMP pilot, Definiens Developer 7 Ecognition[®] software was used.

The Definiens Developer 7 Ecognition[®] classification workflow is as follows: First, raster layers (multi-spectral satellite images) and metadata are entered and re-named.

They include the information needed during the analysis and classification processes. A subset of the image is selected to develop and test the classification method before launching the classification on the entire image.

As a result of the segmentation process of raster layers, objects are delineated. These object characteristics allow one to classify objects using a complex cognitive process more akin to the human way of image recognition³. Finally, the feature space describing objects is applied in order to generate rule sets which classify objects.

The QuickBird image segmentation leading to extraction of objects determines the future quality of the analyses. The segmentation process aims to retain objects of strong spectral and shape homogeneity. Before classifying the created objects based on visual interpretation and aerial photos, two more bands were created: transparency index (TI) and Ln (blue). The transparency index is a combination of reflectance signatures according to the following formula: $\text{Green}2/\text{Red}$. This index can help to have an inventory of underwater vegetation deeper than the low-tide line to a depth of 12 m. The Ln(blue) represents the Neperian logarithm of the blue band values.

(iii) Segmentation

The first segmentation consisted in creating two levels for the analysis. “Land level” was segmented using only the NIR band, with a scale parameters of 1,000 and homogeneity criterion was set to 0.1 for shape and 0.5 for compactness. Choosing a very high scale parameter ensures that objects created are single objects encompassing a high number of pixels. Pixels that did not fall in the “Land Level” were assigned to the “Ocean level”.

The “Ocean level” was then segmented using the blue, green, red and NDVI bands with respective scale parameters of 10, 10, 1 and 1. This means that the spectral information contained in the blue and green bands were ten times more significant for the segmentation than the one contained in the red and NDVI bands.

Use of ancillary data to finalise land cover classification

(i) Bathymetry

Classified objects located in areas deeper than 25 meters were not considered as spectral information, as such elevated depth is no longer considered significant for the analysis.

(ii) Visual interpretation

Since the QuickBird image has a very high resolution, it was possible to edit the final Definiens classification using visual interpretation. For example, the “sea grass” objects could then be distinguished between “dense” and “patchy” sea grass. Similarly, while the software classified some nearshore areas as “coral”, visual interpretation revealed that this was not an accurate interpretation and therefore reclassified these objects as “shallow” consisting of sand and sea grass beds. The final categories are as follows: unclassified (land), sand, shallow (sand and sea grass), patchy sea grass, dense sea grass, shallow coral, deep coral and deep.

3.3. Numerical modelling

In the present study, a nearshore two-dimension (2-D) wave propagation model (WAVE-LS), developed by the University of the Aegean has been used. The model is based on the directional energy balance equation, which describes wave refraction and breaking as (Booij et al., 1999):

$$\frac{\partial E}{\partial t} + \frac{\partial c_x E}{\partial x} + \frac{\partial c_y E}{\partial y} + \frac{\partial c_\theta E}{\partial \theta} = -D \quad [A1]$$

where $E(f, \theta; x, y; t)$ is the directional wave spectral density as a function of frequency f and direction θ , (x, y are the horizontal coordinates and t the time), c_x , c_y and c_θ are the propagation velocities in x , y and θ space respectively and D is the wave energy dissipation due to breaking in shallow waters (Battjes and Stive, 1985).

Diffraction effects are incorporated in the equations by replacing c_θ with C_θ (Holthuijsen et al., 2003):

$$C_\theta = -\frac{c_g}{c} \left(\cos \theta \frac{\partial c}{\partial x} - \sin \theta \frac{\partial c}{\partial y} \right) \sqrt{1 + \delta} + \frac{1}{2\sqrt{1 + \delta}} c_g \left(-\cos \theta \frac{\partial \delta}{\partial x} + \sin \theta \frac{\partial \delta}{\partial y} \right) \quad [A2]$$

where $\delta = \nabla \cdot (c c_g \nabla \sqrt{E}) / [k^2 c c_g \sqrt{E}]$ and (k is the wave number)

The numerical solution is based on a simple backward finite difference according to Booij et al. (1999). The radiation stresses derived from the model are then implemented into a depth-averaged circulation model, based on the Shallow Water Equations, in order to predict the breaking wave-induced current field.

