An Assessment of Coastal Risks and the Role of Environmental Solutions

COASTS *at* RISK

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Front cover photos:

left, a woman collects cockles in Nicaragua. Credit: CRC

middle, a reef of hard and soft corals in the Indo-Pacific Ocean. Credit: Nancy Sefton

right, a fisherman along The Gambian coastline. Credit: James Tobey, CRC

Back cover photos:

left, erosion damages a beach in the Marshall Islands. Credit: James Tobey, CRC

middle, a fisherwoman with her harvest in Thailand. Credit: CRC

right, many vulnerable coastal areas along Ghana's Western Region are highly populated. Credit: CRC

COASTS *at* RISK

An Assessment of Coastal Risks and the Role of Environmental Solutions

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ACRONYMS LIST

BCPR	Bureau for Crisis Prevention and Recovery (United Nations)
C@R	Coasts at Risk
CIESIN	Center for International Earth Science Information Network
CRC	Coastal Resources Center, University of Rhode Island, Graduate School of Oceanography
CreSIS	Center for Remote Sensing of Ice Sheets
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	Food and Agriculture Organization of the United Nations, Statistical Databases
FEMA	Federal Emergency Management Agency
GRIP	Global Health Research Initiative Program
GRUMP	Global-Rural-Urban Mapping Project
IFRC	International Federation of Red Cross and Red Crescent
IPCC	Intergovernmental Panel on Climate Change
OECD	Organisation for Economic Co-operation and Development
SIDS	Small Island Developing States
TEV	Total Economic Value
TNC	The Nature Conservancy
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCC	United Nations Framework Convention on Climate Change
UN-HABITAT	United Nations Human Settlements Programme
UNISDR	United Nations Office for Disaster Risk Reduction
UNU-EHS	United Nations University-Institute for Environment and Human Security

EXECUTIVE SUMMARY

Coastal development and climate change are rapidly changing the world's coastlines and dramatically increasing risks of catastrophic damage. Erosion, inundation and extreme weather events affect hundreds of millions of vulnerable people, important infrastructure and tourism—with significant losses to national economies and human suffering. Environmental degradation compounds these risks, increasing communities' exposure to natural hazards and reducing their access to natural resources (e.g., fish stocks). Coastal and marine habitats, particularly coral reefs and wetlands, are at the front line of many of these changes and are increasingly lost and degraded. Often the loss of these habitats and fish stocks is greatest around population centers. That is, where the most people could benefit from these natural resources is often where their damage and loss are the greatest.

This Coasts at Risk (C@R) report 1) examines the risks that nations face from vulnerability and exposure to coastal hazards; 2) identifies where environmental degradation contributes to these risks; and 3) explores where environmental solutions can contribute to risk reduction. Risk is defined as the interaction between a natural hazard event (including the adverse impacts of climate change) and the vulnerability of societies. This report applies an indicator-based approach to assessing the risk that coastal nations face with respect to natural hazards. The C@R Index builds on the framework and methodology of the index presented in the WorldRiskReport, which was led by the Alliance Development Works and the United Nations University Institute for Environment and Human Security (UNU-EHS). The WorldRiskReport highlighted that across all countries and hazards (e.g., earthquakes, floods, sea level rise, storms and drought); coastal countries were consistently at the greatest risk. This report and the C@R Index focus only on coastal countries and adds new indicators for fisheries and coastal habitats (natural capital) to highlight the connection between environment and social vulnerability in assessing risk for coastal nations.

Many prior papers and reports focus on recommendations for either risk reduction or conservation objectives (e.g., early warning systems for risk reduction or protected areas for conservation).

This report takes an integrated approach by focusing on analyses and recommendations that can benefit both people and nature across risk reduction and environmental conservation objectives.

There are several key findings and considerations raised in the report that help guide the recommendations. First, the nations most at risk overall are tropical and Small Island Developing States (SIDS). Second, environmental degradation increases vulnerability and exposure. Third, environmental conservation and restoration can reduce exposure and improve social vulnerability. Lastly, it is highly likely that future coastal risks will increase with climate change, population growth and further coastal development. Based on the findings, this report offers a series of recommendations relevant to policy-makers, scientists, conservationists and risk managers.

The C@R Index helps to understand the risks that nations face from coastal hazards and identifies where environmental degradation contributes to vulnerability. Indeed, environmental indicators (fisheries, habitat) were linked to vulnerability (r^2=0.10, $p \leq 0.01$), and this connection between people and environment was strongest in tropical countries (r^2=0.15, $p \leq 0.01$).

After assessing risks globally, this report provides review chapters on mangrove forests, coral reefs and fisheries to examine how environmental degradation of these resources contributes to risk, and more importantly, how conservation and restoration could contribute risk reduction solutions. Reefs and mangroves provide important risk reduction benefits to people. These benefits include reductions in exposure (e.g., reefs reduce wave energy by 97%) and the provision of natural resources, which support livelihoods and reduce social vulnerability. These benefits are important to hundreds of millions of people. More than 250 million people live in low-lying exposed areas on the coast (< 10m elevation) and within 10 km of a reef or mangrove habitat. These are the people who most likely receive direct risk reduction benefits from reefs and mangroves.

Most of the world's coastal communities depend on fish and fish-related industries for food and jobs. An estimated 660-820 million people depend on fish (both from wild capture and aquaculture) for their livelihoods, and nearly 3 billion people rely on fish as an important source of animal protein (FAO 2012). The significance of fisheries to livelihoods, food security and coastal economies makes addressing the links between fisheries and social vulnerability central to evaluating and managing overall risk from coastal hazards.

Based on our findings from the C@R Index and reviews of the role of reefs, mangroves and fisheries in risk and risk reduction, the following key recommendations were identified.

There is a need to increase risk prevention measures and opportunities for better post-disaster development choices

- Pre-disaster (i.e., prevention) actions are particularly cost effective but the most difficult to support. Larger and more coordinated coalitions of stakeholder agencies and groups could push more effectively for the support that is needed.
- Post-disaster choices could support both risk reduction and conservation goals if national governments and multinational funders were more cautious about rebuilding efforts in the highest risk, low-lying areas.
- A greater commitment is needed to help SIDS, the most at-risk nations, build adaptive capacity for the future through adaptation (prevention) measures and better post-disaster development choices.

Habitat restoration can contribute to risk reduction, and opportunities exist to focus these restoration efforts

- Coral reef and mangrove restoration offers cost-effective options for risk reduction, which is particularly relevant in tropical, coastal countries that are most at risk from natural hazards.
- Environmental agencies and conservation groups will need to modify priorities to work effectively to support risk reduction. For example, many marine conservation efforts occur in remote areas (i.e., with low population density). More projects should be added in areas with greater population density.
- Even large temperate countries (e.g., China and the U.S.) have the need and opportunities for coral reef and mangrove restoration to reduce risks. In temperate countries, increased oyster reef and salt marsh restoration could also cost-effectively reduce risk.

Targeted research is needed on environmental risk reduction services to create better opportunities for investment

- Governments and multinational funders should develop more integrated risk assessments that better account for drivers of risk, such as environmental degradation.
- Scientists should advance research on the effects of environmental degradation on risk. For example, there needs to be more direct measures of the effects of habitat degradation on coastal erosion and on the connection between fisheries and food security.
- More rigorous accounting for ecosystem services is needed, and the approaches should align with the decision-making frameworks used by hazard managers (e.g., cost: benefit analyses).

- Many nations have substantial critical infrastructure (e.g., ports, airports, power plants, sewage treatment plants) in low-lying and highly exposed areas; governments need to better account for how this affects their national risk.

Leaders need to demand more cost-effective solutions and recognize opportunities to create sustainable investments in natural infrastructure

- Adaptation and development funders should encourage better mainstreaming of cost-effective solutions for risk reduction. Where natural solutions are cost effective, they should become the preferred alternatives. This is already starting to happen as re-insurers assess the cost effectiveness of habitat restoration, and engineering agencies and firms are developing more nature-based coastal defense projects.

- Nature-based risk reduction can be increasingly viewed as an opportunity for investment and business. Engineering firms can find business in designing nature-based defenses. Construction firms and marine contractors can find business in developing restoration projects.

Fisheries management and research need to improve and recognize opportunities to reduce social vulnerability

- Our understanding of the links between fisheries and food security needs to be improved. This research will help drive actions by identifying where to focus conservation for food security.

- Fisheries management can fruitfully be approached from a risk reduction and adaptation viewpoint, which could lead to new partnerships (e.g., with aid groups); new and refined funding investment strategies; and better buy-in towards fisheries enhancement.

- Further research on the link between fisheries and climate change is critical. In the future, tropical areas are predicted to see declines in fisheries productivity. Thus, those countries most at risk overall may face the greatest pressures from climate-related declines in fisheries.

These recommendations require a new level of cooperation between aid, development, and conservation agencies and groups. Some of that cooperation is already happening, and there are many important reasons why it can and must expand. There is great need and opportunity in further integration to meet risk reduction and environmental conservation management objectives.

Erosion damages a beach in the Marshall Islands.
Credit: James Tobey, CRC

1. INTRODUCTION

BY JAMES TOBEY AND HILARY STEVENS

Coastal development and climate change are rapidly changing the world's coastlines and dramatically increasing risks of catastrophic damage. The proportion of the world's GDP annually exposed to tropical cyclones has increased from 3.6% in the 1970s to 4.3% in the first decade of the 2000s (UNISDR, 2011). Erosion, inundation and extreme weather events affect hundreds of millions of vulnerable people, important infrastructure and tourism—with significant losses to national economies and human suffering.

Environmental degradation compounds these risks, increasing communities' exposure to waves, wind and water, and leads to further losses of fish stocks. Coastal and marine habitats, particularly coral reefs and wetlands, are at the front line of many of these changes and are increasingly lost and degraded. Global losses of coastal habitats are as high as 85% for oyster reefs, 30-50% for wetlands and over 25% for coral reefs. Often the loss of these habitats is greatest around population centers. That is, where the most people could benefit from these ecosystems is often where their damage and loss have been the greatest. Owing to overfishing and habitat degradation, fish stocks have suffered major declines. Most global fish stocks are managed unsustainably with many collapsed or collapsing, and these losses have the greatest impacts on the most fisheries-dependent and vulnerable communities.

Billions of dollars are invested in reducing risks from coastal hazards and climate change, creating both threats and opportunities for natural systems. Total Fast Start Finance commitments under the United Nations Framework Convention on Climate Change (UNFCCC) include roughly U.S. $3 billion for climate adaptation assistance. In the United States the Federal Emergency Management Agency (FEMA) spends U.S. $500 million/year to reduce flooding hazards. Middle income countries such as Colombia, Brazil and China are making multibillion dollar investments to address risks of flooding and other disasters. Most of these funds are destined for the creation of "grey infrastructure" such as seawalls, which will further degrade coastal ecosystems and may not be cost effective for risk reduction when compared to more natural and hybrid alternatives.

The C@R report 1) examines the risks that nations face from vulnerability and exposure to coastal hazards; 2) identifies where environmental degradation contributes to these risks; and 3) explores where environmental solutions can contribute to risk reduction. The report exposes the links between coastal natural resources and disaster risks and raises the importance of taking societal action to reduce these risks, particularly in the context of knowledge that they will increase with climate change. This report is intended to inform national, regional and global decision-makers about their risks; the factors that contribute to them; and the role that the environment may play in reducing current and future risks.

This report applies an indicator-based approach to assessing the risk that coastal nations face with respect to natural hazards. The methodology for calculating risk in coastal nations is described in Chapter 2 and follows approaches and definitions developed within the disaster risk reduction community (UNISDR, 2011; IPCC, 2012). Risk is a function of exposure of people and assets to a geophysical hazard (e.g., flood) and the social vulnerability of communities. The three components of vulnerability are susceptibility, coping capacity and adaptive capacity. Susceptibility is the likelihood that people will experience harm or be adversely impacted by a coastal hazard event. Coping capacity is the ability of a society to handle disaster emergencies, and adaptive capacity is long-term institutional, educational and economic ability to deal with actual or future hazard events.

The C@R Index of risk was prepared by building on the framework and methodology of the index presented in the WorldRiskReport (www.worldriskreport.com), which was led by the Alliance Development Works in cooperation with the UNU-EHS. The WorldRiskIndex developed by UNU-EHS is constructed annually through close cooperation between scientists and practitioners, and the methodology of the index is validated by scientists for its reliability.

The WorldRiskReport highlighted that across all countries and hazards (e.g., earthquakes, fires, floods, sea level rise, storms and drought), coastal countries were consistently at the greatest risk. For example, the top 15 most at-risk nations in the 2012 global report were all coastal, tropical nations. The world's coastal regions are centers of population and economic activity, but they are also highly exposed to natural hazards, including those that are climate change related.

This report and index have added a particular focus on coastal and environmental risks. First, this report and index focus only on coastal nations. Second, new indicators for fisheries and coastal habitats (natural capital) have been added to concentrate on the connection between environment and social vulnerability in assessing risk for coastal nations. These coastally focused environmental indicators were added to each component of the assessment of social vulnerability as suggested in the WorldRiskReport 2012 (Welle et al. 2012). All of these indicators were global in scale except for the indicators of reef and mangrove habitats, which occur only in countries with tropical environments.

After assessing national risks, the C@R report provides review chapters that examine the links among natural coastal resources, risk and risk reduction. Individual chapters focus on mangrove forests (Chapter 3), coral reefs (Chapter 4) and fisheries (Chapter 5) to examine how environmental degradation in these resources contributes to risk, and more importantly, where conservation and restoration could contribute to risk reduction.

Mangroves provide habitat for numerous species including birds and juvenile fish and are a source of wood for fuel and construction. Mangrove stands have also been shown to reduce shoreline wave energy, which lessens erosion and can dampen the effects of extreme events, such as storm surge or tsunami. Mangroves also mitigate climate change, as the soils in which they grow can store large amounts of carbon. For all these reasons, mangroves are a valuable resource in reducing risk.

Coral reefs are primarily found in the tropical and subtropical regions of the Western Atlantic and Indo-Pacific oceans and generally in the shallower depths. Coral reefs can reduce adjacent coastal communities' risks from natural hazards, including climate change effects. Like mangroves, they reduce the wave energy that reaches the shore at a level comparable to artificial breakwaters. Coral reefs also reduce vulnerability by providing natural capital in the form of habitat that supports fisheries for food supply and alternate income generation. For these reasons, protecting existing reefs and restoring reefs that have become degraded are important approaches to risk reduction.

Marine fisheries also represent natural capital that is linked to risk reduction by providing animal protein as well as direct and indirect employment and income for the world's coastal communities. The fisheries chapter describes and graphically illustrates these benefits and highlights climate change risks to fisheries. It also discusses the importance of fisheries vulnerability assessments and risk reduction strategies.

Environmental degradation can increase risk for fisheries, coral reefs and mangroves, and environmental health has a strong influence on vulnerability. Consequently, environmental conservation and restoration of coastal habitats and the application of strategies to increase the productivity of fisheries can reduce vulnerability.

This report concludes with recommendations for reducing these risks with a particular focus on measures relevant across management objectives of risk reduction, adaptation and conservation (Chapter 6).

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Many vulnerable coastal areas along Ghana's Western Region are highly populated. Credit: CRC

2. THE COASTS AT RISK INDEX

BY TORSTEN WELLE, MICHAEL W. BECK AND JOERN BIRKMANN

The C@R Index is an indicator-based approach that assesses the risk of coastal nations exposed to natural hazards such as cyclones, floods, storm surges, tsunamis and sea level rise. This Index also examines where environmental degradation of coastal resources contributes to this risk. The C@R index is built on the concept of the WorldRiskIndex developed by UNU-EHS (Birkmann et al., 2011, Welle et al., 2013) with the addition of a particular focus on coastal and environmental risks. The index is intended to inform national, regional and global decision-makers about their risks and the factors that contribute to them so that they can seek solutions in disaster risk reduction and climate change adaptation. The C@R Index is based on the premise that it is not only the intensity of a natural event that is responsible for a coastal hazard turning into a disaster, but also the social, economic and ecological factors of a society. Hence, planning processes and proactive measures could reduce the risk of coastal nations related to coastal hazards and the impacts of climate change.

2.1 Theoretical concept

The concept of the C@R Index is based on the core understanding of risk within the natural hazards and disaster risk reduction community. In this context, risk is defined as the interaction between a natural hazard event (including the adverse impacts of climate change) and the vulnerability of societies (UNISDR, 2004; Wisner et al., 2004; Birkmann, 2013). Social vulnerability is composed of susceptibility, coping capacity and adaptive capacity.

This concept emphasizes that risk is not solely an outcome of the probability and magnitude of the natural hazard event but also is determined by the structure, processes and framework conditions within a society. Consequently, social, economic and environmental factors as well as governance play a major role in determining whether a natural hazard will result in a disaster (Birkmann et al., 2011; IPCC, 2012). The C@R Index is composed of 33 indicators using freely available global data and is based on a modular structure divided into four components of exposure to natural hazards, susceptibility, coping and adaptive capacity (Figure 1). The results of the C@R Index enable a comparison of countries with one another, providing a description of a potential disaster. The index cannot forecast individual disasters.

2.2 From the WorldRiskIndex to the C@R Index

The WorldRiskIndex is the main component of the WorldRiskReport, which is released every year by the German non-governmental organization Bündnis Entwicklung Hilft (Alliance Development Works 2011, 2012, 2013). The WorldRiskIndex ranks 173 nations by examining the level of exposure to natural hazards combined with information on vulnerability composed of susceptibility, coping capacity and adaptive capacity. The results are a set of global indicators for risk, exposure and vulnerability that are visualized in a series of maps.

With the C@R Index, the focus is on coastal nations because of the high risks that such nations face from natural hazards (e.g. storms, tsunamis, floods, storm surges) and the growing impacts of climate change, such as sea level rise. Globally, 1.2 billion people (23% of the world's population) live within 100km of the coast and 50% are likely to do so by 2030 (Adger et al., 2005). It is estimated that some 10 million people already experience coastal flooding each year due to storm surges and cyclones, while projections taking into account sea level rise and increasing population density suggest 50 million people per year will be at risk by 2080 (Adger et al., 2005). Coastal communities are literally in the front lines of coping with sea level rise as well. Some areas worldwide are already struggling with inundation and land loss. Changing weather patterns such as intense rainfall or drought in many areas will heighten issues with coastal flooding and limited fresh water, and it is highly likely that many areas will experience more frequent, intense storms and their concomitant coastal flooding. Additionally, most coastal areas and island states are dependent on resources such as fishing, ports and aquaculture for their livelihoods, making them all the more susceptible to coastal hazards and climate change.

The C@R Index is based on and adds to the WorldRiskIndex (Figure 1). This C@R Index focuses on coastal nations and hazards with the addition of environmental indicators designed to represent natural capital (e.g., coastal habitats and fisheries) and the contribution of environmental degradation (e.g., loss or lack of natural capital) to national risk.

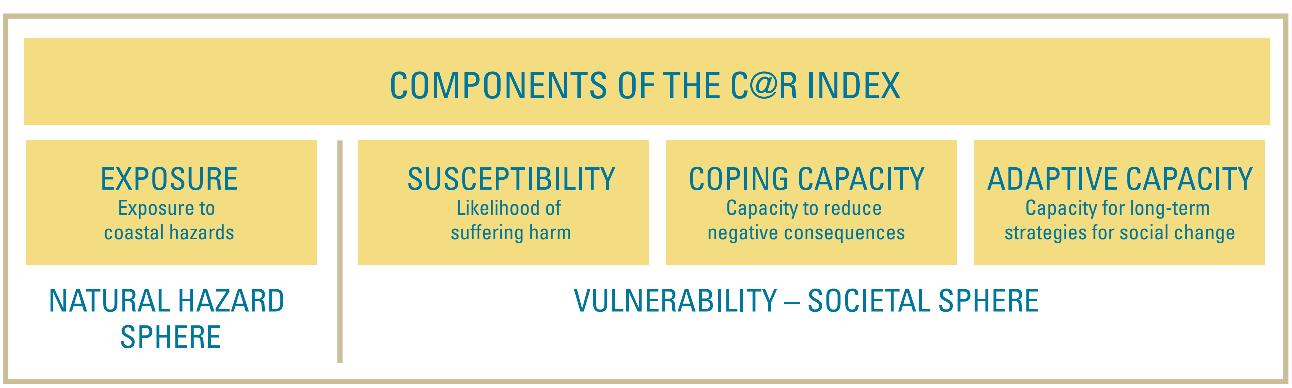


Figure 1: Scheme of the concept of the C@R Index

Coastal hazards and exposure of coastal populations

Exposure refers to entities (e.g., people, resources, infrastructure and goods) exposed and prone to be affected by a hazard event (UNISDR, 2009). Within the C@R Index, exposure is narrowed to refer to entities who may be affected by coastal natural hazards. Coastal hazards are natural events that happen along the coastline. The following coastal hazards were taken into account for the calculation of exposure: storms, storm surges, floods, tsunamis and sea level rise.

The data used for exposure consider the frequency and magnitude of the hazard events, thus exposure is closely linked to characteristics of the hazard phenomena. The number of exposed people is based on models taking into account previous storms, floods, tsunamis, storm surges and population density (for details: http://preview.grid.unep.ch/). The exposure to sea level rise is calculated by considering a conservative estimate of the number of people who would be affected by one meter sea level rise (Welle et al., 2013). The number is conservative because exposure is based on current population without considering future population growth.[1] However, the authors note that the gradual increase of one meter sea level rise is expected to occur only by 2100 and does not include a probabilistic component.

Vulnerability of coastal populations

In this study the vulnerability of coastal populations is defined by three components: susceptibility, adaptive capacity and coping capacity (Figure 1), which are described in further detail in the next three subsections below. In short, these components aim to characterize the current socio-economic condition of countries and their abilities to cope with near-term hazards and to adapt to longer-term hazards and climate change (Birkmann, 2013).

Susceptibility and coping capacity are closely interlinked and clear separation of indicators in practice is thus often difficult because some aspects overlap. This index includes logical subcategories allocated with corresponding indicators. Nonetheless, the authors are aware that many indicators might allocated among subcategories differently. For example, a good economic situation in terms of savings would make people less susceptible compared to those without savings and would increase the coping capacities of the former group.