Several examples of modelling results are provided below (see also Section 4).

Figure 8. Model results for wave heights (a) and wave-induced currents (b) at the Negril coast. Conditions: Offshore wave height (H_{rms}) = 0.85 m and period $T_p=5$ s. Waves approach from the west.

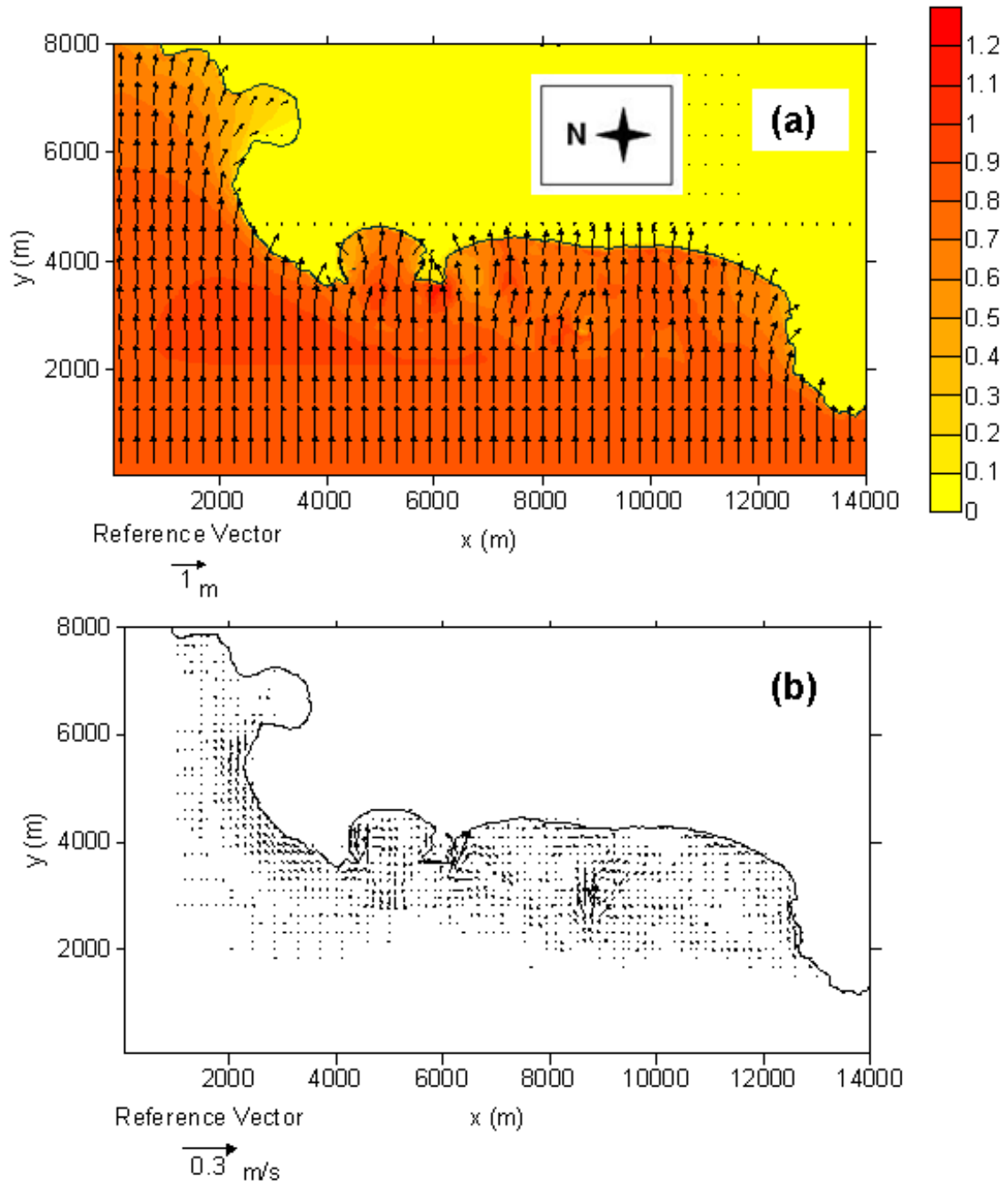


Figure 9. Numerical model results for wave heights (a) and wave-induced currents (b) at the Negril coast. Conditions: Offshore wave height (H_{rms}) = 2.8 m, $T_p=8.7$ s. Waves approach from the west.