Susceptibility of coastal populations

Susceptibility refers to the conditions of exposed people, infrastructure (built capital) and ecosystems (natural capital) that make populations more or less likely to experience harm and to be affected by natural hazards and climate change. If susceptibility is high, the likelihood of the community to suffer harm is also high. Susceptibility is closely linked to social and economic conditions such as nutrition, economic capacities and public infrastructure. It provides a metric of the underlying likelihood that a society can suffer harm due to any stressor from natural hazards. Conceptually, susceptibility has been divided into five subcategories that represent the livelihood situation and living conditions of people within a coastal country. The subcategories are:

- Public infrastructure
- Nutrition
- Poverty and dependencies
- Economic capacity and income
- Natural capital

Coping capacity of coastal populations

Coping is defined as the ability of a society to use direct action and its own resources to face and manage near-term emergencies, disasters or adverse conditions from a hazard event (UNISDR, 2009). Coping mechanisms usually build on experiences that have been made during past disasters. Hence, coping mechanisms are often based on the assumption that what has happened in the past is likely to re-occur in a familiar pattern (Bankoff et al., 2004). Coping capacities encompass measures, resources and abilities that are immediately available to

[1] The combination of projected future extent of a hazard (sea level rise) with present population is a commonly accepted approach particularly when spatial patterns of future social and economic growth are highly uncertain.

minimize harm when a disaster strikes. Consequently, coping is hazard related and primarily short-term oriented. The following three subcategories characterize coping within the C@R Index:

- Government and authorities
- Medical services
- Economic coverage

Adaptive capacity of coastal populations

Adaptation or adaptive capacity encompasses measures and strategies that enable the society to change or to transform in order to deal with the negative impacts of natural hazards and future climate change impacts. O'Brien and Vogel (2003) stress that compared to coping, adaptation is a more structured behaviour that aims to promote change and transformation. Hence, these capacities and measurements focus more on the change of existing structures within a society, such as the environmental status or education. In contrast to coping, adaptation is understood as a long-term process. The following four subcategories were used to describe adaptive capacities within the C@R Index. In the long term, actions designed to address these elements may make societies more resilient and adaptable to the potential impacts of climate change and natural hazards.

- Education and research
- Gender equity
- Environmental status/ecosystem protection
- Investments

2.3 Data and methods

This section provides an overview of some of the individual indicators, the global data sets and the calculation of the C@R Index. All data used were freely available and global in scale. Specific criteria were followed: indicators for exposure should span a range of the main coastal natural hazards; susceptibility, coping and adaptive capacity indicators should be of a generic nature, in order to be relevant for different hazards (i.e., multi-hazard perspective); all indicators should be rational, analytically and statistically sound; reproducible; appropriate in scope, in terms of the assessment; understandable, easy to interpret and comparable (Meyer, 2004).

Indicators

The individual indicators in each component were selected and designed based on the above-mentioned criteria. The challenge was to identify suitable indicators that best reflected the circumstances of coastal nations that could be allocated to the four components: exposure, susceptibility, coping and adaptation and their respective subcategories (Figure 2). The selected indicators for the WorldRiskIndex were discussed, verified and validated among scientists and practitioners at a symposium in Berlin (Fachtagung WorldRiskIndex, 2009). For the calculation of the C@R Index, several new indicators were added (Figure 2). These new indicators include the percentage of animal protein from fish, which was added in the nutrition portion under susceptibility (indicator D). This indicator describes the food dependency of coastal societies. Marine economic revenue related to GDP (indicator H) was added to represent the extent that the economies of coastal societies depend on marine related resources. This economic revenue is a critical component of a society's vulnerability because coastal hazards and their impacts can affect marine related income sources and thus increase their susceptibility. Coastal countries with high marine revenue in relation to overall GDP are per se more susceptible because they have lower income diversity compared to other countries. The new subcategory of natural capital includes a measure of the total marine fish captured (indicator I) in each nation as well as consideration of the natural capital from reefs and mangroves (indicator J), which was only used for the assessment of the tropical C@R Index). Under coping capacity, the fish

EXPOSURE

POPULATION EXPOSED TO

A. Cyclones
B. Floods
C. Sea Level Rise
D. Storm Surges
E. Tsunamis

SUSCEPTIBILITY

PUBLIC INFRASTRUCTURE

A. Percentage of population without access to improved sanitation
B. Percentage of population without access to improved water source

NUTRITION

C. Percentage of population undernourished
D. Percentage of animal protein from fish

POVERTY AND DEPENDENCIES

E. Dependency ratio [share of under 15-and over 65-year-olds in relation to the working population]
F. Extreme poverty population living with USD 1.25 per day or less [purchasing power parity]

ECONOMIC CAPACITY AND INCOME

G. Gini-Index
H. Marine economic revenue (OHI[1]) / GDP per country

NATURAL CAPITAL

I. Fish catch
J. Percentage of population that may receive risk reduction from reefs and mangroves [for tropical analyses only]

COPING CAPACITY

GOVERNMENT AND AUTHORITIES

A. Corruption perception index
B. Good governance [Failed States Index]
C. Fish management effectiveness index

MEDICAL SERVICES

D. Number of physicians per 10,000 inhabitants
E. Number of hospital beds per 10,000 inhabitants

ECONOMIC COVERAGE

F. Insurances [life insurances excluded]
G. Livelihood diversity index

ADAPTIVE CAPACITY

EDUCATION AND RESEARCH

A. Adult literacy rate
B. Combined gross school enrollment

GENDER EQUITY

C. Gender parity in education
D. Percentage of female representatives in the National Parliament

ENVIRONMENTAL STATUS / ECOSYSTEM PROTECTION

E. Water resources [taken from EPI[2]]
F. Biodiversity and habitat protection [EPI]
G. Forest management [EPI]
H. Agricultural management [EPI]
I. Fish stock status

INVESTMENT

J. Public health expenditure
K. Life expectancy at birth
L. Private health expenditure

[1] OHI = Ocean Health Index
[2] EPI = Environmental Performance Index 2012

Figure 2: Indicators, components and subcategories of the C@R Index

management effectiveness index (indicator C) was added under the Government and Authorities component because good management is important to food provision and livelihoods that depend upon fish and seafood. Additionally, the livelihood diversity index (indicator G) was added to focus on the distribution of employment across nine marine employment sectors. Finally, under adaptive capacity, fish stock status (indicator I) was integrated as a proxy for the sustainability of national fisheries. Some of the primary sources of the new indicator data included global databases from the World Bank and the statistic division of the Food and Agriculture Organization of the United Nations (FAOSTAT). The development of the indices was done according to the OECD Handbook on Constructing Composite Indicators (2008). Hence, several methodological steps such as normalisation were taken into account to render all indicators comparable. Figures 3 to 5 show the composition of the indices for susceptibility, coping capacity and adaptation capacity, including their respective weights.

Exposure

The C@R Index takes two different types of natural hazards into account; it focuses primarily on current and sudden onset hazards, such as storms, floods, storm surges and tsunamis, but also includes the slow onset hazard of sea level rise. The data for sudden onset hazards were taken from PREVIEW Global Risk Data Platform (http://preview.grid.unep.ch/). This platform is a multiple agency (UNEP, UNDP/BCPR (GRIP), UNISDR) effort to share spatial data information on global risk from natural hazards. Data obtained from PREVIEW represent an estimation of the average annual exposure to the four selected hazards, including the frequency of the respective hazard and information on the population distribution based on the LandScanTM Global Population Database. This specific data set is called physical exposure, and the number of people exposed per hazard and per country was derived by calculating the zonal statistic with ArcGIS. It has to be stressed that these global data are based on model calculations and therefore the matter of uncertainty within the model calculation has to be taken into account (Peduzzi et al., 2009). The calculation of exposed people to sea level rise by one meter is based on data from the Center for Remote Sensing of Ice Sheets (CreSIS) at the University of Kansas. Using GIS techniques, this data set was combined with the population statistics of the Global-Rural-Urban Mapping Project (GRUMP) run by the Center for International Earth Science Information Network (CIESIN) at Columbia University. With respect to the aggregation of exposed people per hazard, the number of individuals exposed to sea level rise has been weighted by 50%, because it is impossible to calculate an annual average exposure to sea level rise. The overall exposure index that describes the share of the population exposed per country is calculated by summing up all exposed people per hazard divided by the number of inhabitants per country.

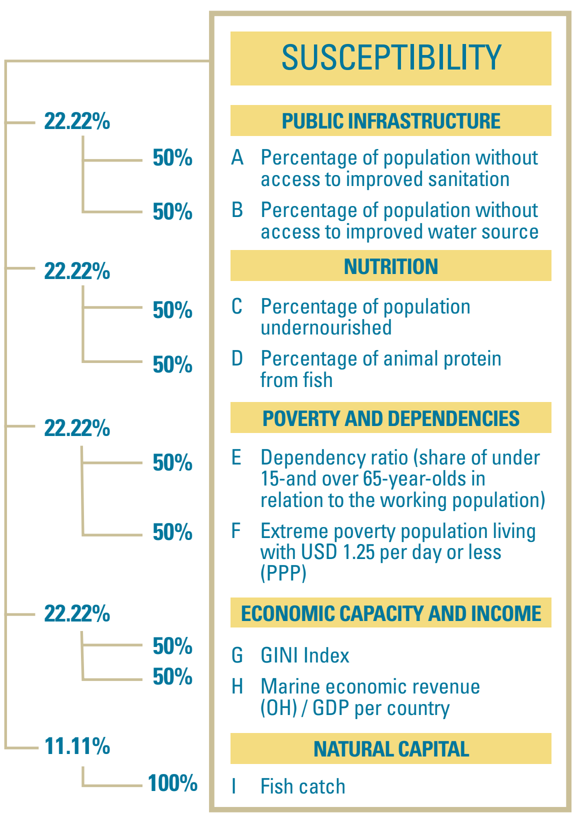


Figure 3: Structure, indicators and weights for the susceptibility component

Susceptibility

The susceptibility index includes nine equally weighted indicators (A-I) distributed among five subcategories (Figure 3). Before summarizing, all indicators were normalized between 0 and 1. The indicator "fish catch" under the subcategory natural capital is a measure of the abundance of catch, however, to focus on susceptibility the indicator is 1 – Fish Catch.

Coping capacity

The coping capacity index (Figure 4) aims to measure society's ability to immediately respond to adverse impacts during a disastrous event. Seven indicators (A-G) were chosen to determine the capacity of a coastal society to immediately react to or manage the impact of a hazardous event. Coping capacities include important resources to reduce the potential impacts of a disaster, such as medical services or economic coverage, as well as structures or framework conditions that could hinder coping measures of a coastal nation, for example, corruption or bad governance. Figure 4 provides the structure, indicators and weights for the coping capacity index. For the aggregation of the C@R Index, the lack of coping capacities will be used instead of coping capacities. Therefore, the calculated value of coping capacity will be subtracted from 1.

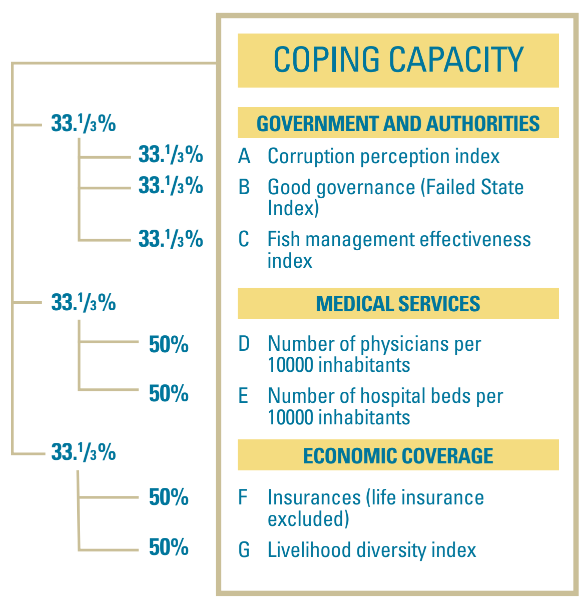


Figure 4: Structure, indicators and weights for the coping capacity component

Adaptive capacity

The indicators for the adaptive capacity of a coastal nation need to portray the long-term response capacities to natural hazards and/or environmental change. They should measure the ability of a society or community to transform or adapt to reduce the vulnerability to this change. The component on adaptive capacity contains four subcategories: education and research, gender equity, environmental status or ecosystem protection and investments (Welle et al., 2013). The indicators selected for adaptive capacity (A-L) are listed in Figure 5. The individual indicator weights as well as the weights for the aggregation of the adaptive capacity index also are illustrated.

Calculation of the C@R Index

The C@R Index is calculated by combining the four components: exposure, susceptibility, lack of coping capacity and lack of adaptive capacity. First, the indices of susceptibility, lack of coping capacity and lack of adaptive capacity are added up to a vulnerability index. The vulnerability index describes the societal component of risk that can turn a natural event into a disaster. In a second step, the vulnerability index is multiplied with the exposure index to develop the overall C@R Index. Figure 6 schematically presents the aggregation, including all weights for the components. The results have consistently been scaled between 0 and 1. For better comprehension and cartographic transformation, all individual indices have been classified using the quantile method within the ArcGIS 10 software. Five classes have been selected and each class contains the same number of cases (e.g. countries), which are translated into a qualitative classification of "very high – high – medium – low – very low."

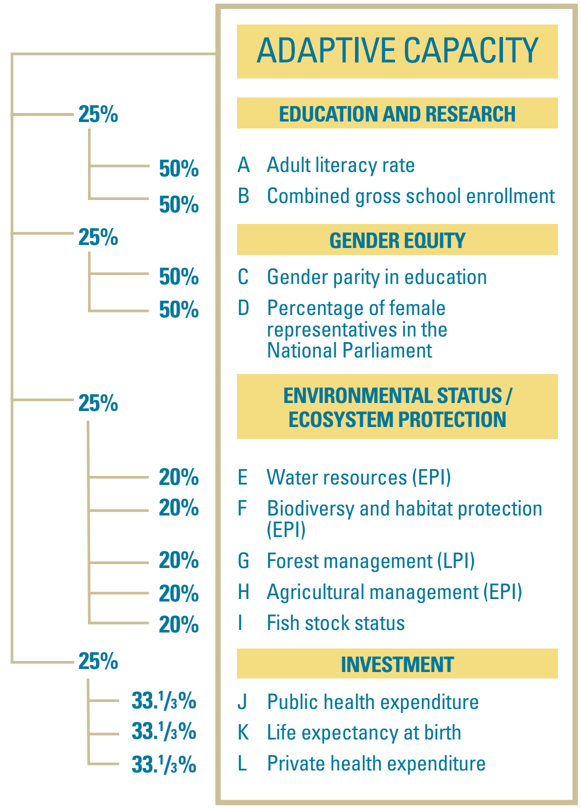


Figure 5: Structure, indicators and weights for the adaptive capacity component

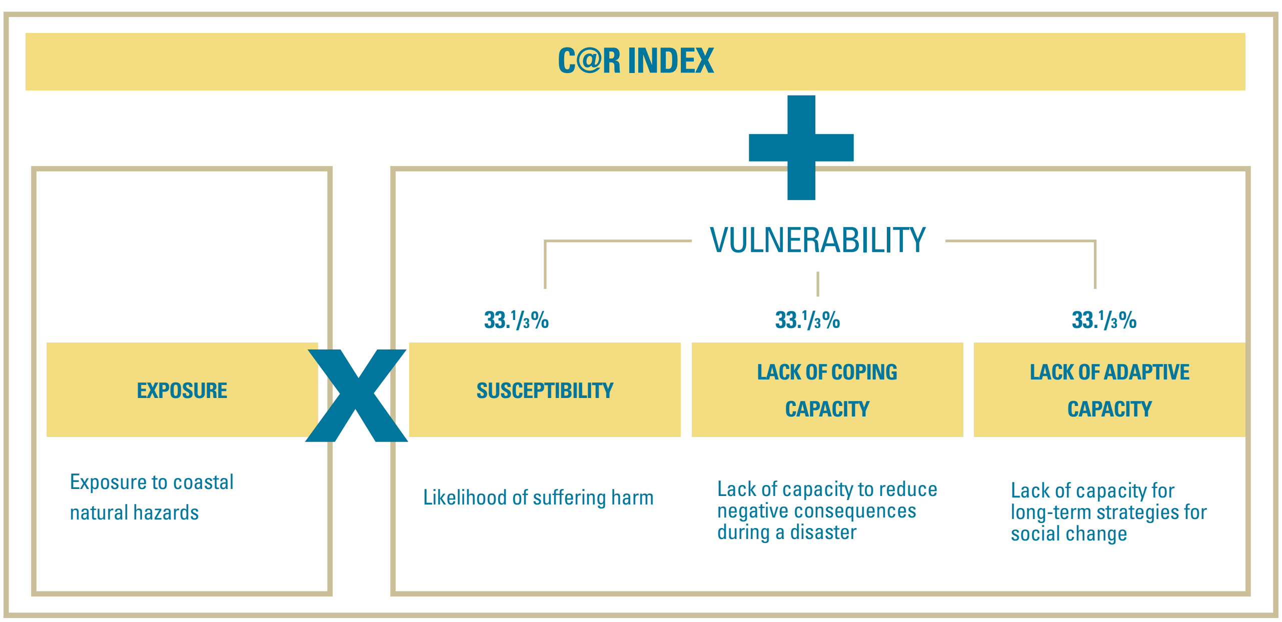


Figure 6: Structure and weights for the aggregation of the C@R index

2.4 Results of the C@R Index

Risk is a multi-causal phenomenon that not only depends on the exposure to natural hazards and climate change, but also on social conditions and capacities (as is represented in susceptibility, lack of coping capacities and lack of adaptive capacities) that can reduce impact. These three components describe the vulnerability of societies and can help signal whether a natural hazard or impacts of climate change could lead to a crisis or disaster. The results of the C@R Index describe the potential risk at national level. It is important to remember that this is neither predictive nor probabilistic; it does not predict when and where a hazardous event may take place. It is meant to characterize underlying risk and highlight areas that are most consistently exposed to coastal natural hazards. Based on data availability, 139 coastal countries were considered. The aggregated results are mapped to facilitate a general understanding and comparison between countries and regions. A deeper analysis can be made by decomposing the numerical indices into indicators. Unfortunately, several small island states, which are probably highly exposed to coastal hazards including the emerging risk of rising sea level, could not be considered due to data limitations. The individual components will be presented first, followed by the vulnerability index and the overall C@R Index.

Women cultivate oysters in the mangrove habitats of the Tanbi Wetlands National Park in The Gambia. Credit: CRC

Exposure

The world map of exposed people shows the potential annual average exposure of each coastal nation to coastal hazards. Some hot-spot regions can clearly be seen, which include the Caribbean, South East Asia and the nations of Japan, the Netherlands, Suriname and Guyana (Figure 7).

Table 1 provides an overview of the 10 most exposed coastal countries: Maximum potential exposure value 1; this would mean the whole country and all people would be exposed.

RANK	COUNTRY	EXPOSURE VALUE
1	SAINT KITTS AND NEVIS	0.5955
2	ANTIGUA AND BARBUDA	0.5893
3	TONGA	0.5108
4	BRUNEI DARUSSALAM	0.2818
5	FIJI	0.2568
6	VANUATU	0.2392
7	PHILIPPINES	0.2095
8	JAPAN	0.2080
9	NETHERLANDS	0.2036
10	BANGLADESH	0.1878

Table 1: Top 10 most exposed coastal countries

Exposure: Exposure of the population to coastal hazards (storms, floods, surges, tsunamis, sea level rise)

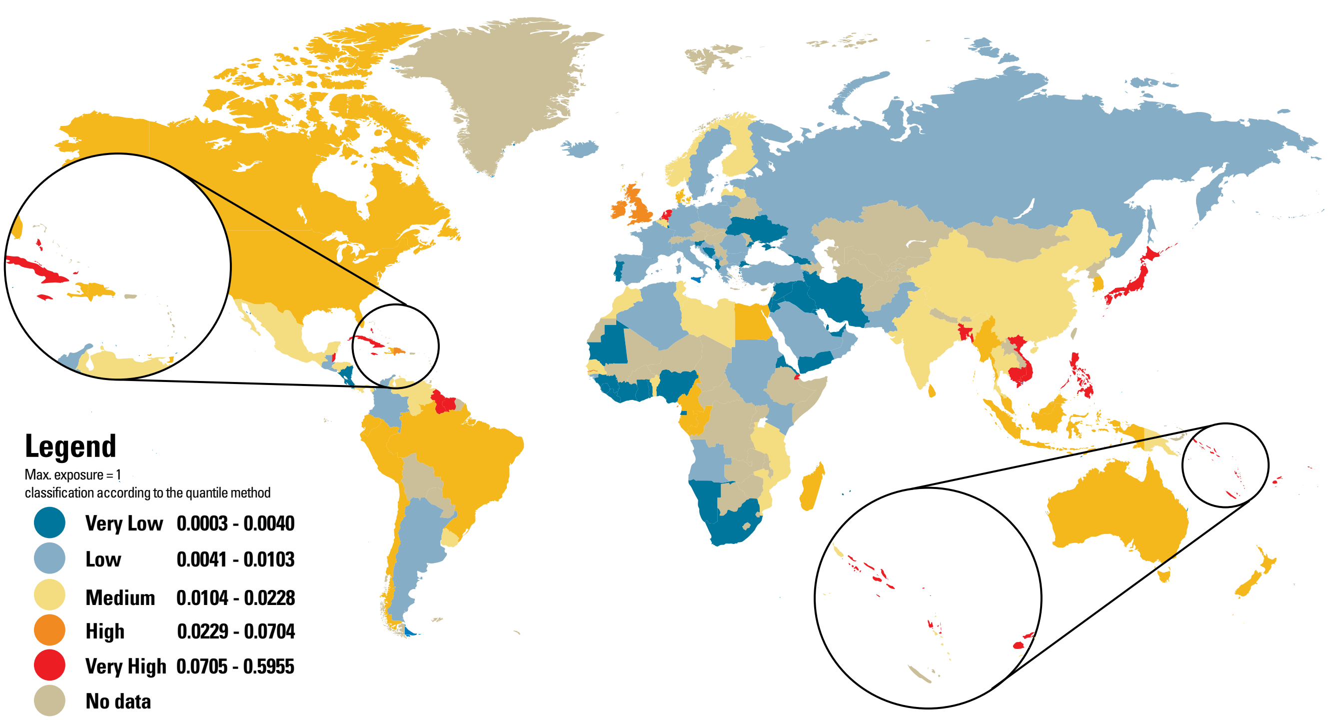


Figure 7: Exposure map

Susceptibility

Figure 8 displays the map for susceptibility by nation based on public infrastructure, nutrition, natural capital, income and economic capacities. Hot-spot regions of Very High susceptibility are clearly seen in West and East African countries, but Very High values also are identified in Haiti and Papua New Guinea, where low income and poorly constructed public infrastructure are factors. Coastal countries within the High class of susceptibility are located in South and Southeast Asia. The globally significant north-south divide is less distinctive in the Americas, where only some countries of Central America as well as Peru and Suriname rank in the High class.

Table 2 shows the 10 most susceptible coastal countries. Maximum potential susceptibility is the value 1; this would mean all nine indicators would reach the worst value.

RANK	COUNTRY	SUSCEPTIBILITY VALUE
1	SIERRA LEONE	0.5250
2	VANUATU	0.5053
3	MADAGASCAR	0.4884
4	MOZAMBIQUE	0.4837
5	COMOROS	0.4824
6	LIBERIA	0.4724
7	TANZANIA	0.4593
8	PAPUA NEW GUINEA	0.4581
9	ERITREA	0.4501
10	HAITI	0.4471

Table 2: Top 10 most susceptible coastal countries

Susceptibility depends on public infrastructure, nutrition, natural capital, income and economic framework of coastal countries.

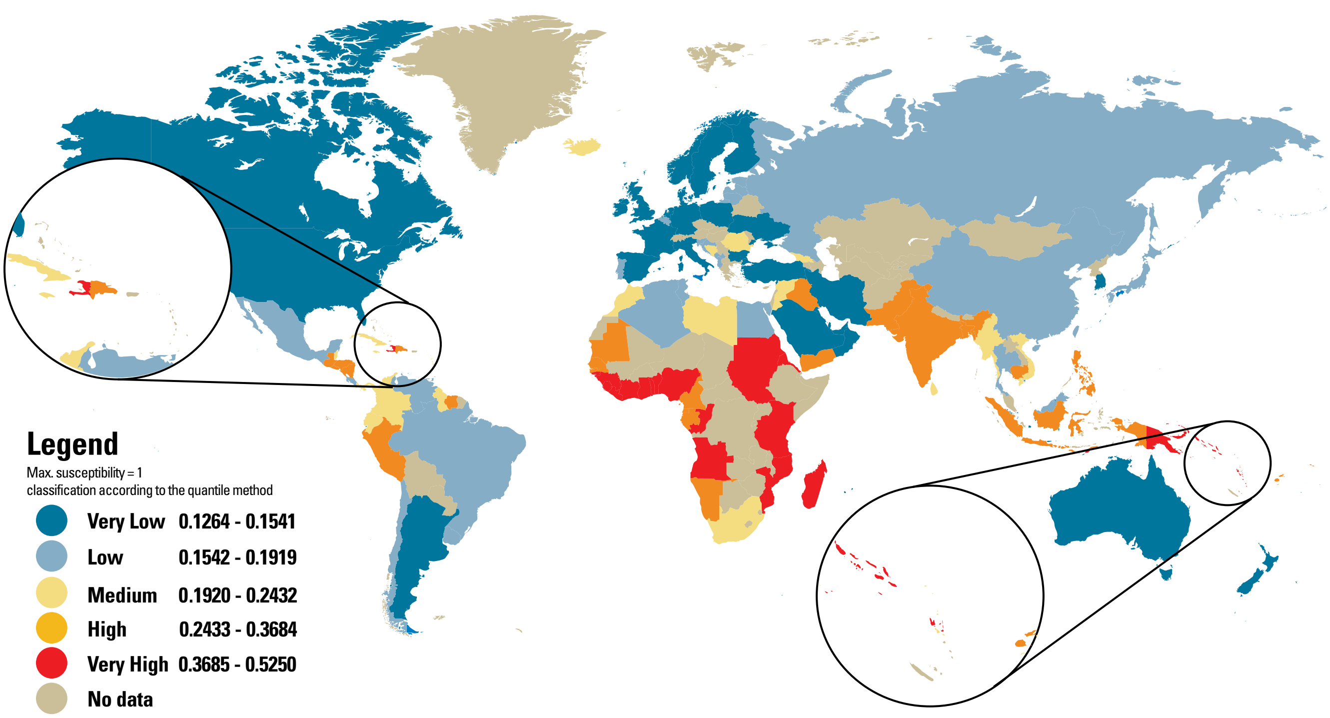


Figure 8: Susceptibility map

Lack of coping capacity

Countries with a high lack of coping capacity will have severe problems in responding and reducing the negative impacts of a disaster. As seen in the susceptibility map, indicators for lack of coping capacity occur along a clear north-south divide that reflects developed vs. less- developed country status (Figure 9). A Very High lack of coping capacity is seen for many coastal countries in Africa as well as for parts of South Asia. In Europe it is interesting to note that Bosnia-Herzegovina, Montenegro and Albania have limited coping capacities. The lasting impacts of war in the 1990s might be the cause. Each country shows unfavorable values for the governance indicators (corruption perception index and failed state index), which contribute to the lack of coping capacity. In South Africa, for example, favorable values for coping capacity are likely due to a stable political system and a well-developed health system.

RANK	COUNTRY	LACK OF COPING CAPACITY VALUE
1	MOZAMBIQUE	0.8577
2	SOLOMON ISLANDS	0.8559
3	HAITI	0.8539
4	MYANMAR	0.8483
5	SUDAN	0.8416
6	PAPUA NEW GUINEA	0.8350
7	CONGO	0.8335
8	LIBERIA	0.8274
9	NIGERIA	0.8269
10	VANUATU	0.8251

Table 3: Top 10 coastal countries with the highest lack of coping capacity

Table 3 lists the top 10 coastal countries with the highest lack of coping capacity. The maximum value for lack of coping capacity is 1.

Coping capacity depends on governance, medical care and material security.

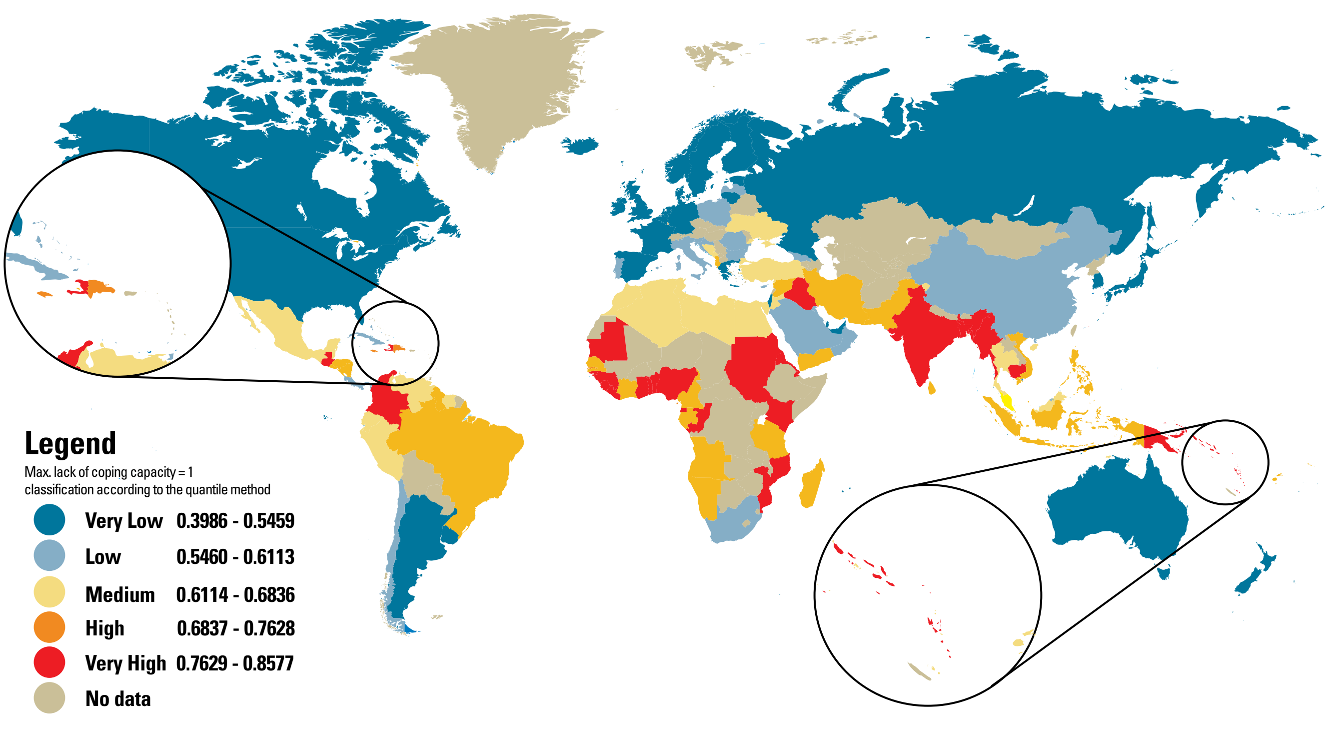


Figure 9: Lack of coping capacity map

Lack of adaptive capacity

Adaptive capacities focus on conditions and strategies that enable a society to change or to transform in order to deal with the negative impacts of climate change and natural hazards. The lack of adaptive capacity map (Figure 10) does not show a clear north-south divide in North and South America as compared to the lack of coping capacity map. This is based on good results in the subcategories of education and research and equal participation. Again, West Africa appears as a hot-spot region, followed by coastal countries in South Asia. Eight of the top 10 coastal countries with the highest lack of adaptive capacities are located in Africa, with Haiti and Pakistan accounting for the other two (Table 4). Maximum potential value for the lack of adaptive capacity is 1.

RANK	COUNTRY	LACK OF ADAPTIVE CAPACITY VALUE
1	ERITREA	0.7212
2	HAITI	0.6781
3	SIERRA LEONE	0.6723
4	PAKISTAN	0.6593
5	BENIN	0.6541
6	GUINEA	0.6539
7	MAURITANIA	0.6479
8	LIBERIA	0.6430
9	NIGERIA	0.6401
10	BANGLADESH	0.6381

Table 4: Top 10 coastal countries with the highest lack of adaptive capacity

Adaptive capacity depends on the status of education, environment, gender equity and health investments.

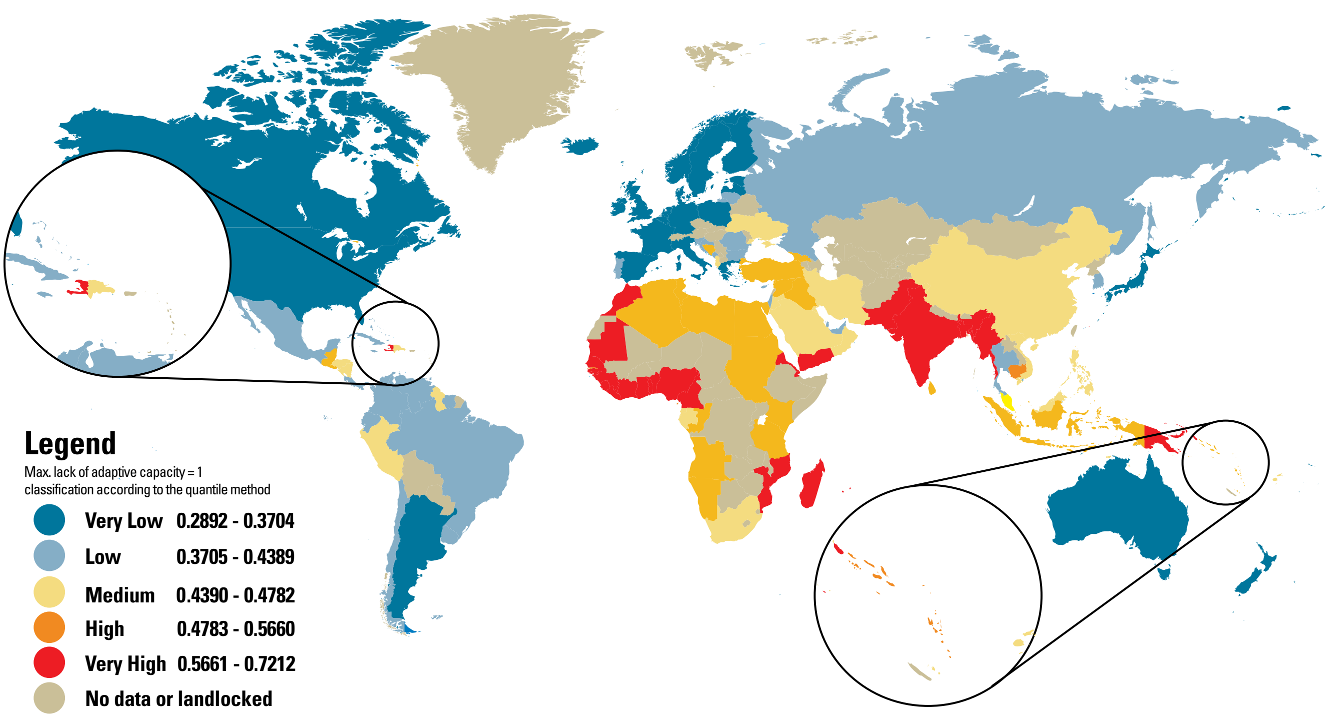


Figure 10: Lack of adaptive capacity map

Vulnerability

Vulnerability is calculated as the combination of susceptibility, lack of coping capacity and lack of adaptive capacity. The map (Figure 11) shows that West and East Africa and parts of Southeast Asia (Bangladesh, Myanmar, Papua New Guinea and Timor-Leste) are hot-spots of vulnerability. The results also underline that the most vulnerable countries (Table 5), such as Haiti, Eritrea, Nigeria and Liberia are characterized by relatively high levels of poverty, environmental stress and severe governance problems or even failed states. Table 5 gives an overview of the 10 most vulnerable countries. Maximum potential value for vulnerability is 1.

RANK	COUNTRY	VULNERABILITY VALUE
1	HAITI	0.6597
2	ERITREA	0.6569
3	SIERRA LEONE	0.6550
4	MOZAMBIQUE	0.6485
5	LIBERIA	0.6476
6	PAPUA NEW GUINEA	0.6353
7	VANUATU	0.6306
8	NIGERIA	0.6306
9	GUINEA	0.6205
10	BENIN	0.6194

Table 5: Top 10 most vulnerable coastal countries

Vulnerability of a society as the sum of susceptibility, lack of coping capacity and lack of adaptive capacity

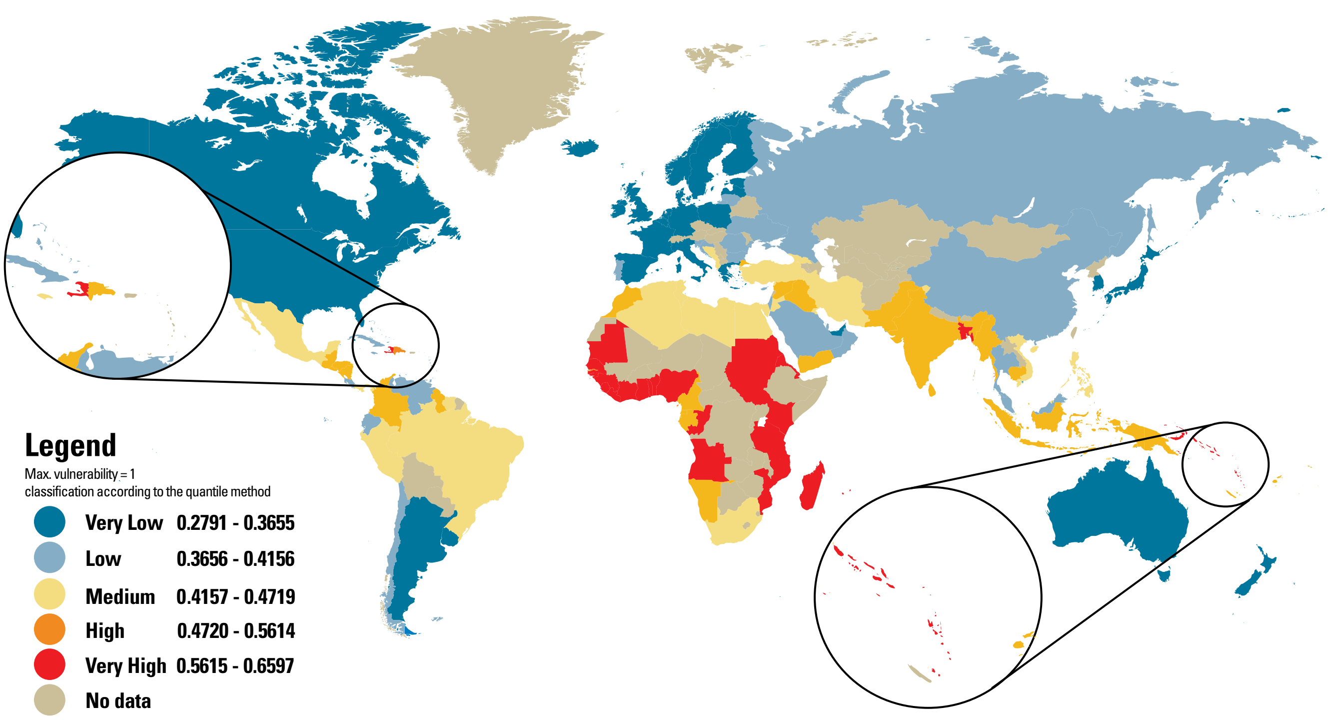


Figure 11: Vulnerability map

Coasts@Risk Index

The coastal areas highlighted as most at risk are in Southeast Asia, the Caribbean and in Oceania, and in particular the SIDS (Figure 12, Table 6). Surprisingly, countries in Africa such as Namibia, Cote d'Ivoire, Liberia and Ghana are identified as at Very Low risk to coastal hazards. This is primarily attributed to a Very Low exposure towards coastal hazards (Figure 7). However, taking their Very High vulnerability into account (Figure 11), one could imagine what could happen if an incalculable extreme event were to hit those countries. Overall, there is a strong influence of exposure on the final risk value because vulnerability multiplies the weight of that factor in the overall risk equation. For example, Japan and the Netherlands have a relatively high risk level for developed countries, mainly caused by the high level of exposure (for the Netherlands the main driver is sea level rise), while the vulnerability levels are rather low compared to less-developed countries. The results show clearly that the social vulnerability of a country is very separate from its exposure to natural hazards. The influence of vulnerability on risk is distinct and plays a central role in the determination of risk to natural hazards and climate change. This case is best illustrated by considering Haiti and New Zealand, which have similar levels of exposure to natural hazards (the exposure in Haiti is even lower than in New Zealand: value 0.0478; New Zealand: value 0.0484), but it is evident that New Zealand's low vulnerability (value: 0.3099) compared to Haiti (value: 0.6597) ranks it lower in the overall C@R index (New Zealand: risk value: 0.0150 and rank: 46; Haiti: risk value: 0.0316, rank: 28).

RANK	COUNTRY	RISK VALUE
1	ANTIGUA AND BARBUDA	0.2702
2	TONGA	0.2482
3	SAINT KITTS AND NEVIS	0.2366
4	VANUATU	0.1508
5	FIJI	0.1254
6	BRUNEI DARUSSALAM	0.1093
7	BANGLADESH	0.1056
8	PHILIPPINES	0.1003
9	SEYCHELLES	0.0851
10	KIRIBATI	0.0830

Table 6: Top 10 coastal countries with the highest risk

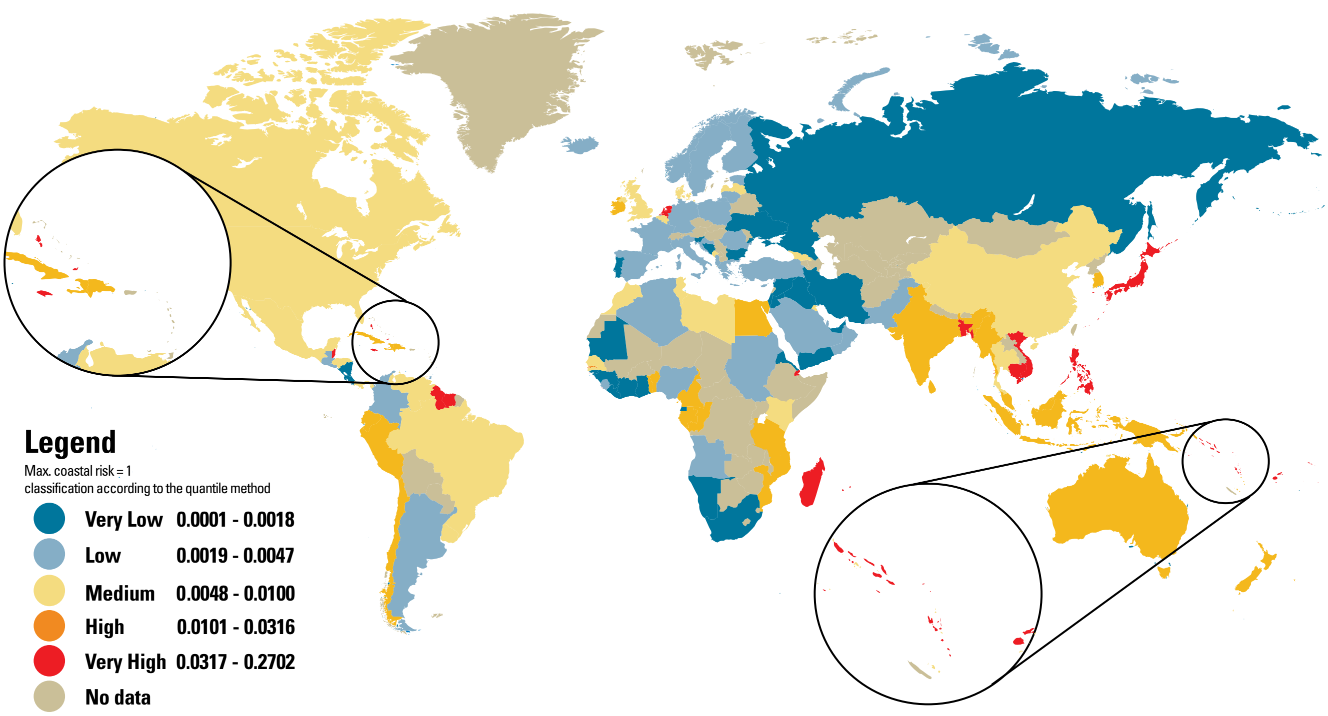


Figure 12: C@R Index map

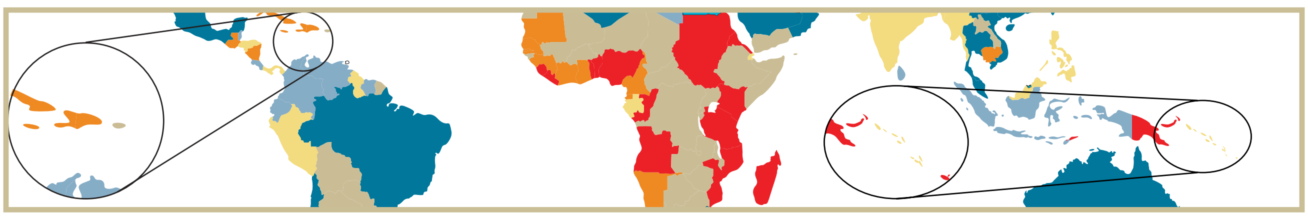
The C@R for tropical nations

Vulnerability and risk were examined further in tropical nations for two reasons. First all of the most at-risk nations are tropical (Table 6) and second an analysis of the effects of natural capital on overall risk could be further expanded because of data availability on tropical coastal habitats. The core addition to this "Tropical C@R" Index was the "Percentage of population that may receive risk reduction from reefs and mangroves" (Figure 2 Indicator "J" under susceptibility). In the future, this indicator could be expanded globally as an indicator for all coastal habitats, not only tropical ones. However, this is one of the few cases where data—and specifically—coastal habitat data are far better for tropical nations than for temperate nations. Data for key temperate habitats such as salt marsh, seagrass and oyster reefs are simply not globally available. Coastal habitats, and in particular coral reefs and mangroves, provide crucial risk reduction benefits that include exposure reduction, nutrition and the provision of livelihoods (including fishery and tourism). These benefits are explained more fully in Chapters 4 and 5. This indicator is calculated as the percentage of a country's population that lives below 10m elevation and within 10 km of a reef or a mangrove forest. These are the low-lying exposed populations near reefs and mangroves that are likely to receive risk reduction benefits from these habitats (see section 5.2 and Ferrario et al. 2014 for a fuller discussion of these considerations). Additionally the overall availability of tropical data for two of the fisheries indicators (fish catch and stock status) is limited (see Discussion Section and Chapter 5). The Tropical C@R