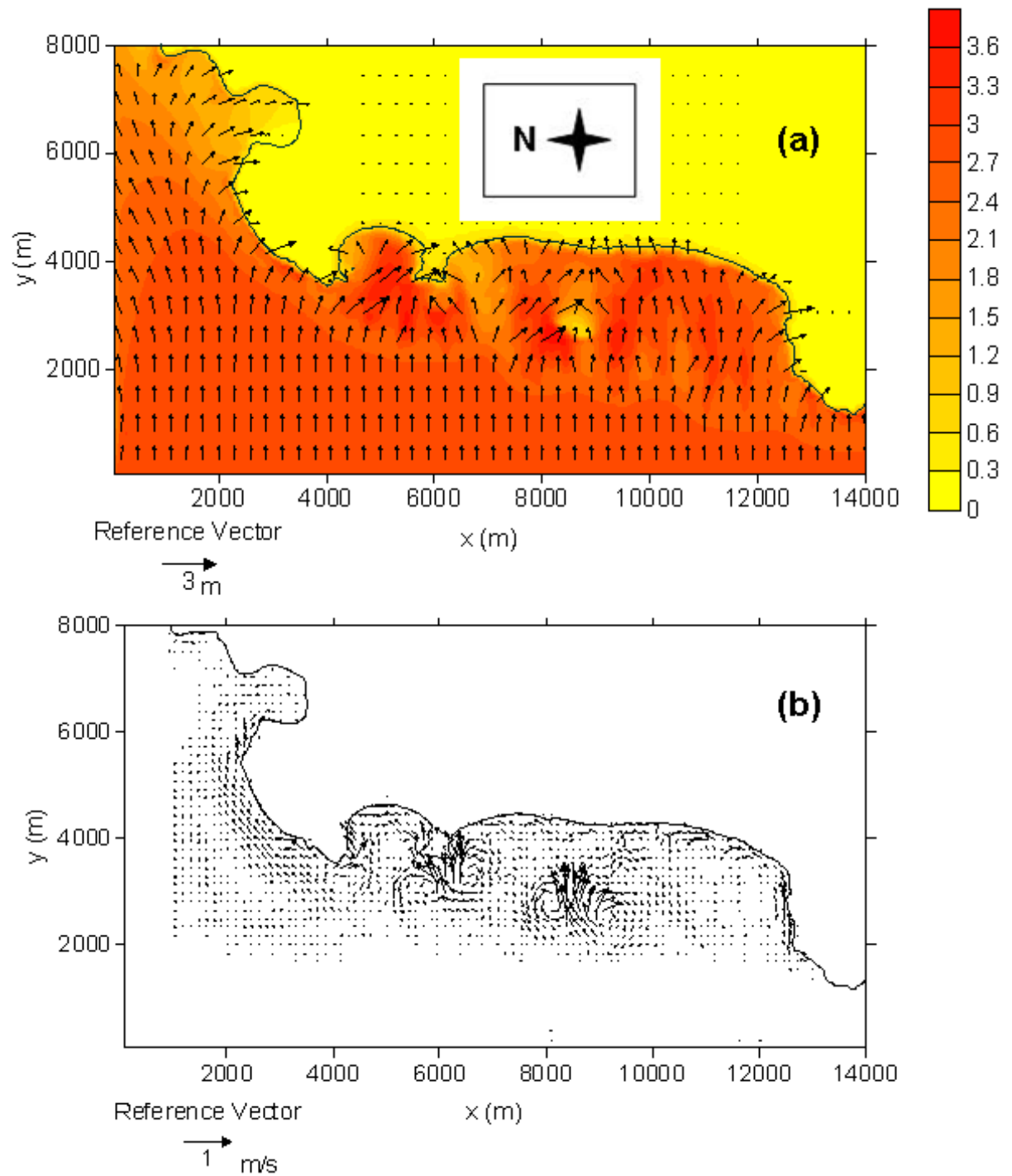