Tropical Susceptibility Index

Dependent on public infrastructure, income, economic framework and natural capital

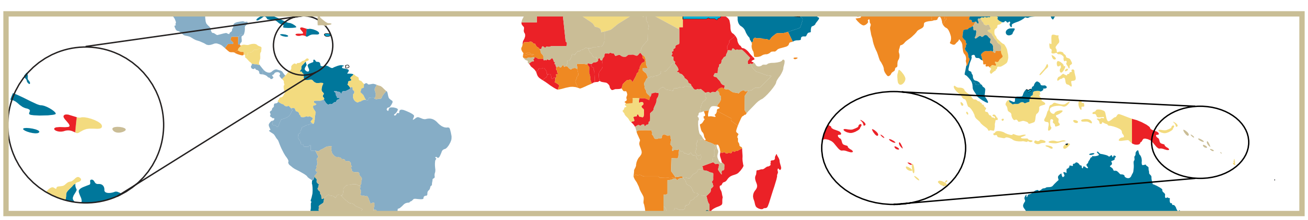
very low	0.2203 - 0.2781	high	0.3728 - 0.4797
low	0.2782 - 0.3188	very high	0.4798 - 0.5739
medium	0.3189 - 0.3727	no data	



Tropical Vulnerability Index

Vulnerability of a society as the sum of susceptibility, lack of coping capacity and lack of adaptive capacity

very low	0.3280 - 0.4320	high	0.5187 - 0.6052
low	0.4321 - 0.4782	very high	0.6053 - 0.6829
medium	0.4783 - 0.5186	no data	



Tropical Coast @ Risk Index

Risk as the combination of exposure and vulnerability

very low	0.0004 - 0.0028	high	0.0184 - 0.0510
low	0.0029 - 0.0085	very high	0.0511 - 0.2651
medium	0.0086 - 0.0183	no data	

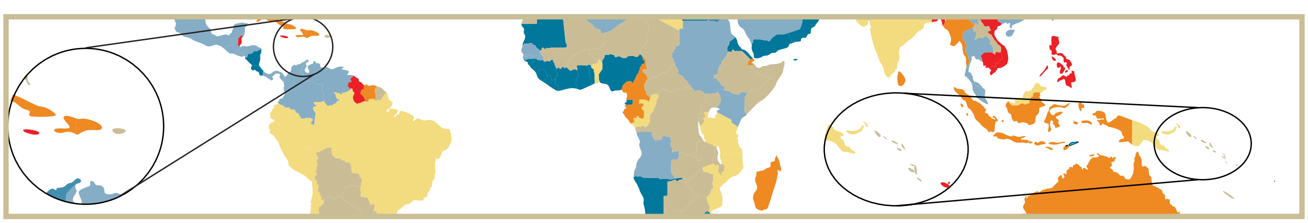


Figure 13: Results for the tropical indices of susceptibility, vulnerability and risk

RANK	SUSCEPTIBILITY (TROPICAL C@R)	RANK	SUSCEPTIBILITY (C@R)	RANK	VULNERABILITY (TROPICAL C@R)	RANK	TROPICAL COASTS@RISK
1	SIERRA LEONE	1	SIERRA LEONE	1	ERITREA	1	ANTIGUA AND BARBUDA
2	MADAGASCAR	2	VANUATU	2	HAITI	2	TONGA
3	MOZAMBIQUE	3	MADAGASCAR	3	LIBERIA	3	SAINT KITTS AND NEVIS
4	LIBERIA	4	MOZAMBIQUE	4	SIERRA LEONE	4	VANUATU
5	ERITREA	5	COMOROS	5	MOZAMBIQUE	5	FIJI
6	VANUATU	6	LIBERIA	6	PAPUA NEW GUINEA	6	BRUNEI DARUSSALAM
7	TANZANIA	7	TANZANIA	7	NIGERIA	7	BANGLADESH
8	PAPUA NEW GUINEA	8	PAPUA NEW GUINEA	8	BENIN	8	PHILIPPINES
9	COMOROS	9	ERITREA	9	TOGO	9	SEYCHELLES
10	CONGO	10	HAITI	10	GUINEA	10	KIRIBATI

Table 7: Top 10 tropical countries for susceptibility compared with top 10 countries from the C@R index filtered with tropical countries and top 10 countries for tropical vulnerability and Tropical C@R

Index was calculated using the same approach as for the C@R Index, but with the narrower geographic focus and the addition of 1 key indicator. The data availability for reefs and mangroves enabled the analysis for 90 tropical countries.

Tropical C@R results

The additional results presented here for the Tropical C@R Index focus only on susceptibility, vulnerability and risk (Figure 13), as no new indicators for coping and adaptive capacities were added.

In considering just the top 10 most susceptible countries, eight of the most susceptible countries in the Tropical C@R Index are African (Table 7). Compared to the top 10 countries of the C@R Index (filtered with tropical countries), the rankings for Vanuatu, the Comoros and Eritrea changed. The susceptibility of Vanuatu and the Comoros was reduced when the reefs and mangroves indicator was added. Almost half of the populations of Vanuatu and the Comoros benefits from coral reefs and mangroves (Vanuatu: C@R Susceptibility rank: 2 and Tropical C@R: Susceptibility rank 6; Comoros: C@R Susceptibility rank: 5 and Tropical C@R: Susceptibility rank 9). Eritrea is more susceptible compared to the overall C@R Index rankings because only 2% of the population benefits from reefs and mangroves (C@R rank: 9 and Tropical C@R: rank 5).

The influence of this "reefs and mangroves" indicator also affects the overall vulnerability scores (Table 7). For example, Eritrea and Haiti changed their ranks compared to the C@R ranking due to the lower percentage of people who are likely to receive benefits from reefs and mangroves (index value: Haiti: 19% and Eritrea: 1.9%). Within the top 10 ranking, Vanuatu and Benin changed compared to the C@R rankings. Vanuatu improved four ranks from rank 7 (C@R) to rank 11 (tropical C@R) due to the benefits they are likely to receive from reefs (index value:

45.50%). Benin changed from rank 10 (C@R ranking) to rank 8 within the Tropical C@R ranking as they are likely to receive few benefits from reefs and mangroves. The ranking of top 10 countries of the Tropical C@R index does not change compared to the C@R index ranking (see Tables 6 and 7), which owes most importantly to the influence of exposure overall.

New environmental indicators of vulnerability

A core addition the C@R Index makes to the WorldRiskIndex is the inclusion of several new indicators that focus on the connection between environment and vulnerability. These indicators include three new fishery indicators for the whole index and a fourth habitat indicator (reefs and mangroves) for the tropical index. These are in addition to the four environmental indicators (E-H in the adaptive capacity component from the Yale Environmental Performance Index 2012) that were considered in the WorldRiskIndex. Coastally focused environmental indicators were added into each component of the assessment of vulnerability as recommended in the WorldRiskReport 2012 (Welle et al., 2012). Natural assets and the condition of those assets have a clear link to disaster risk reduction (Welle et al., 2012).

Under susceptibility, a natural capital component was added to include a measure of the total marine fish catch in each nation and to consider the value of reefs and mangroves. Within coping capacity fish management effectiveness is an indicator of the value of governance of fisheries. In general, coping capacity is assumed to be closely tied to the effectiveness of current governance. Under adaptive capacity, fish stock status was added to the four natural assets indicators from the Yale EPI 2012. It is assumed that when fish stocks, as with other resources, are in better condition, they increase the adaptive capacity by creating more resource options for the future.

These environmental indicators described significant variation in social vulnerability. First, all seven global environmental indicators were equally weighted and calculated to an overall index. This index represented the scores for environmental status (very high=1, very low=0). In the global analyses, this indicator was significantly and negatively correlated with overall vulnerability (r^2=0.10, with $p \leq 0.01$);

RANK	COUNTRY	ENVIRONMENTAL VALUE
1	CAPE VERDE	0.305
2	LIBYA	0.318
3	MAURITANIA	0.319
4	ERITREA	0.325
5	HAITI	0.334
6	TIMOR-LESTE	0.379
7	LIBERIA	0.392
8	ALGERIA	0.397
9	GUATEMALA	0.409
10	NIGERIA	0.416

Table 8: Top 10 countries with the lowest environmental values

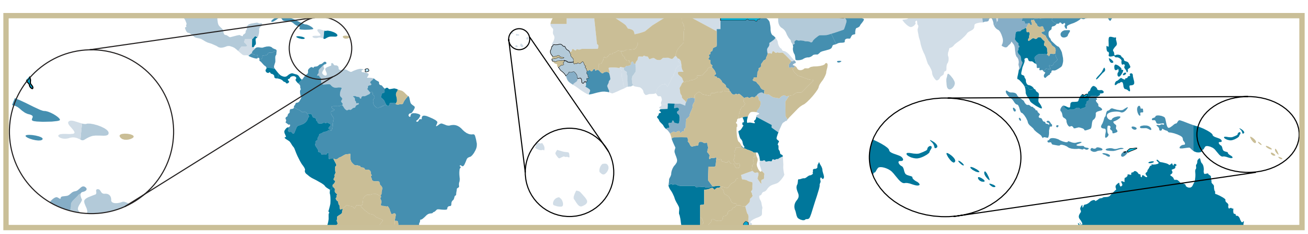


Figure 14: Environmental scores for tropical countries based on eight environmental indicators (fish catch, fish management effectiveness, fish stock status, benefits from reefs and mangroves, water resources, biodiversity and habitat protection, forest management, agricultural management)

where environmental status was greater, vulnerability was lower. The same analysis was repeated solely for tropical countries (90 countries, see Figure 14) with the addition of the indicator for reef and mangrove natural habitat capital. In this case the relationship was even stronger in its significant and negative correlation (r^2=0.15, $p \leq 0.01$). These results show these environmental indicators are linked to social vulnerability, and that this linkage is even stronger in tropical countries where the connection between people and environment is critical. The top 10 countries within the tropics with the lowest environmental values are shown in Table 8.

2.5 Conclusion

The C@R Index helps to understand the risks that nations face from coastal hazards and social vulnerability and identifies where environmental degradation contributes to this vulnerability. The results of the index should facilitate further discussions on how to reduce exposure and susceptibility and increase coping and adaptive capacities to natural coastal hazards including the impacts of climate change. This analysis also helps highlight the crucial role that natural resources can play in disaster risk reduction and risk management.

There are important limitations to any index, which include subjectivity regarding variable selection and weighting; lack of data availability for key variables; normalization; problems with aggregation to different scales and difficulties validating the results (OECD, 2008). Composite indices are much like mathematical or computational models. As such, they are constructs; there are no universally accepted scientific rules for exactly how they should be encoded. As for models, the justification for a composite indicator lies in its fitness to the intended purpose and the acceptance of peers (Rosen, 1991). In this regard the WorldRiskIndex, which offers the base for the C@R Index, was approved by scientists and practitioners during an international symposium and also was published in peer reviewed literature (Welle et al., 2013). The C@R team ran a reliability analysis and sensitivity analysis to proof the model assumptions. The reliability analysis resulted in a Cronbachs Alpha= 0.889, which describes a very good correlation between model output and input variables. The sensitivity analysis showed that all indicators have a median greater than zero, indicating that every indicator contributed sufficiently to the model output (see Appendix at http://www.ehs.unu.edu/CoastsatRisk for more details). Also, as with any model, the effectiveness of the outputs relies on the quality of the data used. The accuracy of the indicators provided in the global data and their ability to effectively and equally capture conditions across a range of latitudes impact the reliability of the outputs. For example, the C@R Index can only be calculated for 139 coastal nations, and thus not all SIDS could be considered because either socio-economic or exposure data were not available (more information regarding the individual indicators could be found in the Appendix at http://www.ehs.unu.edu/CoastsatRisk). Also some of the data used to calculate fish related indicators (i.e., fish catch and stock status) are known to be less reliable for some tropical countries in particular given limitations in fisheries data collection in those countries. These issues are common to virtually all global indicators, yet there is still a pressing need for quantitative indicators to help in reducing complexity, measuring progress, mapping and setting priorities, which makes them an important tool for decision makers (Cutter et al., 2008).

While the magnitude and frequency of coastal hazards and the adverse impacts of climate change cannot be prevented, a society can adopt measures that will help prevent natural events from becoming disasters. Focusing on social, economic and ecological aspects within vulnerability and risk assessment, instead of solely on natural hazards, opens new and innovative approaches for decision makers and practitioners. This risk assessment hopes to facilitate discussions on long-term development approaches for coastal nations that integrate risk management, prevention, protection, preparedness and climate change adaptation.

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Sunset with a view of the mangroves in Piedras Blancas National Park in Costa Rica. Credit: Sergio Pucci\TNC

3. THE ROLE OF MANGROVES IN COASTAL RISK REDUCTION

BY ANNA McIVOR AND MARK SPALDING

Mangroves can play an important role in coastal risk reduction, both directly, by reducing exposure to hazards such as tropical cyclones and associated storm surges, and indirectly, by providing resources, income and livelihoods. They contribute to reduced susceptibility to disasters, increased ability to cope when disasters occur and the ability to adapt to future changes in coastal hazards (Figure 15). This chapter describes some of the ways that mangroves can help to reduce risk. It focuses primarily on how mangroves help to reduce exposure to hazards, as this has been studied best. How mangroves reduce social vulnerability and improve resilience in the face of coastal hazards also is considered; this topic is less well-covered in the available literature though interest in it is growing. This review also provides a basis for the inclusion of mangroves in the C@R Index for tropical analyses (see Chapter 2).

CONTRIBUTIONS OF MANGROVES TO RISK REDUCTION

REDUCING EXPOSURE

Hazard Risk Reduction – help reduce wave energy, erosion, storm surge water levels and may reduce tsunami damage

Climate related hazards – mangroves sequester carbon, mitigating climate change

REDUCING SUSCEPTIBILITY

Natural capital (fisheries) – mangroves provide fish, crabs, shrimp and mollusks

INCREASING COPING CAPACITY

Livelihood diversity – several livelihoods are based on mangroves, e. g. fishing, timber harvesting, charcoal making, beekeeping, etc.

Emergency supplies – mangroves provide timber, fuel and food immediately post-disaster to help people survive and rebuild

INCREASING ADAPTIVE CAPACITY

Future risk reduction – potential for restoration of mangroves, if local conditions are suitable

Future natural capital – source of natural capital for the future, providing options for future resource use if managed sustainably

Figure 15: Some of the ways that mangroves contribute to coastal risk reduction, showing how these link to components of risk in the C@R Index in Chapter 2

Mangroves form dense forests along many tropical and subtropical coasts (Figure 16). They are found in 123 countries and territories globally and are estimated to cover over 150,000 square kilometers (Spalding et al., 2010). However, approximately one third of the world's mangroves have been lost over the last 50 years as land has been cleared for agriculture, aquaculture and other forms of development (Alongi, 2002), leaving coastal communities more exposed to hazards. In response, a number of mangrove restoration efforts have been undertaken with the aim of reducing exposure to coastal hazards and also reducing social vulnerability (IFRC, 2011; Primavera and Esteban, 2008). For these restoration efforts to be effective at reducing risk, a more detailed understanding of the ways that mangroves reduce risk is needed. The following discussion reviews some of the ways that mangroves can contribute to reducing coastal risk.

3.1 Mangroves reduce exposure to natural hazards

Dense mangrove vegetation can contribute directly to coastal risk reduction by reducing exposure to coastal hazards, for example by reducing the height of wind waves, slowing storm surge water flows and reducing local wind speeds. Mangroves can also reduce exposure to longer term hazards such as erosion and sea level rise by binding together soils and helping soils build up.

Figure 16: The global distribution of mangrove forests (adapted from The World Mangrove Atlas; Spalding et al., 2010)

Figure 17: Waves passing through mangroves

Waves

Mangroves tend to grow in sheltered locations that usually receive small wind and swell waves (i.e. waves created on the water surface by the wind; Figure 17). However, during storms, they may receive larger waves. Recent studies suggest that mangroves are highly effective at reducing waves over relatively short distances. Wave height can be reduced by 13 to 66% over 100 m width of mangrove, and 50 to 100% over 500 m width (Mazda et al., 2007; Quartel et al., 2007; reviewed in McIvor et al., 2012a).

The reduction in wave height depends on the density of vegetation that the waves pass through, which in turn depends on the density and spacing of the trees and the presence of aerial roots (Figure 18). Waves entering dense mangrove vegetation, for example the dense aerial roots of *Rhizophora* (Figure 19), will be reduced more rapidly than waves passing through sparse vegetation, for example an area with mangrove trees spaced several meters apart. Wave reduction also depends on tidal level, as this alters the water depth and hence the part of the vegetation which waves pass through; for species with pneumatophores (aerial roots projecting upwards from the soil; Figure 21), waves may be reduced most effectively in shallow water depths (Brinkman et al., 1997; Mazda et al., 2006; Quartel et al., 2007; reviewed in McIvor et al., 2012a).

Storm surges

Storm surges are caused by large storms and cyclones (also called hurricanes and typhoons). The very high winds and low atmospheric pressure raise water levels at the coast, causing the water to flood onto land. This can cause widespread flooding over coastal lowlands.

Mangrove forests can slow the storm surge water flows, resulting in reductions in flood depth and flood extent (reviewed in McIvor et al., 2012b). Studies in Florida, in the Southeast United States, estimated that mangroves reduced peak water levels during Hurricanes Wilma and Charley by between 4 and 48 cm per kilometer of mangroves that the surge passed through (Krauss et al., 2009 Zang et al ,2012). For Hurricane Wilma, the reduction in

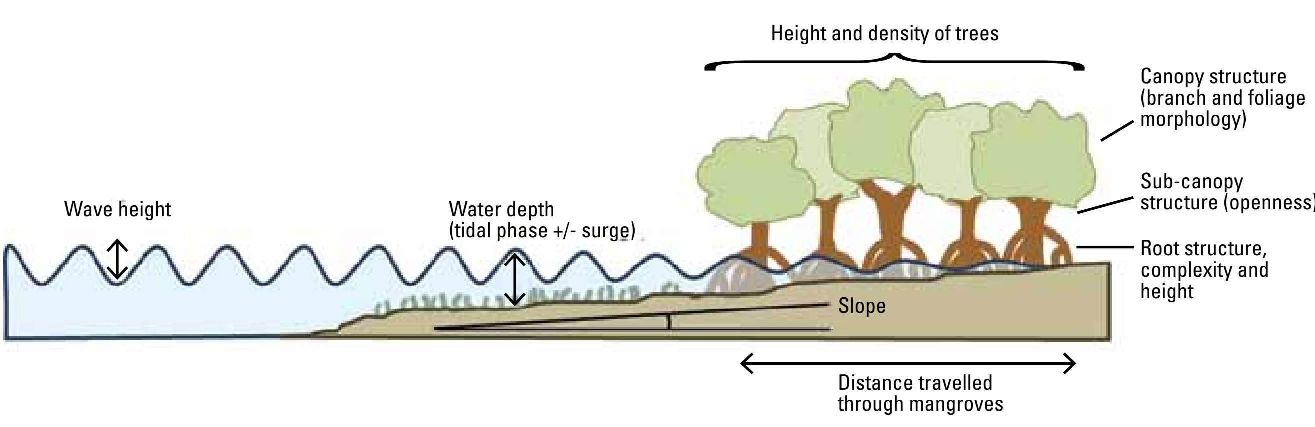

Figure 18: Schematic diagram showing some of the factors influencing wave reduction by mangroves

peak water level occurred over a very large area of mangroves (more than 10 km wide in places). A numerical model that simulated this storm surge suggested that the mangroves reduced the area flooded by 40% (the flooded area was 4,220 km^2 without mangroves and 2,450 km^2 with mangroves) (Zhang et al, 2012).

Clearly, relatively wide bands of mangroves (several hundred meters or wider) are needed to significantly reduce storm surge flooding. However, even a small reduction in water level can result in a relatively large reduction in flood extent in areas with gently sloping topography. Additionally, by reducing wind waves riding on top of the storm surge, mangroves can reduce damage to structures. Mangroves can also reduce wind speed, further reducing damage to structures such as houses (Das and Crepin, 2013).

The capacity of mangroves to reduce storm surge water levels will depend on the density of vegetation. Dense vegetation is likely to be most effective, as water will easily flow through sparse mangrove forests. The rate of water level reduction with distance will also depend on the forward speed of the surge: Fast-moving surges are likely to be reduced most effectively (Zhang et al., 2012; Liu et al., 2013), while slow-moving surges may be reduced very little by mangroves.

The effectiveness of mangroves also depends on the mangroves themselves surviving the effects of the storm surge and high winds. Under extreme conditions, mangrove trees may be defoliated or even blown over (McCoy et al., 1996). Such extreme effects rarely occur beyond the center of the storm track, and mangroves can still provide benefits along other areas of the coast, where the storm surge and storm waves may still be significant.

Figure 19: Dense coastal mangrove vegetation in Tierra Bomba, Cartagena, Colombia. Credit: Carmen Lacambra

Because of this variability in storm surge reduction, other risk reduction measures (e.g. levees/dikes, early warning systems) will usually be needed alongside mangroves (Box 1 and Figure 21). By using a variety of measures, risk reduction can be maximized given available resources, and mangroves can contribute to the overall level of risk reduction.

An example that demonstrates how mangroves can reduce risk comes from Orissa in India. In 1999 a cyclone produced a 9 m storm surge, resulting in the death of 10,000 people. An analysis of different villages found that fewer people lost their lives in those villages that had retained mangroves as compared to villages where mangroves had been lost (Das and Vincent, 2009). Notably, the early warning system was the most effective life-saving measure (the early warning system saved 5.84 lives per village, compared to 1.72 saved by mangroves), demonstrating that mangroves should be used alongside other risk reduction measures. Crop losses were also lower in areas protected by mangroves, where the storm surge water was able to rapidly drain away through tidal channels, reducing the time that crops were exposed to sea water (Badola and Hussain, 2005).

Tsunamis

Coastal forests such as mangroves cannot provide full protection from tsunamis, but they can absorb some of the energy of the flowing water and so reduce the force of the impact (Tanaka, 2009). In this way, they may be able to reduce loss of life (Laso Bayas, et al., 2011) and damage to property (Alongi, 2008). Coastal forests are very unlikely to provide adequate protection from a large tsunami, and therefore other risk reduction measures (e.g. physical barriers, early warning systems, evacuation plans and refuge centers) should be put in place alongside mangroves in areas where tsunamis could occur.

As with all coastal defense measures, mangroves may be overwhelmed by large tsunamis, with trees being knocked over, their trunks broken and their branches torn off (Laso Bayas, et al., 2011). The debris created can add to the destructive force of the flowing water (Tanaka, 2009). However, mangrove trees can also provide places of refuge, and the canopies may provide soft landings for those swept up in the water (Tanaka, 2009).

BOX 1.

MANGROVE RESTORATION FOR DISASTER RISK REDUCTION IN VIETNAM

Between 1994 and 2010, the Vietnamese, Danish and Japanese Red Cross restored 9,000 hectares of mangroves as part of a large-scale Disaster Preparedness Program in Vietnam (IFRC, 2011; Jegillos et al., 2005), contributing to the 100,000 hectares of mangroves that have been restored in Vietnam since the 1970s (Kogo and Kogo, 1997). The mangroves were planted in front of 100 km of dike to protect it from wind waves during storm surges caused by typhoons, which regularly affect the area (Figure 20). The mangroves reduce the risk of waves overtopping the dikes during these typhoons, and they also reduce the action of waves on the dikes. Excessive wave action can result in dikes being damaged or breached. Mangroves can thus reduce the cost of dike maintenance and the damage caused to property behind the dikes.

Figure 20: The use of mangroves in hybrid structures to reduce risk from storm surge flooding in Vietnam; here mangroves reduce the energy of wind waves reaching the dike, reducing the likelihood of damage to the dike or of waves overtopping it. Credit: Mai Sỹ Tuấn (used with permission)

As part of the same program, more than 300,000 students, teachers, volunteers and commune wards were trained in disaster preparedness. Together, the mangrove restoration and disaster preparedness training have ensured that 2 million people are now better protected from typhoons and associated flooding.

In terms of economic benefits, when the level of damage from similar typhoons was compared before and after the mangrove restoration program, mangroves reduced the cost of damage to dikes by between U.S. $80,000 and $295,000. Avoided losses to public infrastructure and private property were calculated to be between U.S. $5 and $15 million in two of the communes studied. The mangrove replanting also provided substantial livelihood co-benefits in the form of honey production from bees and other products from the mangrove area.

This project demonstrates how mangroves can be used in "hybrid structures," meaning the use of ecosystems alongside more traditionally engineered structures to reduce risk from coastal hazards. The project also demonstrates how several risk reduction measures can be used in combination to maximize risk reduction (Figure 22). In this case disaster preparedness training was used alongside mangrove planting and dike maintenance (IFRC, 2011; Jegillos et al., 2005). The mangroves also contributed to local livelihoods, reducing social vulnerability and increasing coping capacity post-disasters.

Figure 21: Dense aerial roots (pencil roots shown here) slow flows of water over the substrate, increasing sedimentation and reducing erosion. Credit: Carmen Lacambra

Erosion

By reducing waves, mangroves mitigate the shear forces acting on the sediment surface, thus helping to reduce erosion. Mangrove sub-surface roots also bind the soil together, further reducing erosion. Additionally, benthic mats made up of algae, dead organic matter and mangrove roots are often found on the sediment surface within mangroves, and these both protect the soil surface from the action of waves and help bind newly sedimented particles in place (McKee, 2011). A study of erosion rates along Thailand coasts found that where mangroves were present, less erosion occurred over a 30-year period (Thampanya et al., 2006). When mangroves are removed, mangrove soils lose their strength, which potentially leads to erosion, as seen on islands in Belize (McKee and Vervaeke, 2009).

Sea level rise

As sea levels rise, mangrove soils may be able to build upwards by trapping sediment and through sub-surface root growth. This can allow them to keep pace with sea level rise in some areas (McIvor, et al., 2013). Mangrove vegetation helps to trap incoming sediments by altering water flows, allowing particles to settle out in some areas and thus increasing sedimentation (Furukawa and Wolanski, 1996). Mangroves can also help to build up soils by producing sub-surface roots that literally push the soil up from below (McKee, 2011).

Mangroves have kept pace with sea level rise over thousands of years in some locations (Ellison, 2009). This has occurred both in locations with large sediment inputs (e.g., in the South Alligator River in Australia, which accreted sediments at rates of up to 6 mm/yr over a 2,000

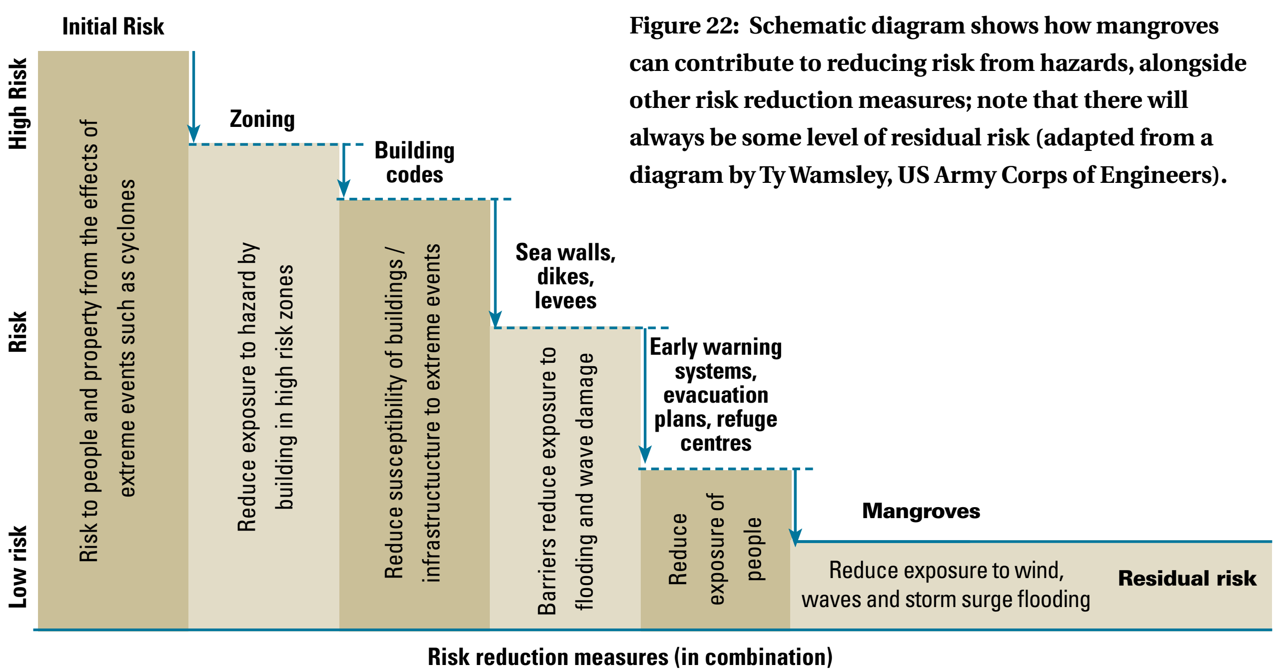

Figure 22: Schematic diagram shows how mangroves can contribute to reducing risk from hazards, alongside other risk reduction measures; note that there will always be some level of residual risk (adapted from a diagram by Ty Wamsley, US Army Corps of Engineers).

year period up to 6,000 years ago (Woodroffe, 1990)) and in areas with very low sediment inputs (e.g., the Twin Cays islands of Belize, which have kept pace with sea level rise rates of up to 3 mm/yr over the last 7,600 years (McKee et al., 2007)).

However, mangroves' capacity to build up soils is dependent on maintaining adequate supplies of incoming sediment and on tree health, which affects root growth. In areas where sediment supplies have been disrupted (e.g., through the damming of rivers) or where mangrove health has been compromised,(e.g., through overharvesting of wood), mangroves are less likely to be able to keep pace with sea level rise. In such locations, mangroves will only survive if there is space available further inland for young trees to colonize, allowing mangrove areas to migrate landward.

Mitigating climate change

Mangroves are highly productive ecosystems and are among the most carbon-rich forests in the tropics. Recent calculations estimate that mangrove forests contain between 690 and 1,000 tonnes of carbon per hectare of forest (Donato et al, 2011; Hutchison et al., 2013). Carbon is stored both in the living trees (trunks, branches, leaves and roots) and more importantly in the deep organic peats that underlie mangroves in many areas. The waterlogged mangrove soils create conditions that slow the decomposition of dead roots in the soil; these dead roots make up the mangrove peat, which can build up over thousands of years, with burial rates of up to 1.8 tonnes per hectare per year (Brunskill et al., 2002).

By taking up and storing carbon dioxide, mangroves help reduce atmospheric carbon dioxide concentrations (Warren-Rhodes et al., 2011). Destruction of mangrove forests can release this stored carbon, increasing carbon dioxide emissions. Despite being present only along tropical and subtropical coasts, mangrove loss may contribute 10% of total carbon emissions from deforestation (Donato et al., 2011). Carbon emissions contribute to rising carbon dioxide levels in the atmosphere, resulting in increased climate risk, such as a predicted increase in the intensity of tropical cyclones (Christensen et al., 2013). Therefore, protecting mangroves from deforestation and restoring mangroves can contribute to reducing exposure to climate risk. Recognition of the importance of mangroves in carbon storage and sequestration could lead to policies and funding schemes that seek to protect or restore mangroves.

3.2 Mangroves reduce social vulnerability and improve coping capacity

Mangroves also reduce risk by reducing social vulnerability for example by increasing access to natural capital, in the form of fisheries and other forest products. This aspect of risk reduction by mangroves has been included in the Tropical C@R Index, as described in Chapter 2. Fish, shellfish and other forest products contribute to local livelihoods and provide an important source of nutrition.

The importance of mangrove fisheries

Mangroves support rich coastal fisheries, both inshore and offshore, including subsistence, commercial and recreational fisheries (Rönnbäck, 1999). Species harvested include a variety of fish, shrimp, crabs and molluscs. Most of these benefit from the very high productivity of the mangroves and the abundant algae and bacteria that grow on the mangrove vegetation and soils. For some species, the mangrove vegetation provides sheltered habitats where the species can live throughout their life span; for other species, mangroves provide nursery grounds and feeding grounds where the young animals can grow in relative safety and have a more plentiful supply of food before they head out to deeper waters (Manson et al., 2005; Chong et al., 1990). In this way, mangroves also support off-shore fisheries (Morton, 1990; Manson et al., 2005; Aburto-Oropeza et al., 2008). Organic matter exported from mangrove areas into the sea by high tides can also form the basis for off-shore food chains, ultimately increasing stocks of off-shore fisheries (Sukardjo, 2004).

In many areas, species that depend on mangroves for some or all of their life cycles make up a large proportion of the fish catch. For example, it has been estimated that mangrove-related species make up 67% of the commercial catch in eastern Australia, 80% of the species with commercial or recreational value in Florida, 60% of the

BOX 2

MANGROVE FISHERIES IN PAK PHANANG, THAILAND

A recent study of mangrove fisheries in Pak Phanang, on the east coast of southern Thailand (Islam and Ikejima, 2010), provides an example of the importance of mangrove fisheries to coastal communities. In this area, fishing provides an important source of food and livelihoods for the people living in or near the mangroves, who are relatively poor with few other livelihoods available to them. The study explored fishing activities within an area of mangroves covering approximately 7,000 hectares, focusing on fishing methods, catch composition, annual catch size and the monetary value of the catch.

Several types of fishing gear are used in this area. Channel traps, gill nets and lift nets were used to catch multiple species, and other methods included crab traps (for portunid crabs), catfish hooks (for ariid and plotosid fish) and hand capture (for sesarmid crabs), as well as traditional angling and cast netting. A total of 57 species were caught, with penaeid shrimp and various types of fish being the most abundant species (by number of individuals) from the channel traps, gill nets and lift nets. Overall, hand capture of sesarmid crabs contributed the greatest biomass (46% of the total caught) but accounted for only 15% of the monetary value. The trapping of portunid crabs contributed only 12% of the catch by biomass, but accounted for the highest monetary value (39%).

The annual catch was estimated around 500 tons with a value of U.S. $368,000 to $734,000. By area, the estimated annual catch was 63 to 79 kg/ year/ hectare of mangroves with a market value of U.S. $52-$105 /year/ha. Most of the catch was used locally. Some catch was consumed fresh, while other parts of the catch were dried (mostly mugil fishes), salted (sesarmid crabs), used in aquaculture feeds (small fish used in crab culture ponds) or used as bait (sesarmid crab and gobiid fishes) for crab fishing (Islam and Ikejima, 2010).

Figure 23: Mangroves provide important habitat for fish, supporting subsistence fisheries, as shown here in Pemalang, Java, Indonesia, where a cast net is being used for fishing. Credit: Femke Tonneijck

This study demonstrates how mangrove fisheries may include a wide variety of capture methods and species and can provide an essential source of food and income to coastal communities.

commercially important coastal fish species in India and in Fiji and 30% of the fish catch plus 100% of the shrimp catch in the Association of Southeast Asian Nations (ASEAN) countries (Rönnbäck, 1999).

Subsistence fishing is vitally important in many coastal communities (Rönnbäck, 1999), providing a source of food that is rich in protein (Albert and Schwarz, 2013). An example of the importance of subsistence fisheries to a community in Thailand is described in Box 2.

Based on a meta-analysis, the average harvest of fish, shellfish and molluscs from mangrove areas is 539 kg per hectare per year (ranging up to 2,500 kg/ha/yr), while average shrimp harvests are 146 kg/ha/yr (up to 349 kg/ha/yr) (Salem and Mercer, 2012).The mean value of mangrove fisheries from this study was U.S. $23,600/ha/yr, ranging up to U.S. $555,000/ha/yr (Salem, 2012).

Mangrove products and livelihoods

In addition to fisheries, mangroves provide a wide variety of products that can be harvested and used, and these support a diversity of livelihoods. Foods derived from mangroves include birds and their eggs, honey, seaweed, vegetables and fermented drinks, in addition to the fish, shrimps, molluscs and crabs described above (Warren-Rhodes et al., 2011; and watlters et al, 2008). Wood harvested from mangroves is put to a variety of uses, including firewood, charcoal, construction materials (houses, boats, jetties, stakes, fences), tools (hoes for use on the land; poles for fish traps) and household furniture (Warren-Rhodes, 2011; Rönnbäck, 1999; Walters, 2008). A variety of non-timber forest products are also harvested to make fishing materials (e.g. nets, traps), roofing materials, traditional medicines, fertilizers and artwork (Warren-Rhodes, et al, 2011; Kathiresan, 2012). Mangroves also provide livestock fodder in some areas (Walters et al., 2008).

By providing this wide array of renewable products, mangroves help people to persevere after disasters, improving coping capacity and thus contributing to reduced risk. Fisheries can provide a critical food supply post-disaster, and this may be particularly important if food supply chains are disrupted or food storage has been compromised. Likewise, mangrove wood can provide both fuel and building materials.

As well as providing for the subsistence needs of local communities (Warren-Rhodes et al., 2011), mangroves form the basis for local livelihoods, such as fishing, timber extraction, charcoal-making and bee-keeping (Walters et al., 2008). Mangrove eco-tourism can also generate significant income for local communities (Salem and Mercer, 2012). By supporting local livelihoods, mangroves reduce social vulnerability. For example, income generated from these livelihoods can help people to afford adaptation and risk reduction measures, such as houses that can withstand high winds or the force of waves.

3.3 Mangrove loss and the success of restoration programs

While mangroves can help to reduce coastal risk, they are often at risk themselves. Approximately a third of the world's mangroves may have been lost over the last 50 years, primarily due to clearance for aquaculture or agriculture (Alongi, 2002). Between 2000 and 2005, annual loss rates were estimated to be 0.66% (Spalding et al., 2010), which is three times higher than mean global rates of forest loss (FAO, 2006). The loss of mangroves leads to the loss of mangrove livelihoods and increases the vulnerability of coastal communities to hazards such as coastal erosion (Hamilton and Collins, 2013).

The loss of mangroves can lead to rapid rates of erosion as mangroves hold together soils that may have formed over thousands of years. In some areas, erosion rates are as high as 50 m per year. The loss of mangroves is considered to be a contributing factor to these high loss rates (Mazda et al., 2002) in what may be a negative feedback loop.

Mangroves are also likely to be threatened by sea level rise, particularly in areas where subsidence is also occurring, such as parts of Java and Florida. This can result in the loss of seaward mangroves, as is currently occurring in Bermuda (Ellison, 1993). In some areas, mangroves may be able to keep pace with rising sea levels, but this is dependent on appropriate management of mangrove areas (as discussed earlier). For this reason, it is important to carry out vulnerability assessments (Ellison, 2012) of mangrove areas to sea level rise when carrying out management, conservation or adaptation activities, especially when planning restoration to assess potential areas.

Mangrove restoration

In response to the high rates of mangrove loss, a number of mangrove restoration projects have taken place around the world, ranging in size from a few hectares to almost 150,000 hectares in Bangladesh (Spalding et al., 2010). Many of these restoration programs have been operating for decades, with several projects starting in the 1970s and ’80s. Consequently, a high level of expertise has built up on how to restore mangroves, and success rates are high. Key factors include choosing appropriate species and planting saplings at the right height above sea level to ensure that they can cope with the level of tidal flooding (Spalding et al., 2010).

Mangrove restoration or afforestation can increase risk reduction services provided by mangroves, as demonstrated in Vietnam (Box 1). Of course, the protection of existing mangroves will generally be more economical than the restoration of mangroves; therefore conservation remains a priority.

Managing mangroves for risk reduction

In many countries, mangrove belts are maintained between the sea and other land uses (Lacambra, 2008) to reduce erosion, provide protection from waves and storm surges and maintain traditional livelihoods. Such mangrove belts need to be sufficiently wide to maintain ecosystem functions, such as sedimentation processes needed to prevent erosion (Winterwerp et al., 2005). The required width will depend on the desired mangrove ecosystem services.

For example, a mangrove belt in front of a dike needs to be wide enough to reduce storm waves such that the dike is adequately protected from the waves and to ensure that waves do not overtop the dike even when water levels rise during a storm surge. Calculations of the required width of the mangrove belt should be based on an understanding of the frequency and magnitude of coastal hazards within a particular area and the ability of the mangrove forest to reduce this hazard to an acceptable level (Narayan et al., 2010).

3.4 Conclusion

Mangroves can play an important role in reducing risk to communities from coastal disasters. Mangroves reduce exposure to coastal hazards and reduce social vulnerability by providing a source of natural capital in the form of fisheries and other mangrove-derived products. Mangroves can also help communities cope after disasters by providing food and fuel in the immediate aftermath and by supporting livelihoods during the recovery period and thereafter. The conservation or restoration of mangroves can form part of local adaptation strategies aimed at reducing risk from future disasters, which may become more frequent as the climate changes and sea levels rise.

As such, the inclusion of mangroves within indices such as the C@R Index is necessary to ensure that these indices take full account of all factors that can influence risk at the coast. The many ways that mangroves can contribute to coastal risk reduction also strengthen the case for the protection and wise management of existing mangrove forests, which should remain a high priority within the portfolio of disaster mitigation and response planning.

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A reef of hard and soft corals in the Indo-Pacific Ocean. Credit: Nancy Sefton

4. CORAL REEFS AND RISK REDUCTION

BY CHRISTINE SHEPARD, FILIPPO FERRARIO, RACHEL FABIAN AND MICHAEL W. BECK

Coral reefs are one of the most biologically diverse habitats in the world. Though they cover only a small portion of the world's ocean floor, coral reefs are extremely productive habitats that billions of people worldwide depend on for the ecosystem services they provide—over 1 billion people are dependent on reefs for protein, and millions are employed in reef-dependent industries in Asia alone (Whittingham et al., 2003). Coral reefs are typically managed or restored to maximize ecosystem services related to habitat biodiversity, fish production or ecotourism. Despite the important defense benefits coral reefs provide by protecting coasts from waves, flooding and erosion, few coral reef restoration projects have been initiated to maximize these benefits. Coral reefs reduce risk by decreasing both exposure and vulnerability through attenuation of wave energy reaching the shore and provisioning of essential resources before, during and after catastrophic events. The conservation and disaster risk reduction communities could better align their efforts to ensure that coastal nations that depend on the risk reduction provided by coral reefs will continue to receive these benefits in the future.

Coral reefs

Corals are found throughout the world's oceans. Most reef-building corals occur throughout the tropical and subtropical Western Atlantic and Indo-Pacific oceans. Reef-building corals are generally found in shallow water depths of up to 150 feet (46m) because corals have microscopic algal symbionts that require sunlight.

Coral reefs are classified into several types based on their arrangement and morphology. Fringing reefs are fairly narrow, range in length from hundreds of meters up to several kilometers, are found near land and can be separated from the coast by a lagoon or channel. Barrier reefs are broader and are generally found farther away from the coast. They are separated from the coast by a wide, deep stretch of water. Patch reefs are isolated, comparatively small reef complexes, and atolls are large, ring-shaped reefs surrounding a lagoon.

Different levels of wave action create three main zones on a coral reef: the reef flat, reef crest and fore reef (Figure 24). The reef flat is the closest to land and is very sheltered. The reef crest is the seaward edge of the reef flat. The crest is often the shallowest part of the reef flat and is where wave breaking first occurs. The fore reef is the outermost part of the reef, which is exposed to open ocean waves.

4.1 How coral reefs reduce risk

Coral reefs help reduce risk by limiting both exposure and vulnerability, the two most important components in risk assessment (see Chapter 2). Coral reefs directly reduce exposure by attenuating the amount of wave energy hitting the shoreline. Healthy coral reefs also reduce vulnerability by providing natural capital (e.g., food and alternative income generation) to the coastal communities that may depend on reefs during a natural disaster or agricultural and economic hardships. Coral reefs play a multifaceted role in reducing risk at the global level. The tropical C@R Index (Chapter 2) included an indicator of the role of coral reefs and mangroves in risk reduction in the susceptibility component. This indicator was chosen because 1) the population's susceptibility to the effects of a hazard is directly related to the amount of natural capital (e.g., reefs, mangroves) available to the coastal population and 2) habitat and population maps are available for each country.