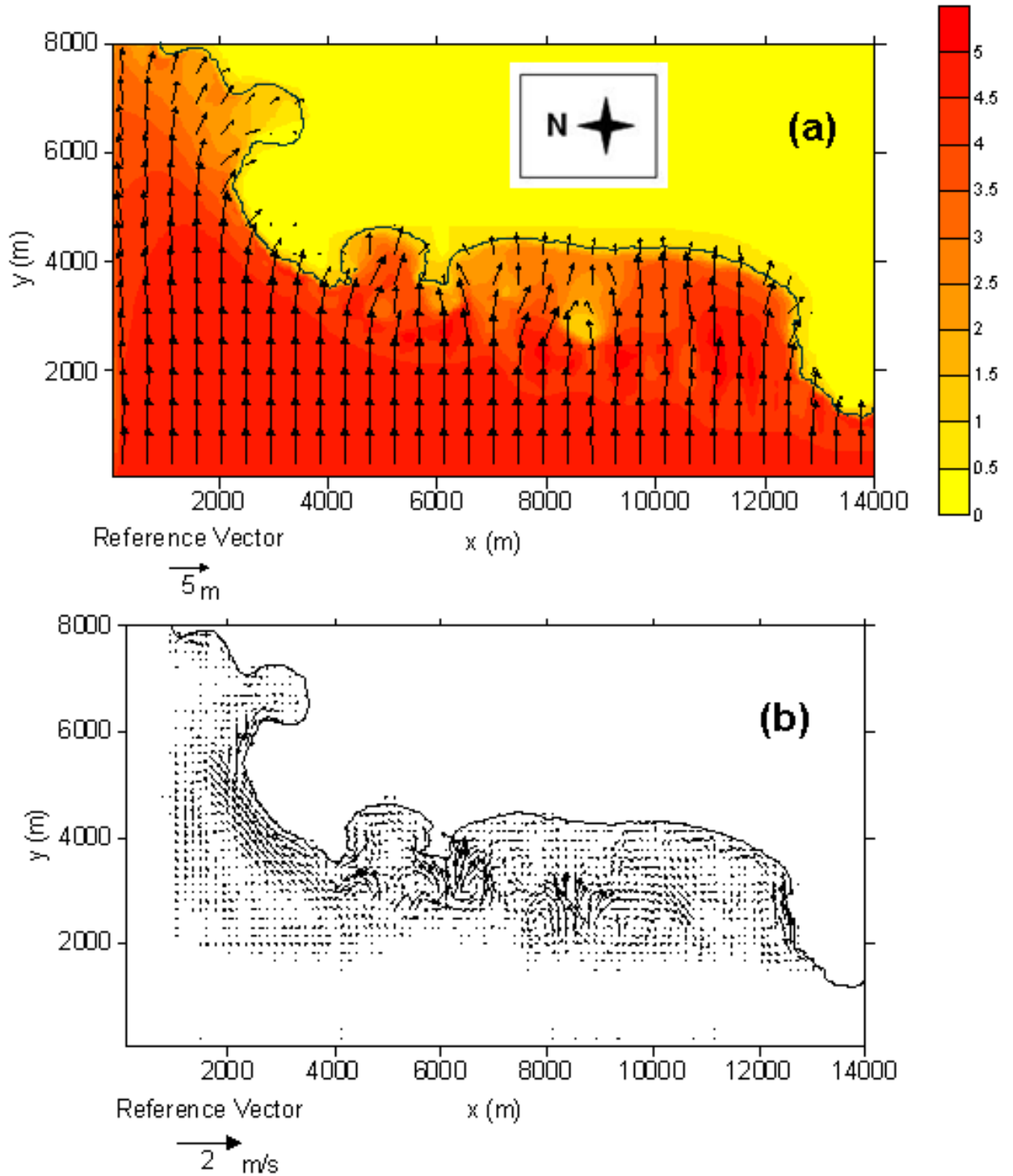