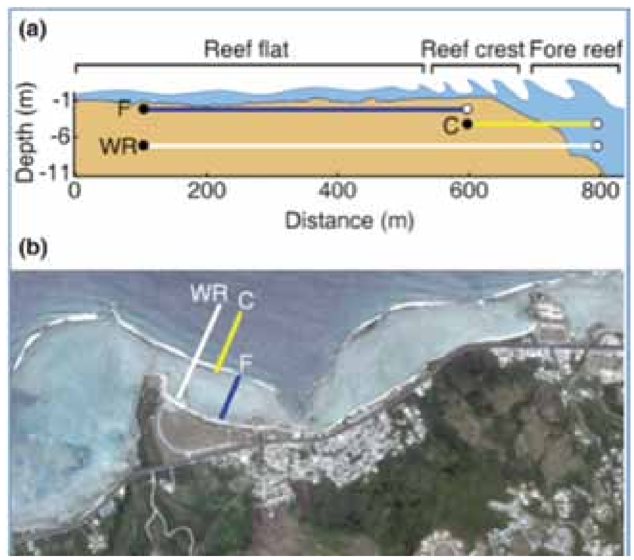

Figure 24: Diagram (a) and aerial photo (b) showing different zones of the whole reef: reef flat (F), reef crest (C) and whole reef (WR) (Adapted from Ferrario et. al., 2014)

4.2 The valuation of coral reefs

Economic Valuation

Coral reefs are one of the most economically valuable coastal ecosystems, providing vital ecosystem services to billions of people worldwide (Whittingham et al., 2003). Benefits are often valued using a total economic value (TEV) approach, which seeks to identify and value each benefit provided by a given reef. Benefits are categorized into direct use, indirect use (including coastal defense) and non-use values. Tourism, fisheries and coastal defense typically contribute the most to reef TEVs (Cesar et al., 2003). The majority of coral reef valuation studies focus on direct use values of fisheries and tourism, which are easily quantified. Protection from flooding and erosion is one of most critical benefits provided by coral

REEF LOCATION	VALUE
CARIBBEAN – low development (Burke, 2004)	US $ 2,000 - 20,000/km
CARIBBEAN – high development (Burke, 2004)	US $ 100,000 - 1,000,000/ km
FLORIDA (Spurgeon, 1999)	US $ 170,000 / km
ST. LUCIA (Burke, 2008)	US $ 28 - 50 million / yr
TOBAGO (Burke, 2008)	US $ 18 - 33 million / yr
BELIZE (Cooper, 2009)	US $ 120-180 million / yr
TURKS AND CAICOS (Carleton, 2005)	US $ 16.90 million / yr
GUAM (van Beukering, 2007)	US $ 107 million
AMERICAN SAMOA (Spurgeon, 2005)	US $ 8.4 million / yr
INDONESIA/PHILIPPINES (Burke, 2002)	US $ 447,000 / yr
LAMI TOWN, FIJI (Rao, 2013)	US $ 343,624 / yr
NAVAKAVU, FIJI (O'Gara, 2012)	US $ 826,140 / yr
SAIPAN, N. MARIANA ISLANDS (van Beukering, 2006)	US $ 8.04 million / yr
SRI LANKA (Berg, 1998)	US $ 12160-172,000 / km^2 / yr

Table 9: Economic values of coastal defense provisions of coral reefs

reefs, but sometimes these values can be difficult to quantify relative to direct use benefits. Coastal defense benefits are usually estimated by flooding and erosion damages that are avoided due to the presence of intact reefs. Property values are most commonly used to calculate avoided damages; therefore, coastal defense values are greater in areas with more infrastructure, particularly in tourism-dependent areas. More sophisticated valuation techniques, such as those used in the Coastal Capital project of the World Resources Institute (Burke, 2008), adjust avoided damages by also accounting for the dependency of coastal communities on reefs and incorporating site-specific data on land use, shoreline sensitivity, frequency and magnitude of storms, proximity of reefs to shorelines and wave absorbing capacities. Including these factors can improve estimates of coastal defense value because they account for more than just the property values of adjacent land.

Local or project-scale valuations can be difficult to scale up to national coastal defense values, so mechanisms such as benefit transfers are often used to approximate coastal defense values. Calculations of coastal defense benefits from coral reefs range from hundreds to millions of U.S. dollars per linear km depending on land use (Table 9) and average U.S. $32,000/km2 worldwide. This figure does not incorporate values of infrastructure, such as roads, water supply networks or hospitals, nor avoided flood relief costs and is surely underestimated.

Effectiveness of coral reefs for coastal protection

Coral reefs reduce exposure to coastal hazards through wave attenuation and erosion reduction. Though there is a growing body of evidence that suggests that nature-based solutions can be effective for risk reduction, most assessments of nature-based risk reduction approaches have focused on mangroves and marshes (Barbier et al., 2008; Gedan et al., 2010; Shepard et al., 2011; McKee et al., 2010; Zhang et al., 2012; Wells et al., 2006).

Ferrario et al., (2014) provide the first global synthesis and meta-analysis of the contributions of coral reefs to risk reduction and adaptation. They assess the effects of reefs on wave attenuation and examine which parts of the reef have the greatest effects on wave attenuation. They extracted data from 27 independent studies that covered reefs from the Caribbean, Maldives, Australia, China, Japan, Guam and Hawaii to quantitatively estimate the effectiveness of coral reefs and examine wave attenuation across three reef environments: the reef crest, reef flat and the whole reef.

They found that reefs significantly reduced wave energy across all three environments. The whole reef accounted for a total wave energy reduction of 97%. Reef crests dissipated on average 86% of the incident wave energy. Reef flats dissipated 65% of the remaining wave energy. The effect of the whole reef in dissipating wave energy was consistent across a variety of wave types from small through hurricane-level waves with the reefs reducing a constant percent of the incident wave energy.

These wave attenuation values are similar to those of constructed low-crested breakwaters. The wave attenuation efficiency of low-crested detached breakwaters is measured by the transmission coefficient K^t, which is the ratio of the transmitted to the incident significant wave height (H^t/H^i). K^t depends on design parameters such as crest freeboard, crest width and structure permeability. The transmission coefficient, K^t, of low-crested detached breakwaters typically ranges from 0.3-0.7, which represents a wave height reduction of 30-70% (Burcharth and Hughes, 2011; Armono et al., 2003; Calabrese, 2008; Zanuttigh et al., 2010; Irtem et al., 2011). This range is comparable to the range estimated from Ferrario et al. for coral reefs (51-74%). In fact, the average wave height reduction for reefs (64%) is in the upper range of values evaluated for artificial structures, suggesting that coral reefs can provide comparable wave attenuation benefits to artificial defenses such as breakwaters.

Social valuation: reefs and the coastal populations that depend on them

Coral reefs can be an effective first line of defense, and coastal nations benefit from the coastal protection and resource provisioning services provided by reefs. To identify coastal populations that likely benefit from coral reefs, global population, elevation, coral reef and country data were compiled, and a geospatial analysis was completed to identify low-lying populations adjacent to coral reefs. Country border and exclusive economic zone boundaries were factored in to tally the total number of people by country living in these low-lying areas near reefs. Globally up to 197 million people live both below 10m elevation and within 50km of a reef and may receive risk reduction benefits from reefs. If only areas within 10km of a reef and below 10m elevation are considered (i.e., an 80% reduction in distance), some 100 million people still are likely to receive risk reduction benefits from reefs (Table 10). This latter approach of identifying people living below 10 m elevation and within 10km of a reef from Ferrario et al. (2014) was the basis for the reefs and mangrove indicator in the C@R Index.

The countries with the greatest number of people living in low-lying areas who likely receive risk reduction benefits from reefs are Indonesia, India and the Philippines,

PEOPLE < 10 KM FROM REEF	
Country	Number in Millons
Indonesia	19
India	17
Philippines	12
Brazil	6
USA	3
Vietnam	2
Tanzania	2
China	2
Haiti	2
Cuba	2
Sri Lanka	2
Singapore	1
Japan	1
Saudi Arabia	1
Kenya	1
TOP 15 COUNTRIES	**74**
GLOBALLY	**100**

PEOPLE < 50 KM FROM REEF	
Country	Number in Millions
Indonesia	41
India	36
Philippines	23
China	16
Vietnam	9
Brazil	8
United States	7
Malaysia	5
Sri Lanka	4
Taiwan	3
Singapore	3
Cuba	3
Hong Kong	2
Tanzania	2
Saudi Arabia	2
TOP 15 COUNTRIES	**163**
GLOBALLY	**197**

Table 10: Number of people in millions who may receive risk reduction benefits from reefs by country; values are the number of people living below 10 m elevation and within 10 or 50 km from reefs (# of people * 1mil) (adapted from Ferrario et al. 2014).

regardless of whether distances of 10 or 50 km from reefs were considered. These three countries alone include approximately 50% of the global population living in low, exposed areas near reefs. The United States and China, which are often categorized as temperate nations, rank within the top 10 countries in number of people that likely benefit from tropical coral reefs.

4.3 Reef restoration as a risk reduction strategy

Active restoration of degraded reefs is a common approach to re-establish reef diversity, function and ecosystem services. Active restoration methods include biological restoration, physical (or structural) restoration or both. Biological restoration most often involves transplanting of coral fragments or colonies to enhance populations of threatened species (such as staghorn coral in the Caribbean) or to help re-establish live coral cover on coral "skeletons."

Physical or structural restoration projects typically include reef repair and/or additions of artificial reef components. Coral reef restoration projects typically seek to restore ecosystem services related to biodiversity, coral cover and fisheries production, though these projects may also provide wave attenuation benefits if the physical structure of the reef is restored. Coral restoration projects with principally coastal defense objectives are far less common. There are a very few of these projects and most are just offshore of resort beaches in sandy habitats; they have thus been focused more on erosion reduction than reef restoration per se.

Structural reef restoration approaches include "reef balls," concrete structures such as blocks, BioRock, EcoReefs and rock and rubble piling (Goreau and Hilbertz, 2005; Clark and Edwards, 1999; Spurgeon and Lindhal, 2000; Fox et al., 2005). There are thousands of structural reef restoration projects globally, but very few of these projects provide clear information on size, costs or measured benefits, particularly coastal defense benefits. Where measures of benefits do exist, they are typically restricted to surveys of live coral cover and fish abundance or diversity.

Ferrario et al. (2014) provide insight into the cost effectiveness of coral reef restoration when compared to the building of traditional breakwaters. The costs of building tropical breakwaters ranged between U.S. \$456 and \$188,817 m^{-1} with a median project cost of U.S. \$19,791 m^{-1} (n=16). The costs of structural coral reef restoration projects ranged between U.S. \$20 and \$155,000 m^{-1} with a median project cost of U.S. \$1,290 m^{-1} (n=13). On average, the costs of the restoration projects were significantly cheaper than costs of building tropical breakwaters.

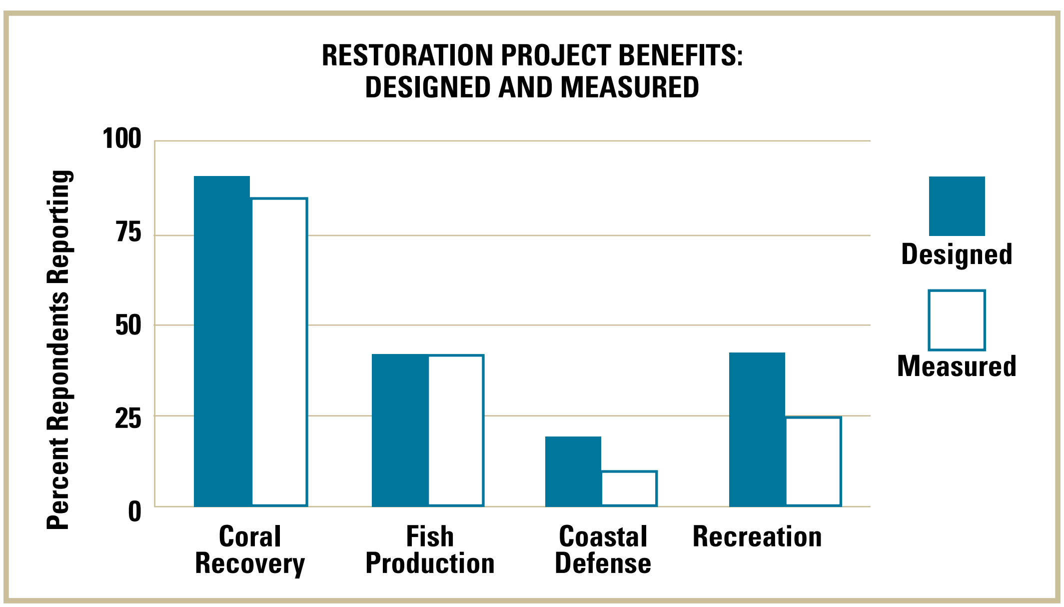

Figure 25: Benefits of coral reef restoration projects incorporated into project design and measured

Though structural reef restoration can be cheaper than building a traditional tropical breakwater, the process is not without its challenges. We recently conducted a global survey to assess the benefits being monitored and delivered by reef restoration projects and received responses from 53 coral reef restoration practitioners. Many reported on multiple restoration projects. Few survey respondents (20%) reported planning projects for coastal defense. Even when the practitioners planned projects for coastal defense benefits, they rarely assessed whether these benefits were actually delivered (Fabian, 2013). (Figure 25).

This survey identified that one of the greatest challenges for measuring delivered benefits, and for project success overall, is lack of funding for post-project monitoring and maintenance. Most projects (67%) were monitored for five years or less, which is often not sufficient time to assess benefits delivered by a project, even if benefits are systematically measured. A full analysis of coastal defense benefits delivered by reef restoration projects should include the effects of restored reef depth and roughness on wave attenuation, reef failure points during high-energy events and the recovery time periods and costs after these events. Other significant challenges for successful reef restoration include ineffective management, political problems and direct threats to the reefs that include sedimentation, bleaching and water quality issues. Enforcement of regulations against destructive practices has often been critical to project success. As living structures, reefs have the potential for self-repair and thus lower maintenance costs as compared with artificial structures, but reef restoration is still a comparatively new field. The addition of ecosystem benefits and considerations of maintenance costs in a full benefit: cost analysis would likely add to the relative cost effectiveness of reefs for coastal defense.

4.4 The future of coral reefs as coastal defense

Increases in coastal development, climate change and the degradation of coral reefs threaten to increase the coastal exposure of hundreds of millions of coastal residents worldwide (Sheppard et al, 2005). When destruction or mortality structurally degrade a reef, the water depth over the reef increases. This increase in water depth allows more wave energy to reach coastlines and heightens risks of flooding and erosion. Loss of three-dimensional structure diminishes frictional drag on incoming waves, contributing to increases in wave energy reaching the shore. If reef degradation continues to increase, coastal countries will be exposed to increasing wave energy and associated coastal hazards of inundation and shoreline erosion (Sheppard et al., 2005).

Though reefs' dissipation of wave energy is clearly visible (in waves breaking offshore), wave attenuation by coral reefs often goes unnoticed and unprioritized until a reef is degraded to the point that the resulting wave energy increases coastal erosion. There are multiple anecdotal reports of this occurring, yet few scientific publications quantify the impacts of degraded coral reefs on adjacent beaches and coastal infrastructure (Sheppard et al., 2005; Brown and Dunne, 1988; Frihy et al., 1996; Knight et al., 1997; Moran et al., 2007). In many tropical nations, including Mexico and Indonesia, there are inferred relationships between increases in coastal development, reef degradation and investments in artificial defenses, but only a few direct studies on causality.

Given increased development pressure and climate change projections, there is concern about whether reefs will survive, but there is reason for some optimism. The effects of temperature and sea level rise will be species- and site-specific (Barshis et al., 2013; Hughes et al., 2012; Pandolfi et al., 2011; Anthony et al., 2011; Gardner et al., 2005; Mumby et al., 2007). Additionally, many of the direct drivers of reef degradation can be mitigated through better management (Gardner et al., 2005; Mumby et al., 2007; Maina et al., 2013; Haisfield et al., 2010). It may be more cost effective in the long run to mitigate risk now by abating the more manageable local threats, such as overfishing and sedimentation, to reduce the pressure on coral reef systems. Coral reefs have been shown to be more resilient to large-scale disturbances, such as bleaching and storm damage, when these local threats are reduced through effective management (Gardner et al., 2005; Mumby et al., 2007; Maina et al., 2013; Haisfield et al., 2010).[4]

Conclusion

A management focus on coral reefs for risk reduction will require changes within both the conservation and disaster risk reduction communities and will require collaboration between coastal engineers, ecologists and policy makers. Conservation efforts historically focused on corals reefs in remote areas because these reefs experience minimal human-driven stressors. Though restoring and maintaining coral reefs closer to the people who depend upon and benefit from them is not without its challenges, investing in these reefs has the potential to reduce risk to millions of people along the world's coastlines and aligns well with the goals of disaster risk reduction. Coral reef restoration and protection provide measurable reductions in both components of risk—exposure and vulnerability—through provisioning of coastal defense and natural capital, respectively. In addition, restoring reefs is significantly cheaper than building artificial breakwaters in tropical environments. The conservation and disaster risk reduction communities can and should adjust and align their efforts to ensure that the coastal nations that benefit and depend on coral reefs can continue to do so in a changing world.

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A fisherman along The Gambian coastline.
Credit: James Tobey, CRC

5. MARINE FISHERIES, SOCIAL VULNERABILITY AND RISK

BY VERA N. AGOSTINI AND SHAWN W. MARGLES

Most of the world's coastal communities depend on fish and fish-related industries for food and jobs. An estimated 660-820 million people depend on fish (both from wild capture and aquaculture) for their livelihoods, and nearly 3 billion people rely on fish as an important source of animal protein (FAO, 2012). Fish and fishery products are among the most traded food commodities worldwide and account for about 10% of total agricultural exports and 37 percent by volume of world production traded internationally (FAO, 2012).

This chapter examines

1. the links between fisheries[2] and the social vulnerability and risk to coastal communities from coastal hazards,
2. the role that integrated vulnerability assessments play in evaluating and managing risk and
3. the need to develop targeted solutions to help reduce risks to fisheries.

This examination focuses on connections between fisheries and social vulnerability, specifically in the context of disaster risk reduction and adaptation. The objective is to understand linkages in this context and to examine where fisheries focused activities could reduce social vulnerability as a component of disaster risk reduction from current and future coastal hazards. Many other approaches focus first on meeting fishery management targets or in broadly examining social-ecological links in fisheries and improving resilience (e.g., Barsley et al., 2013; Monnerau et al., 2013; Cinner et al, 2011; Allison et al., 2009). These approaches are all relevant in different management contexts, and it is critical that fisheries are better appreciated in risk reduction and climate adaptation management contexts.

5.1 Fisheries, social vulnerability and exposure

The significance of fisheries to livelihoods, food security and coastal economies makes addressing the links between fisheries and social vulnerability central to evaluating and managing overall risk from coastal hazards. Of a global population of more than 7 billion, over 6 billion people live in coastal countries and heavily depend on marine capture fish for nutrition and jobs. From 2006-2009 marine fisheries directly accounted for an average of 4.5 g/person/day of fish protein consumed by humans,[3] with maximum consumption reaching almost 70% of the daily animal protein intake for some countries (Figure 26). Globally, over the same period, approximately 13% of the daily animal protein intake was derived from marine fish (Figure 27). The figure jumps to over 16% for coastal countries and nearly 25% for the top 25 most at-risk coastal countries (Figure 27). Many of the countries with moderate and high disaster risk scores rely on fish for protein consumption (Figure 27). Marine fisheries contribute an average of more than 11 million jobs globally (FAO, 2014), and these jobs are particularly important in some of the countries at greatest risk (Table 11). These figures suggest that fishery vulnerability is important to consider when developing strategies to reduce social vulnerability to climate and disaster risk of coastal communities. Losses to fisheries generate losses in livelihoods and protein available to support diets, which can severely impact the underlying vulnerability of communities to any perturbation including natural hazards.

In addition to a consideration of how fisheries affect risk from coastal hazards, the great effect of coastal hazards on fisheries also must be considered. Climate change and extreme weather events impact fisheries in a variety of ways. For example, the increasing frequency and/or intensity of extreme climatic events can affect fish habitat, productivity and species distributions (Cheung et al., 2010). These same events can also have direct impacts on fishing operations and the physical infrastructure of coastal communities. Storm and severe weather events can destroy or severely damage assets such as boats, landing sites, post-harvesting facilities and roads. This loss of infrastructure often leads to a decrease in harvesting capacity and access to markets, affecting both local livelihoods and the overall economy of coastal communities (Sumaila et al., 2011).

Fishing practices can indirectly affect risk. For example, the ability of habitats such as coral reefs to reduce exposure to coastal hazards can be compromised by fishery practices that use destructive fishing gear (e.g., dynamite blasting). The removal of grazers such as parrotfish from coral reefs can also have impacts on the structural complexity of the reef and its ability to provide protective services to coastal communities. This highlights the importance of examining the links between exposure and fisheries in evaluating and managing overall risk to coastal communities. Appropriate resource management that includes measures to improve fishing practices on targeted coastal habitats can contribute to reducing overall risk of coastal communities.

2 Throughout this chapter we focus exclusively on marine-capture fisheries unless otherwise specified.

3 Data for protein consumption in all tables and figures is an average for the years 2006-2009 (g/person/day); data was downloaded from the FishStat Food Supply database for the category
"Fish-Seafood" and freshwater fish were removed from calculations (FAO, 2013).

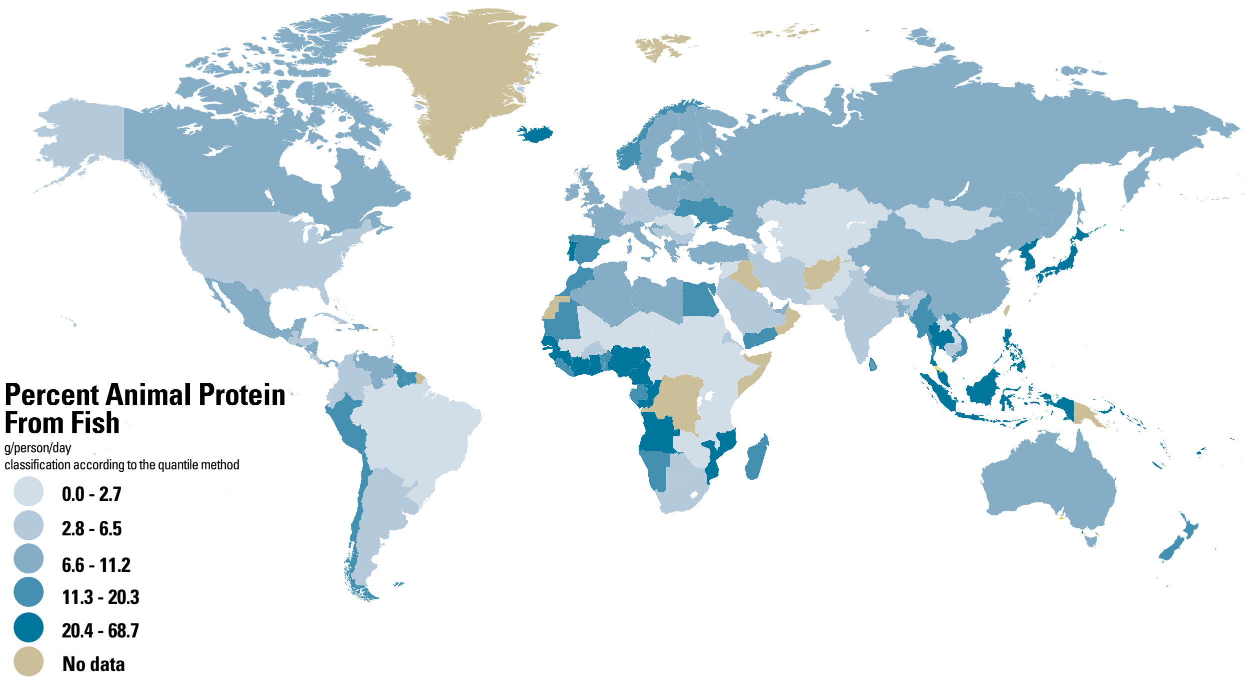


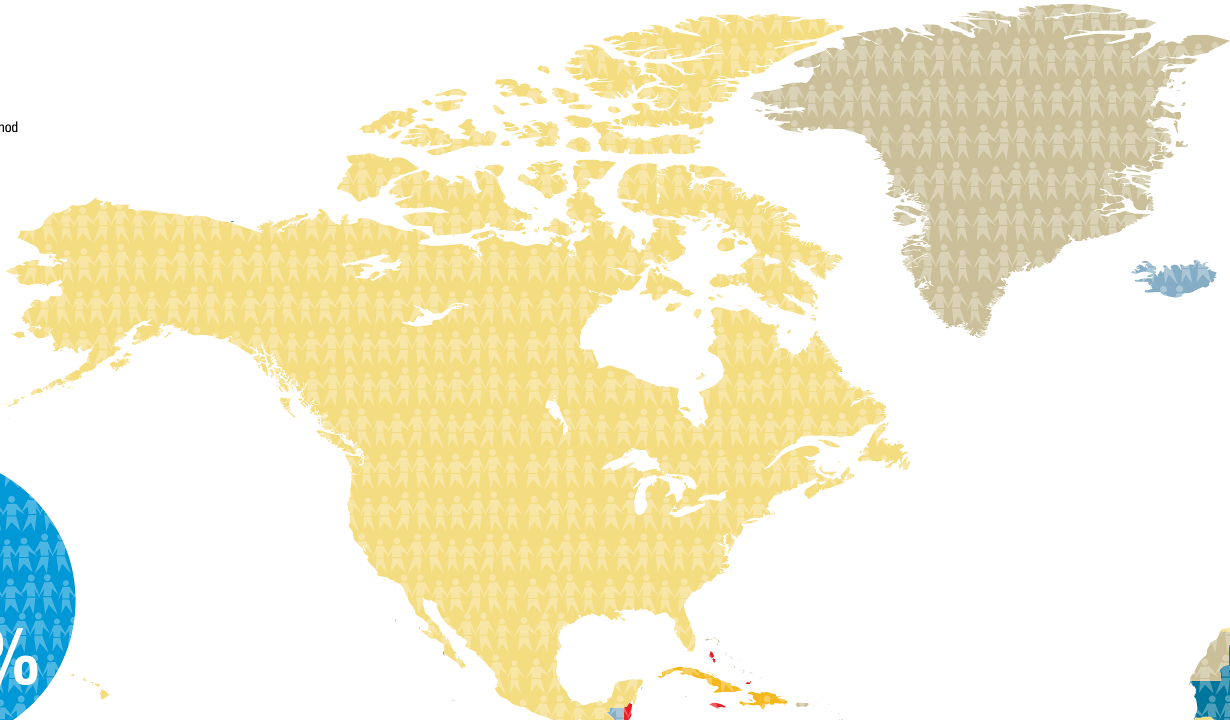
Figure 26: Dependence on marine fish for animal protein. Figure shows percent of daily marine fish protein in diets as a proportion of the total daily animal protein in grams per person per day. Data source: FAO.

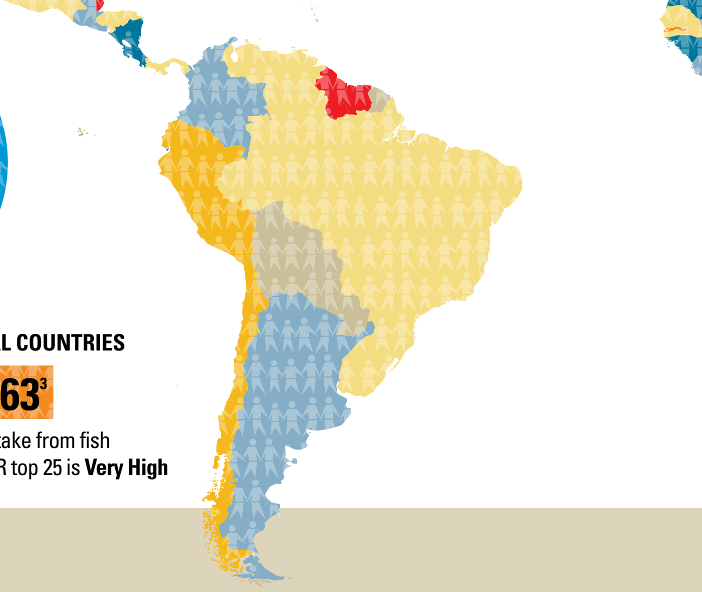
Country	Total 2012 Population	Number of Fishing Jobs	C@R Index Rank
China	1,350,695,000	2,570,274	medium
Indonesia	246,864,191	1,640,705	high
India	1,236,686,732	1,011,471	high
Viet Nam	88,775,500	944,788	very high
Burma	52,797,319	513,879	high
Brazil	198,656,019	497,819	medium
Taiwan	23,315,000	406,475	not included in C@R
Philippines	96,706,764	365,141	very high
Nigeria	168,833,776	294,558	low
Thailand	66,785,001	220,813	medium

Table 11: Top 10 countries with the highest number of fishing jobs and the C@R Index ranking. Fishing jobs include marine and subsistence fishing (see http://www.ehs.unu.edu/CoastsatRisk for methods for calculating fishing jobs). Data sources: World Bank and FAO.

Legend
Max. coastal risk = 1
classification according to the quantile method

- Very Low
- Low
- Medium
- High
- Very High
- No data





GLOBAL

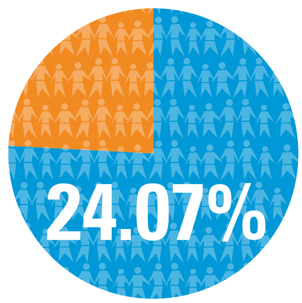
6,838,522,561[2]

13.25% average daily protein intake from fish
C@R Index Average Score: **N/A**

[1] Regional population figures in this illustration reflect 2012 World Bank population figures for C@R countries for which corresponding FAO 2006-2009 average protein consumption data exists. Countries with no protein consumption data were removed from total population and average risk score calculations.

[2] This number reflects total 2012 population for countries that report fish protein consumption data to FAO (176 countries).

[3] Total population for the top 25 most at risk coastal countries is 509,255,857 (one C@R country, Tonga, did not have nutrition data from FAO even though it has population data from the World Bank).



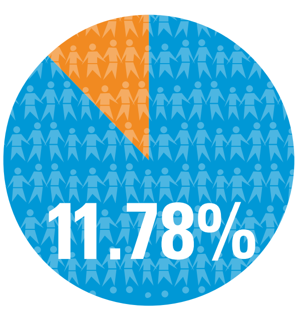
TOP 25 MOST AT RISK COASTAL COUNTRIES

509,150,916[3]

24.07% average daily protein intake from fish
C@R Index Average score of C@R top 25 is **Very High**

Figure 27

Global and regional C@R country dependence on marine fish for animal protein.



North America, Central America and the Caribbean

550,845,900

11.78% average daily protein intake from fish
C@R Index Average Score: **Very High**

South America

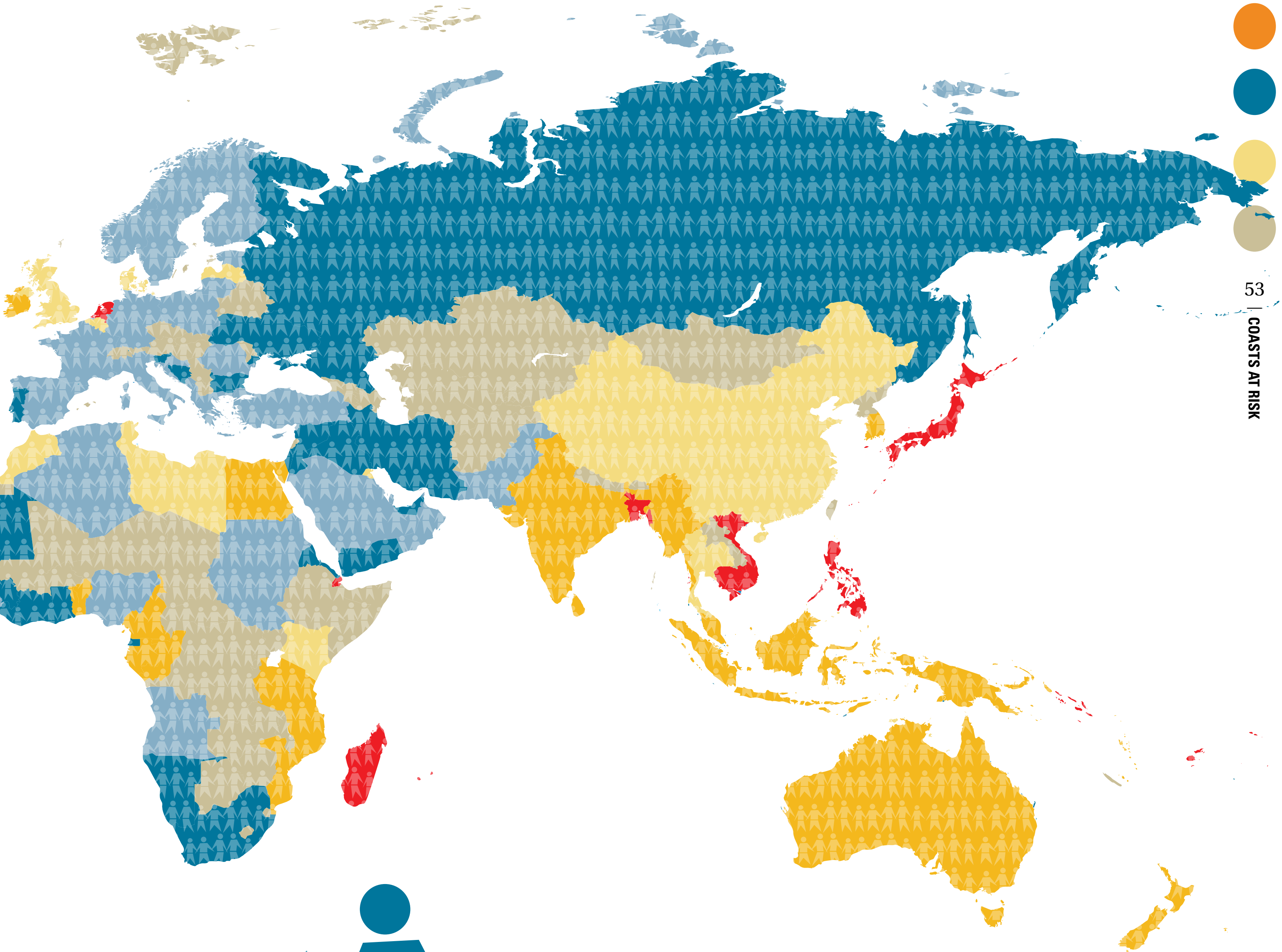
385,072,196

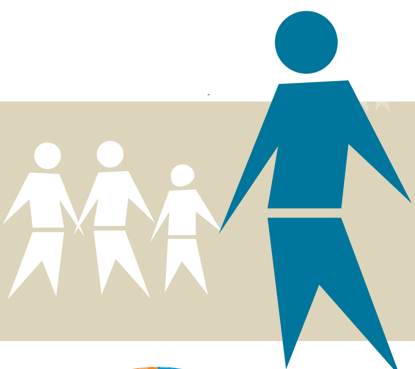
11.02% average daily protein intake from fish
C@R Index Average Score: **High**

Oceania

29,077,977

34% average daily protein intake from fish
C@R Index Average Score: **Very High**



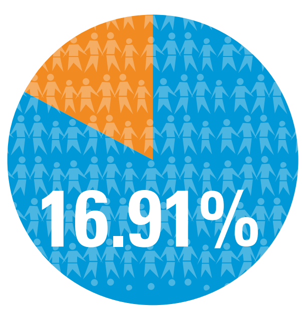


This figure shows globally and regionally the marine fish protein in diets as a proportion of total animal protein in at-risk coastal countries (percent grams/person/day) and the number of people that depend on marine fish for a percentage of their daily total animal protein intake[1]. The map colors indicate C@R values. Data sources: World Bank and FAO, 2013.

Europe

675,127,467

9.92% average daily protein intake from fish
C@R Index Average Score: **Medium**



Asia

3,978,833,779

16.91% average daily protein intake from fish
C@R Index Average Score: **High**

Africa

729,161,947

20.96% average daily protein intake from fish
C@R Index Average Score: **High**

5.2 Vulnerability assessments and fisheries

There is a growing body of work across a range of geographies and disciplines documenting experiences on and making the case for assessing vulnerability within fisheries and aquaculture (e.g., see Barsley et al., 2013). Vulnerability assessments are excellent tools to identify communities that are most vulnerable to climate and disaster risk and allow decision makers to focus risk-related resources where they are most needed.

Many fishing communities are spread across rural coastal areas with poor access to infrastructure, markets and social services, making these communities economically, socially and politically marginalized. This puts these communities at risk to many factors and highlights the importance of conducting assessments, such as the one outlined in Chapter 2, that examine risk across sectors. This type of approach can: 1) provide a better understanding of fisheries vulnerability; 2) highlight the links between the sector and the overall risk of coastal communities; 3) lead to better- targeted and more effective climate and disaster risk reduction solutions; and 4) help the fisheries sector access funding and policy levers around adaptation and disaster risk management.

Climate variability and change are among the various stresses fishing and fish-farming communities face that can be evaluated with the assistance of a cross-sectoral vulnerability assessment.

A fisheries vulnerability assessment can identify the high-value fisheries infrastructure at risk from a storm event; the critical fisheries habitats that could be impacted by severe storms or climate events such as bleaching; climate-induced changes in fish stock distribution that may impact distances between landing sites and fishing grounds; and the fishing communities that lack mechanisms (such as a functioning fisheries cooperative) to facilitate social cohesion—a critical aspect of adaptive capacity. A fisheries vulnerability assessment can supply this kind of information and support the development of specifically targeted solutions. These types of solutions will help the fisheries sector build its socio-ecological resilience, and therefore, its ability to respond to the opportunities and challenges of climate change.

5.3 Towards identifying disaster risk reduction solutions for fisheries

Vulnerability assessments are an important first step in managing fisheries in the face of climate and disaster risk. Additional efforts are needed to understand and document how people dependent on marine resources can adapt their resource-use patterns to maintain the flow of goods and services, reduce their sensitivity to change and increase their adaptive capacities in the face of climate change and meteorological hazards.

To date, most of the discussion around marine capture fisheries risk and adaptation tends to focus on general statements about building resilience through reducing stressors and improving governance. This approach ensures a continued focus on important aspects of sustainable fisheries, however, it is delaying the fisheries sector from effectively adapting to a changing future and in some cases is impeding the ability to capitalize on new funding streams that include those for climate adaptation or hazard mitigation. Reducing stresses such as overfishing, marine pollution, habitat degradation and competing ocean uses clearly will help a fishery to be more resilient to climate change. However, in order to effectively support fisheries adaptation into the future, more targeted solutions aimed at addressing specific pieces of the fisheries vulnerability challenge must be developed.

A number of possible solutions to help decrease the vulnerability of coastal communities by addressing fisheries exists. Some examples are provided in Cochran et al., (2009) and Shelton (2014). Here the focus is on the role that spatial vulnerability assessment can play in developing more tailored solutions, and some examples of types of solutions are provided. The inclusion of spatially explicit fisheries vulnerability assessments is an important step in identifying and describing potential solutions to decrease climate and disaster risk to coastal communities. A spatial assessment can highlight particular weak points in a fishery within a climate and disaster risk context. Management solutions specifically designed to address highlighted weak points can then guide sustainable practices that have a chance of withstanding the impacts of current and future coastal hazards including climate change. For example, fishers can adapt to climate-induced shifts in species distributions by switching target species, gear type or accessing a variety of fishing grounds (Sumaila et al., 2011). Tools such as marine spatial planning, zoning and marine protected area networks specifically designed to take into account the outputs of a fisheries vulnerability assessment (e.g., where the most climate resilient fishing grounds and habitats can be found), are examples of measures that could enable a fishery to effectively adapt. Furthermore, a full understanding of what contributes to the social vulnerability of a fisheries, for example the degree or lack of social cohesion within a community, can enable the design of adaptation strategies (e.g., development of fisher networks in specific communities) that are tailored to overcome weak points highlighted by spatial vulnerability assessments.

5.4 Conclusion

Examining fisheries within a risk and adaptation context leads to the following set of recommendations to help strengthen the sector's ability to prepare, adapt and respond to climate and disaster risks:

Expanding the fisheries management lens

Fisheries management has historically focused on resource enhancement by examining socio-economic and ecological drivers of sustainable access to resources. An expanded lens, such as the one provided by the ecosystem approach to fisheries that also includes overall risk management and adaptation considerations, could lead to new partnerships (e.g., with aid groups), new and refined funding investment strategies and better buy-in towards fisheries management from sectors not traditionally focused on fisheries (e.g. conservation). Developing strategies for fisheries management in countries most at risk could bring to the table new financial resources (e.g., ability to access adaptation funding for fisheries and aquaculture) and help diversify the portfolio of current investments in conservation. In addition, current fisheries management strategies could obtain wider buy-in if outcomes were described as wide reaching with impacts beyond the fisheries sector (i.e., connected to wider coastal risk management goals such as disaster management).

Mainstreaming fisheries in the climate policy discussions

Given the dependency of coastal communities on fish and fish-related industries to provide nutrition and jobs, addressing fisheries within the wider climate and disaster risk context will increase not only the adaptive capacity of the fisheries sector but of coastal communities overall. However, in contrast with agriculture and freshwater, fisheries have been largely ignored in climate policy discussions (Dulvy et al., 2009). There is a need to mainstream fisheries considerations in these discussions. Vulnerability assessments such as the one discussed above can be a good vehicle for this. They will help the fisheries sector come to the table with a specific set of needs and recommendations related to risk and facilitate conversations between fisheries and other development sectors, ultimately enabling participation of the fisheries sector in the broader adaptation planning processes.

Integrating fisheries into an overall cross-sectoral response

Risk reduction and adaptation planning and management, which operate across the ecological and socio-economic spectrum of risk, will play a critical role in guiding recommendations supporting long-term resiliency of fisheries and coastal communities. They also hold great promise to deliver effective adaptation strategies for fisheries. Spatial vulnerability assessments such as the C@R Index offer great vehicles for cross-sectoral planning and management. This type of planning and

GLOBAL INDICATORS FOR FISHERIES: OPPORTUNITIES AND CHALLENGES

Fisheries indicators play a critical role in raising awareness of important global fisheries patterns and trends. To date they have been mainly used to assess the status of ocean resources and management. This report assembles a select set of global fisheries indicators and uses them in conjunction with other indicators in the C@R Index to represent the important role that fisheries play in the risks of natural hazards to coastal communities.

Regardless of the application, using indicators to describe fisheries at the global level is complex. A number of issues such as data availability, country misreporting or lack of reporting and access to existing indicators, make assembling global fisheries indicators challenging. A number of strong global indicators for fisheries are available (FAO, 2012) and the C@R fishery indicators were based on these. Any manipulation of existing indicators for purposes different than the ones for which they were originally intended can lead to misleading or spurious patterns and great care was taken to use the indicators as intended.

Global fisheries indicators play a critical role in shaping important policy, development and funding decisions. As a result, priority should continue to be given to strengthening existing indicators, filling existing gaps and promoting informed and responsible use of these indicators. The following could contribute to reaching these goals:

- **Continue to strengthen ecological indicators**
  Ecological indicators are critical in the assessment of the status of fisheries resources and their management. There are significant gaps in these indicators particularly for some of the most at-risk countries that have major limitations in their ability to monitor fisheries (i.e., data-poor stocks) and for which a limited number of stocks are assessed.

- **Develop indicators of socio-economic status and trends**
  A fishery is a linked social and ecological system. To date the status of most fisheries is described by ecological and economic indicators. The status of these fisheries also needs to be described with social indicators if we are to effectively assess fishery management in general and particularly to support adaptation and risk reduction decisions.

- **Develop indicators that are grounded at the local level**
  Global assessments are mainly utilized as tools to help drive the discussion and formulate policy agendas at the global and regional level. However, the indicators from these assessments also have practical application and impact at the national and local level. There is a strong body of work related to local and national indicators (Cinner et al., 2011, 2013; McClanahan and Cinner, 2011; Monnerau et al., 2013). The indicators developed by these efforts suggest what is most relevant at this scale and provide a different perspective. Despite the challenges that scaling up or scaling down indicators present, more effort should be focused on examining how indicators developed within a local context could translate to a global or regional scale context and vice versa. There are important opportunities that are lost due to the limited exchange between local and global indicator efforts.

- **Facilitate access to existing global indicators**
  Existing fisheries indicators are not always easy to access, and the methodologies used to assemble them are not always clear. In order to facilitate proper use of indicators, priority should be given to remedy these problems.

management has been recommended previously (e.g., in the ecosystem approach to fisheries), and lessons learned from those efforts will be critical in helping to guide successful implementation within a risk and adaptation context.

Supporting the development of forecasting tools and applications

The ability to incorporate future projections into risk management strategies is growing. For fisheries, this will mean being able to project the abundance and distribution of fish resources into the future given climate projections. The science in this arena is relatively young, and few examples exist of how to integrate these climate forecasts into management. Research on projected impacts to fish stocks and tools to integrate this information into fisheries and resource management should be prioritized. For example, current projections (Cheung et al., 2013) note that tropical countries are predicted to see greater declines in fisheries productivity compared to temperate countries. The C@R Index shows that these tropical countries are the most at risk. This suggests that overall risk management strategies for tropical countries should prioritize planning and adapting to fisheries declines.

Understanding the relationship between marine habitats and food security

Research efforts examining links between marine habitats and food security need to be prioritized. A better understanding of the links between marine and coastal habitats and food security would help drive restoration and habitat management investments to benefit fisheries. There are parallels to the work on habitat restoration and coastal defense, where ecological, economic and engineering research are all identifying where and how coastal habitats can contribute substantively to reducing exposure to wave, surge and sea level rise. The research on these exposure reduction linkages is now helping to drive risk reduction and adaptation investments. These benefits could also be achieved by similar work on marine habitats, fish and food security.