Figure 10. Numerical model results for wave heights (a) and wave-induced currents (b) at the Negril coast. Conditions: Storm offshore wave height (H_{rms}) = 4.7 m and period $T_p=8.7$ s. Note the prediction of a considerable coastal set-up. Waves approach from the west.

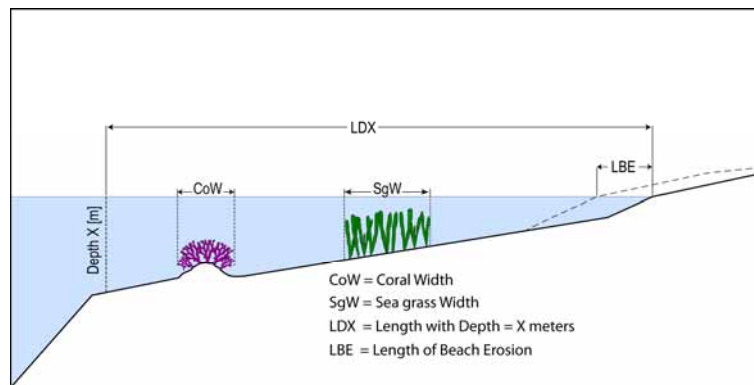


3.4 Determining the variables used for the multiple regression analysis

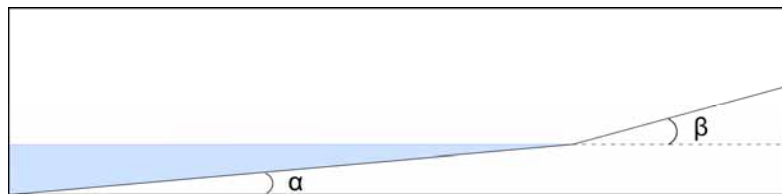
The main hypothesis established that beach erosion depends on the level (width) of protection from sea grasses and or coral reefs (Figure 11). The proximal beach slope (β) was estimated from the 2006 beach profiles, whereas the submarine beach slope (angle α in Figure 11b) was estimated by either extracting (using GIS techniques) the length at which a certain depth is recorded at fixed distances, or conversely by finding the distance of a fixed depth.

Figure 11. Variables extracted for the multiple regression (see Section 4.5.2)

a)



(b)



In order to study the effects of the prevailing wave regime on beach morphology, the Iribarren Number (Iribarren and Nogales, 1949) was computed (Equation 1), which represents the relationship between the beach slope and the wave characteristics (i.e. steepness) and provides an indication of beach vulnerability to the wave energy. This was computed for four wave conditions, i.e. ‘normal’ wind waves (wave height (H) of 0.8 m and wave period (T) of 6 seconds), swell waves (H=2.8 m and T= 8.7 s) and the 5- and 10-year return waves (SWI, 2007).

$$IrbnY = \frac{\beta}{\sqrt{H/L}} \quad [1]$$

where: β is the submarine beach and H and L the wave height and wave length, respectively.