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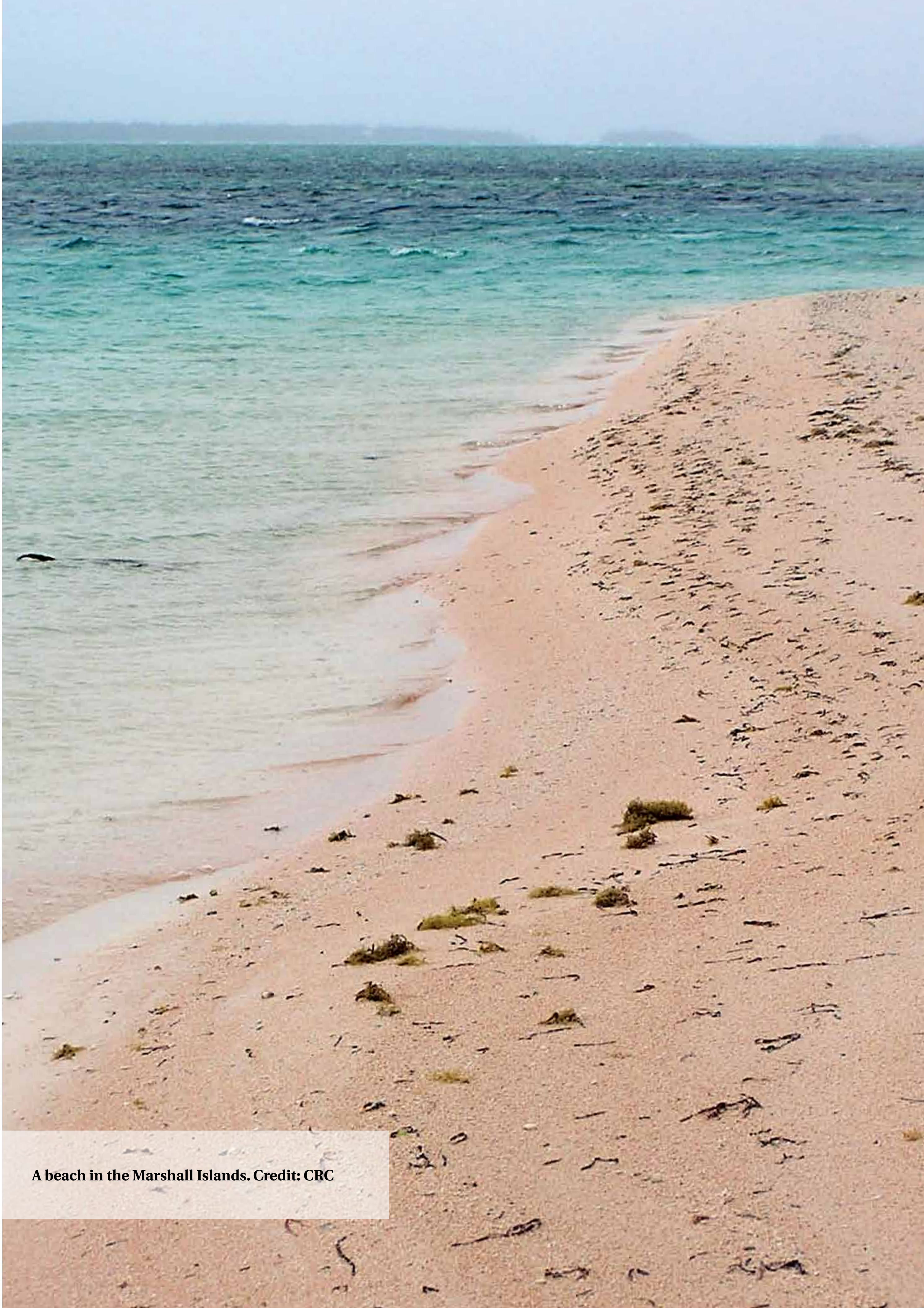
A fisherwoman with her harvest in Thailand. Credit: CRC



A beach in the Marshall Islands. Credit: CRC

6. RECOMMENDATIONS FOR MEETING RISK REDUCTION & CONSERVATION GOALS

BY MICHAEL W. BECK

Many prior papers and reports focus on recommendations for either risk reduction or conservation management goals (e.g., early warning systems for risk reduction or protected areas for conservation). **This report focuses on recommendations that are integrated across risk reduction and environmental conservation objectives and that can benefit both people and nature.** Though the authors do not focus recommendations for single management goals, it supports many of them. This report generally assumes that actions in current risk reduction and conservation also foster future adaptation and identifies where this overlap is likely to be particularly important. There are several key findings and considerations raised in the report that help guide the recommendations. First, the nations most at risk overall are tropical and small island developing states. Second, environmental degradation increases vulnerability and exposure. Third, environmental conservation and restoration can reduce exposure and improve social vulnerability. It is increasingly clear that the role of environment and natural resources in risk and risk reduction should be accounted for. Lastly, it is highly likely that future coastal risks will increase with climate change, population growth and coastal development. Based on the findings, this report offers a series of recommendations relevant to policy-makers, scientists, conservationists and risk and hazard managers.

There is a need to increase risk prevention measures and opportunites for better post-disaster development choices

- It is well known that pre-disaster (i.e., prevention) actions are particularly cost effective but the most difficult to support. Larger and more coordinated coalitions of stakeholder agencies and groups could push more effectively for the support that is needed. Many environmental agencies and conservation groups should become more active in supporting these risk reduction efforts because many of these efforts could also support the restoration of coastal habitats and fisheries.

- Many post-disaster choices could support both risk reduction and conservation goals if national governments and multi-national funders were more cautious about rebuilding efforts in the highest risk, low-lying areas. In many cases such prudence would reduce human risks and generate environmental benefits as these low-lying developments are often around heavily impacted wetlands. These habitats could instead be restored to offer a better first line of coastal defense.

- SIDS remain at the top of most risk indices, and their risks are set to increase with climate change, which will create further impacts to people, habitats and fisheries. A greater commitment is needed to help these nations build adaptive capacity through adaptation (prevention) measures now and better post-disaster development choices later.

Habitat restoration can contribute to risk reduction, and opportunities exist to focus these restoration efforts

- Coral reef and mangrove restoration offers viable and cost-effective options for risk reduction. This restoration is particularly relevant in the tropical, coastal countries that are most at risk from natural hazards. Doing these restoration projects well means careful attention must be paid to meeting both conservation and risk reduction goals in project design and placement. Poorly conceived projects (e.g., planting mangroves in places where they did not previously occur) will fail to meet goals, may create new hazards and will make it harder to implement well-designed projects in the future.

- Environment agencies and conservation groups will need to change some of their priorities to work effectively to support risk reduction. For example, many marine conservation efforts occur in remote areas (i.e., with low population density). To these efforts, more projects should be added in areas with greater population density. The environment in these areas may be more degraded but its restoration would benefit many people. Further, significant consideration must be given to combining species-focused restoration with structural restoration efforts (i,e., rebuilding reef structure).

- Even large temperate countries (e.g., China and the United States) have opportunities for coral reef and mangrove restoration to reduce risks. These are particularly relevant in some of the regions in those countries that have some of the greatest exposure to coastal hazards (e.g., southeast Florida, USA). In temperate countries, increased oyster reef and salt marsh restoration could also cost-effectively reduce risk.

- Many aid and development agencies are beginning to incorporate joint environmental objectives in their work. The pace of this work can and should be accelerated as there is growing evidence that these conservation measures can contribute effectively and efficiently to reducing exposure and social vulnerability.

Targeted research is needed on environmental risk reduction benefits to create better opportunities for investment

- Governments and multinational funders should develop more integrated risk assessments that better account for drivers of risk such as environmental degradation.
- Scientists (social, natural and economic) should advance research on the effects of environmental degradation on risk. Work in this area is increasing; it can be more quickly advanced. For example, there are measures of the effects of mangrove loss on communities during storms, but there are not many direct measures of the effects of coral reef degradation on coastal erosion and defense or on the connection between fisheries production and social vulnerability.
- More rigorous accounting for ecosystem services such as coastal protection and fisheries production is needed. While current assessments clearly show that conservation and restoration can make economic sense, future science and demonstration projects can even more directly target the steps in the decision-making frameworks used by hazard managers, for example in cost:benefit analyses of alternatives.
- Many nations have substantial critical infrastructure (e.g., ports, airports, power plants, sewage treatment plants) in low-lying and highly exposed areas; governments need to better account for how this affects their national risk. This is an area where businesses (e.g., insurance), aid and conservation groups could work together to assess risk and identify priorities for risk reduction. Reasonable indicators of coastal infrastructure exposure could also be developed for future risk indices.

Leaders need to demand more cost-effective solutions and recognize opportunities to create sustainable investments in natural infrastructure

- Adaptation and development funders should encourage better mainstreaming of cost-effective solutions for risk reduction. Where natural solutions are cost effective, they should become the more preferred alternatives. For example, when assessing the cost effectiveness of solutions for coastal defense and adaptation, governments and multinational funders should ensure that nature-based defenses are considered by engineering and risk assessment agencies and firms. This is already starting to happen. Re-insurance firms such as Swiss Re already assess the cost effectiveness of reef and mangrove restoration alongside built approaches for risk reduction. The Army Corp of Engineers and Deltares already have Engineering with Nature and Building with Nature initiatives, respectively, that are aimed at developing more nature-based coastal defense projects. Further, many engineering firms already work on building living shorelines projects. Nonetheless, many disincentives still need to be addressed over time, such as the fact that these greener approaches usually do not yet have engineering standards backing them.
- Nature-based risk reduction can be increasingly viewed as an opportunity for investment and business. Sometimes conservation is depicted as bad for business and development. Engineering firms can find business (and market niche) in designing nature-based defenses. Construction firms and marine contractors can find business in developing restoration projects and creating local jobs. Risk modelers can find business in assessing the cost effectiveness of nature-based alternatives as compared to other alternatives.

Fisheries management and research need to improve, and opportunities to reduce social vulnerability should be recognized

- Our understanding of the links between fisheries, habitats and food security need to be improved. This research will help drive actions by identifying where and how to focus on restoration actions that enhance food security. There are parallels to the work on habitat restoration for coastal defense where ecological, economic and engineering research has helped identify how coastal habitats can contribute substantively to reducing exposure to coastal hazards. The strength of this science and field demonstrations makes it much easier for decision-makers to invest in conservation and restoration for exposure reduction; similar efforts are needed on fisheries and food security.

- Fisheries management can fruitfully be approached from a risk reduction and adaptation viewpoint. Fisheries management has mostly focused on resource enhancement by examining socio-economic and ecological drivers of sustainable access to resources. An expanded lens that includes overall risk management and adaptation considerations could lead to new partnerships (e.g., with aid groups); new and refined funding investment strategies; and better buy-in towards fisheries enhancement. A focus for example on developing strategies for fisheries management in countries most at risk could bring to the table new financial resources, e.g., ability to access adaptation funding for fisheries applications and help to diversify the portfolio of current investments.

- Further research on the link between fisheries and climate change is critical. Present research already points towards actions in some of the most at-risk countries. Fisheries productivity is predicted to increase in some countries (adding to their adaptive capacity) and decrease in others (reducing overall adaptive capacity). Most ominously, tropical areas are predicted to more often see declines in fisheries productivity than temperate countries. Thus, where overall risks are the greatest is where countries may face the greatest pressures from climate-related declines in fisheries.

- As the fisheries sector gains better access to adaptation funding, tradeoffs will need to be considered between immediate access to fishery resources (reducing current susceptibility) and management to improve fisheries stocks for the future (increasing coping and adaptive capacities). Better stock assessments and more participatory co-management approaches will play a critical role in informing these trade-offs.

Annex: Coasts at Risk Index final results

NAME	COAST at RISK	Exposure	Vulnerabililty	Susceptibility	Lack of Coping Capacity	Lack of Adaptice Capacity
Antigua and Barbuda	0,2702	0,5893	0,4584	0,3304	0,6052	0,4398
Tonga	0,2482	0,5108	0,4859	0,2823	0,7256	0,4497
Saint Kitts and Nevis	0,2366	0,5955	0,3973	0,2211	0,5854	0,3853
Vanuatu	0,1508	0,2392	0,6306	0,5053	0,8251	0,5613
Fiji	0,1254	0,2568	0,4884	0,2568	0,7470	0,4615
Brunei Darussalam	0,1093	0,2818	0,3878	0,1919	0,6011	0,3704
Bangladesh	0,1056	0,1878	0,5626	0,2706	0,7792	0,6381
Philippines	0,1003	0,2095	0,4786	0,2630	0,7298	0,4431
Seychelles	0,0851	0,1776	0,4791	0,3738	0,6113	0,4522
Kiribati	0,0830	0,1558	0,5329	0,4264	0,6713	0,5010
Belize	0,0779	0,1685	0,4622	0,2375	0,6624	0,4866
Cambodia	0,0737	0,1333	0,5533	0,3037	0,8178	0,5385
Bahamas	0,0701	0,1717	0,4080	0,2298	0,5720	0,4221
Japan	0,0694	0,2080	0,3337	0,1674	0,4767	0,3569
Viet Nam	0,0677	0,1445	0,4686	0,2035	0,7309	0,4714
Samoa	0,0665	0,1409	0,4719	0,2414	0,6999	0,4743
Mauritius	0,0658	0,1548	0,4251	0,2180	0,6204	0,4368
Guyana	0,0642	0,1352	0,4752	0,2408	0,7243	0,4607
Netherlands	0,0634	0,2036	0,3112	0,1339	0,4892	0,3106
Jamaica	0,0522	0,1135	0,4599	0,2562	0,6846	0,4389
Suriname	0,0508	0,1146	0,4429	0,2503	0,6442	0,4342
Solomon Islands	0,0480	0,0799	0,6016	0,4104	0,8559	0,5385
Djibouti	0,0479	0,0869	0,5515	0,2760	0,7754	0,6032
Grenada	0,0368	0,0832	0,4422	0,2720	0,6033	0,4513
Saint Lucia	0,0352	0,0768	0,4591	0,3054	0,6095	0,4625
iint Vincent and the Grenadin	0,0348	0,0820	0,4248	0,2270	0,5764	0,4709
Madagascar	0,0336	0,0558	0,6021	0,4884	0,7358	0,5821
Haiti	0,0316	0,0478	0,6597	0,4471	0,8539	0,6781
Cape Verde	0,0314	0,0629	0,4986	0,3157	0,6351	0,5449
Cuba	0,0299	0,0739	0,4039	0,2260	0,6112	0,3746
Cameroon	0,0295	0,0541	0,5441	0,3232	0,7091	0,5999

Dominican Republic	0,0277	0,0585	0,4744	0,2540	0,7097	0,4595
Barbados	0,0264	0,0704	0,3745	0,2427	0,5179	0,3630
Indonesia	0,0259	0,0520	0,4982	0,2511	0,7527	0,4908
Bahrain	0,0251	0,0604	0,4164	0,1442	0,6266	0,4782
Myanmar (Burma)	0,0220	0,0393	0,5604	0,2384	0,8483	0,5944
Australia	0,0207	0,0676	0,3070	0,1400	0,4359	0,3451
Sri Lanka	0,0201	0,0413	0,4858	0,2408	0,7207	0,4958
Gabon	0,0190	0,0393	0,4826	0,3030	0,7051	0,4397
Ireland	0,0177	0,0523	0,3390	0,1432	0,5236	0,3501
Peru	0,0176	0,0399	0,4418	0,2460	0,6313	0,4482
Malaysia	0,0174	0,0422	0,4134	0,1852	0,6121	0,4428
Chile	0,0172	0,0452	0,3800	0,1875	0,5492	0,4034
Korea, Republic of	0,0170	0,0522	0,3265	0,1478	0,4473	0,3845
Maldives	0,0157	0,0323	0,4876	0,3971	0,6199	0,4456
New Zealand	0,0150	0,0484	0,3099	0,1490	0,4716	0,3091
Mozambique	0,0148	0,0228	0,6485	0,4837	0,8577	0,6041
Congo	0,0143	0,0233	0,6116	0,4393	0,8335	0,5621
Ecuador	0,0142	0,0342	0,4152	0,2012	0,6128	0,4315
Papua New Guinea	0,0136	0,0214	0,6353	0,4581	0,8350	0,6129
Benin	0,0131	0,0211	0,6194	0,3945	0,8094	0,6541
India	0,0123	0,0227	0,5415	0,2519	0,7684	0,6043
Egypt	0,0115	0,0258	0,4461	0,1657	0,6580	0,5145
United Republic of Tanzania	0,0110	0,0189	0,5837	0,4593	0,7627	0,5290
Timor-Leste	0,0101	0,0171	0,5889	0,4150	0,7628	0,5890
Brazil	0,0100	0,0232	0,4318	0,1790	0,6870	0,4294
Lebanon	0,0097	0,0216	0,4492	0,2086	0,6606	0,4784
Denmark	0,0093	0,0298	0,3117	0,1359	0,4768	0,3224
Gambia	0,0092	0,0156	0,5880	0,3764	0,7535	0,6342
Comoros	0,0090	0,0150	0,5995	0,4824	0,6814	0,6348
Singapore	0,0089	0,0239	0,3734	0,2189	0,5678	0,3337
Tunisia	0,0085	0,0200	0,4241	0,1759	0,6161	0,4804
Canada	0,0084	0,0271	0,3107	0,1267	0,4671	0,3384
Libyan Arab Jamahiriya	0,0082	0,0179	0,4565	0,2059	0,6496	0,5140

Thailand	0,0082	0,0197	0,4147	0,1562	0,6522	0,4356
United Kingdom	0,0078	0,0233	0,3337	0,1414	0,5218	0,3377
Trinidad and Tobago	0,0076	0,0185	0,4137	0,1895	0,6166	0,4350
United States	0,0075	0,0240	0,3134	0,1320	0,4825	0,3257
Cyprus	0,0075	0,0193	0,3884	0,1720	0,5683	0,4250
Honduras	0,0074	0,0150	0,4896	0,2677	0,7321	0,4692
China	0,0072	0,0180	0,3996	0,1745	0,5644	0,4597
Senegal	0,0066	0,0115	0,5723	0,3684	0,7379	0,6105
Morocco	0,0066	0,0137	0,4813	0,2139	0,6543	0,5756
Venezuela	0,0066	0,0158	0,4156	0,1852	0,6333	0,4282
Guinea-Bissau	0,0059	0,0099	0,5997	0,3765	0,8125	0,6102
Qatar	0,0058	0,0159	0,3638	0,1365	0,5263	0,4285
Mexico	0,0058	0,0136	0,4252	0,1737	0,6765	0,4254
Kenya	0,0057	0,0098	0,5799	0,4053	0,7698	0,5647
Uruguay	0,0056	0,0153	0,3655	0,1706	0,5255	0,4003
Panama	0,0055	0,0129	0,4233	0,2426	0,6113	0,4161
Latvia	0,0054	0,0140	0,3829	0,1796	0,6034	0,3658
Belgium	0,0052	0,0163	0,3199	0,1567	0,4744	0,3285
Malta	0,0052	0,0132	0,3914	0,1706	0,5627	0,4410
Angola	0,0047	0,0083	0,5704	0,4288	0,7431	0,5392
Sudan	0,0046	0,0077	0,5988	0,3887	0,8416	0,5660
El Salvador	0,0045	0,0095	0,4708	0,2432	0,6781	0,4911
Guatemala	0,0043	0,0079	0,5348	0,2908	0,7776	0,5361
Colombia	0,0041	0,0087	0,4752	0,2198	0,7714	0,4343
Norway	0,0039	0,0139	0,2791	0,1414	0,3986	0,2972
Kuwait	0,0039	0,0098	0,3941	0,1521	0,5877	0,4426
Turkey	0,0038	0,0090	0,4212	0,1524	0,6274	0,4837
Greece	0,0037	0,0103	0,3570	0,1663	0,5364	0,3683
Finland	0,0033	0,0110	0,2981	0,1437	0,4446	0,3059
Estonia	0,0032	0,0091	0,3516	0,1594	0,5367	0,3587
Sweden	0,0031	0,0099	0,3142	0,1402	0,4979	0,3047
Algeria	0,0031	0,0067	0,4633	0,1744	0,6741	0,5414
Pakistan	0,0029	0,0053	0,5395	0,2463	0,7129	0,6593

Saudi Arabia	0,0028	0,0069	0,4024	0,1484	0,5892	0,4697
Oman	0,0027	0,0066	0,4061	0,1530	0,5910	0,4743
Spain	0,0025	0,0072	0,3402	0,1402	0,5354	0,3450
Romania	0,0023	0,0058	0,4039	0,2121	0,5613	0,4381
Sierra Leone	0,0023	0,0035	0,6550	0,5250	0,7677	0,6723
Argentina	0,0022	0,0062	0,3523	0,1519	0,5400	0,3651
France	0,0021	0,0069	0,3101	0,1388	0,4585	0,3330
Iceland	0,0020	0,0066	0,3035	0,2051	0,4163	0,2892
Croatia	0,0020	0,0053	0,3694	0,1644	0,5679	0,3759
Germany	0,0020	0,0062	0,3143	0,1339	0,4626	0,3465
Nigeria	0,0019	0,0030	0,6306	0,4247	0,8269	0,6401
Italy	0,0019	0,0052	0,3626	0,1504	0,5892	0,3483
Albania	0,0019	0,0040	0,4627	0,1901	0,7285	0,4695
Poland	0,0019	0,0053	0,3530	0,1461	0,5540	0,3591
Georgia	0,0018	0,0040	0,4434	0,2309	0,6073	0,4921
Nicaragua	0,0017	0,0036	0,4829	0,2789	0,7095	0,4604
Russia	0,0016	0,0043	0,3690	0,1561	0,5351	0,4157
Montenegro	0,0016	0,0040	0,4037	0,1878	0,6455	0,3777
Bulgaria	0,0016	0,0042	0,3766	0,1541	0,5582	0,4174
Costa Rica	0,0016	0,0039	0,4039	0,1898	0,6836	0,3382
Lithuania	0,0015	0,0044	0,3501	0,1814	0,4924	0,3764
Ukraine	0,0015	0,0037	0,4135	0,1392	0,6457	0,4556
Bosnia and Herzegovina	0,0015	0,0032	0,4566	0,2224	0,6667	0,4808
Yemen	0,0014	0,0025	0,5614	0,3379	0,7166	0,6299
Togo	0,0012	0,0019	0,6171	0,3994	0,8177	0,6341
United Arab Emirates	0,0011	0,0031	0,3540	0,1264	0,5269	0,4088
Namibia	0,0011	0,0021	0,5118	0,3642	0,6890	0,4823
Slovenia	0,0011	0,0030	0,3478	0,1661	0,5554	0,3219
Iran (Islamic Republic of)	0,0010	0,0024	0,4321	0,1337	0,6845	0,4782
Portugal	0,0010	0,0028	0,3679	0,1675	0,5499	0,3863
Syrian Arab Republic	0,0010	0,0019	0,4923	0,2049	0,7150	0,5569
Israel	0,0008	0,0022	0,3759	0,1942	0,5459	0,3877
Equatorial Guinea	0,0008	0,0015	0,5280	0,2921	0,7801	0,5119

Iraq	0,0007	0,0014	0,5233	0,2441	0,7646	0,5613
South Africa	0,0006	0,0015	0,4314	0,2233	0,6038	0,4672
Cote d'Ivoire	0,0006	0,0011	0,5661	0,3702	0,6953	0,6328
Liberia	0,0006	0,0009	0,6476	0,4724	0,8274	0,6430
Ghana	0,0006	0,0009	0,5851	0,3698	0,7920	0,5936
Guinea	0,0004	0,0007	0,6205	0,4055	0,8021	0,6539
Eritrea	0,0004	0,0006	0,6569	0,4501	0,7993	0,7212
Mauritania	0,0004	0,0007	0,6037	0,3646	0,7986	0,6479
Jordan	0,0001	0,0003	0,4510	0,2130	0,6658	0,4743