Another crucial parameter of beach morphodynamics dynamics which was included in the analysis is the wave run-up height (WRu), as it does not only control the upper limit of the beach flooding, but also the beach sediment and morphodynamics (e.g. Vousdoukas et al., 2009a). A good approximation of the maximum run up heights is given by Stockdon et al. (2006) in Equation 2:

$$WRu_{2\%} = 1.1 \left(0.35\beta(H_o / L_o)^{1/2} + \frac{[H_o L_o (0.563\beta^2 + 0.004)]^{1/2}}{2} \right) \quad [2]$$

where: WRu_{2%} is 2% exceedence of the peak run-up height.

Table 1 provides a sample of all the variables extracted for the multiple regression analysis.

Table 1. Variables extracted for the multiple regression analysis

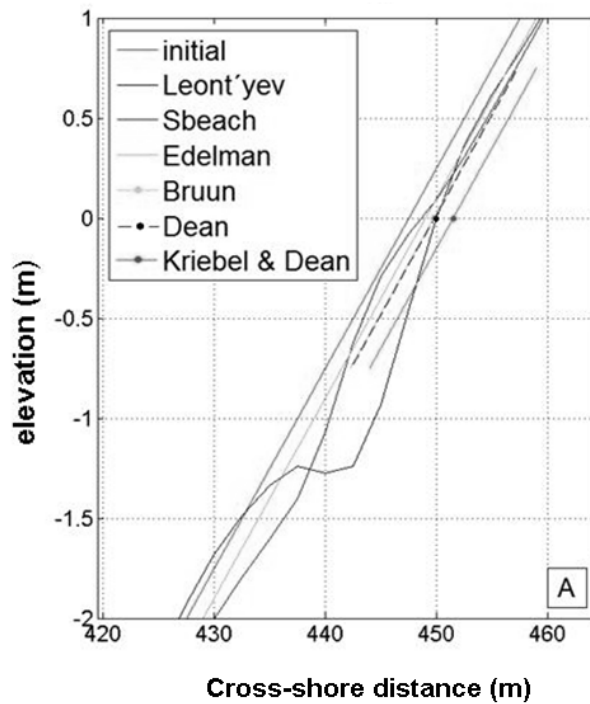
Length of Beach Erosion	LBE	In meters
Length of Sea grass Width	SgW	In meters
Length of Coral Width	CoW	In meters
Distance at which the depth equal X m	LDX	Depth X: 4, 5, 6, 7, 8, 9, 10, 12, 14, 16, 20m
Depth at fix distances from shore	DX	Distance X: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0 km
Iribaren number for different wave regimes	IrbnY	Normal wind waves, swell waves and 5- and 10-year return waves
Wave Run up for different wave regimes	WRuY	Normal wind waves, swell waves and 5- and 10-year return waves

3.5 Details of the morphodynamic model ensemble used to estimate beach erosion under varying conditions of sea level rise and storm surges

An ensemble of six coastal morphodynamic models have been used to assess the potential range of shoreline retreat. The Bruun model (Bruun, 1988) is based upon the concept of the equilibrium profile, with the coastal retreat controlled by the height of the beachface and the distance between the coastline and the closure depth (Komar, 1998). Edelman's (1972) model can deal more effectively with realistic beach profiles and temporally-variable sea level changes. The Kriebel and Dean (1985) model is also founded on the equilibrium profile concept, with the solution involving the sediment continuity equation and a 'stair-step' profile discretisation. The Dean (1991) model is also based on the equilibrium profile concept, with the coastal retreat controlled by the water depth at wave breaking, the height of breaking waves, the surf zone width and the beach sediment texture.

The SBEACH model (Larson και Kraus, 1989) is a ‘bottom-up’ morphodynamic model, consisting of combined hydrodynamic and sediment transport modules and containing detailed descriptions of the wave transformation and sediment transport in the coastal zone. The sediment continuity equation is addressed by finite differences and a ‘stair-step’ beach profile discretisation, whereas sediment transport is controlled by the wave energy flux and the beach slope. Finally, the model based on the Leont’yev (1996) algorithm uses the energetics approach (Battjes and Janssen, 1978), with the wave energy balance in the cross-shore direction controlled by the wave propagation angle, the wave energy and its dissipation; sediment transport rates are predicted separately for the surf and swash zones.

Figure 12. Example of the ensemble modelling results for the upper part of the beach profile (sea level rise, 0.22 m; wave height (H), 2 m; wave period (T), 6 s; and d_{50} , 1 mm), and beach slope of 1/10.

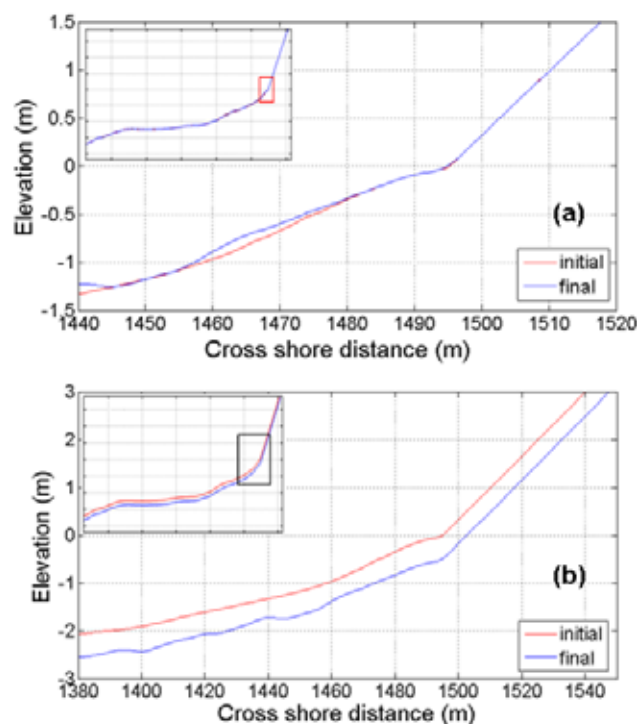


3.6 Further validation of the ensemble modelling of beach erosion under rising sea levels and storm surges

In order to qualify the findings reported in Section 4.6, a confined number of experiments were carried out using a robust morphodynamic model, the full details of which can be found elsewhere (Karambas and Koutitas, 2002; Vousdoukas et al., 2009b). The model was used for realistic conditions, i.e. for actual, non-linear Long Bay profiles, recorded wave conditions and realistically-sized sediments.

The results show that if the actual Negril morphological, sedimentological and hydrodynamic conditions are used instead of the generalized conditions used in the ensemble modelling, then beach retreats fall well within the limits prescribed by the ensemble modelling, being nevertheless closer to the lower end of the ensemble's predictions (Figure 13).

Figure 13. Example of the modelling results for the upper part of the beach profile 69 for swell waves conditions (offshore wave height (H_s) = 2.8 m; wave period (T) = 8.7 s; and D_{50} = 0.5 mm): (a) present sea level (b) sea level rise of 0.52 m. Coastal retreat estimated at 7.6 m.



¹ Cho H.J., Kirui P. et al. (2008). "Test of Multi-spectral Vegetation Index for Floating and Canopy-forming Submerged Vegetation". *Int. J. Environ. Res. Public Health*. 5: pp. 477-483.

² Blaschke T., Burnett C., et al. (2004). "New contextual approaches using image segmentation for object-based classification", In S. de Jong and F. van der Meer (Eds), *Remote Sensing Image Analysis: Including the spatial domain*. Kluwer Academic Publishers: Dordrecht, Boston, London.

³ Urbanski J.A. et al. (2009). “Object-oriented classification of QuickBird data for mapping seagrass spatial structure”. *Oceanological and Hydrobiological Study*. 28 (1): pp. 1-17.

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