Reefs at Risk

Revisited

SUMMARY FOR DECISION MAKERS

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Reefs at Risk Revisited is a project of the World Resources Institute (WRI), developed and implemented in close collaboration with The Nature Conservancy (TNC), the WorldFish Center, the International Coral Reef Action Network (ICRAN), the United Nations Environment Programme - World Conservation Monitoring Centre (UNEP-WCMC), and the Global Coral Reef Monitoring Network (GCRMN). Many other government agencies, international organizations, research institutions, universities, nongovernmental organizations, and initiatives provided scientific guidance, contributed data, and reviewed results, including:

- Atlantic and Gulf Rapid Reef Assessment (AGRRA)
- Coastal Oceans Research and Development in the Indian Ocean (CORDIO)
- Conservation International (CI)
- Coral Reef Alliance (CORAL)
- Healthy Reefs for Healthy People
- Institut de Recherche pour le Développement (IRD)
- International Society for Reef Studies (ISRS)
- International Union for Conservation of Nature (IUCN)
- National Center for Ecological Analysis and Synthesis (NCEAS)
- Oceana
- Planetary Coral Reef Foundation
- Project AWARE Foundation
- Reef Check
- Reef Environmental Education Foundation (REEF)
- SeaWeb
- Secretariat of the Pacific Community (SPC)
- Secretariat of the Pacific Regional Environment Programme (SPREP)
- U.S. National Aeronautics and Space Administration (NASA)
- U.S. National Oceanic and Atmospheric Administration (NOAA)
- University of South Florida (USF)
- University of the South Pacific (USP)
- Wildlife Conservation Society (WCS)
- World Wildlife Fund (WWF)

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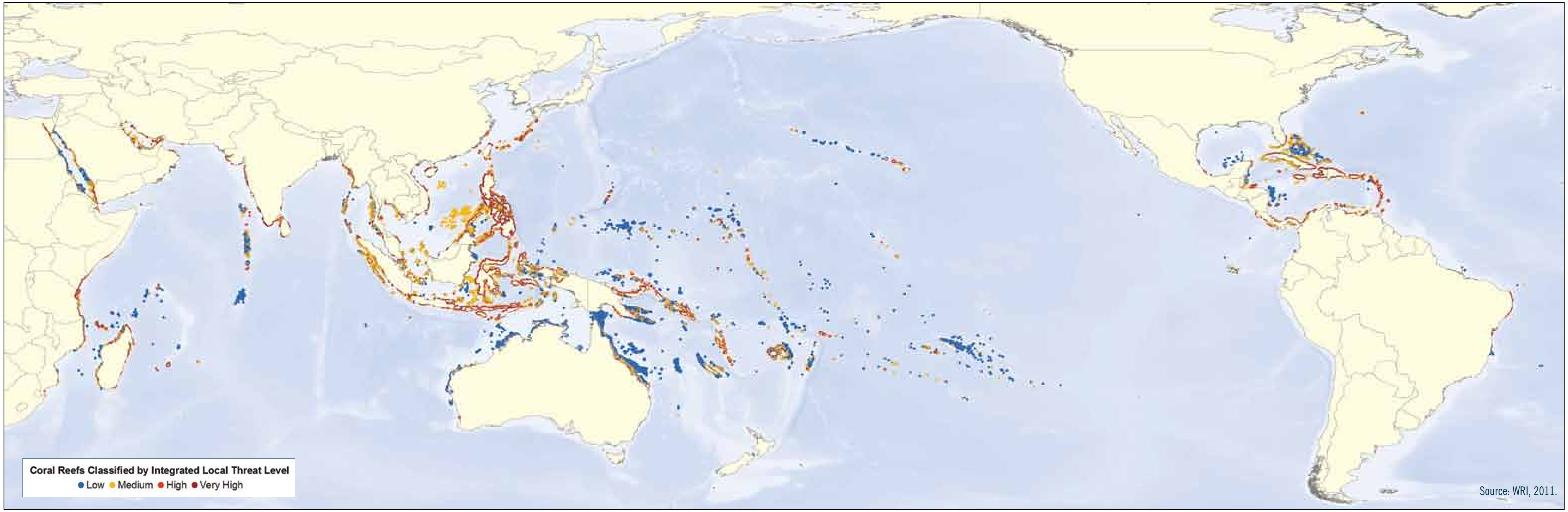
- The Ocean Foundation
- Roy Disney Family Foundation
- The Tiffany & Co. Foundation
- U.S. Department of the Interior
- U.S. Department of State

Coral Reefs of the World Classified by Threat from Local Activities



Coral reefs are classified by estimated present threat from local human activities, according to the Reefs at Risk integrated local threat index. The index combines the threat from the following local activities:

- Overfishing and destructive fishing
- Coastal development
- Watershed-based pollution
- Marine-based pollution and damage.

This indicator does not include the impact to reefs from global warming or ocean acidification. Maps including ocean warming and acidification appear later in the report and on www.wri.org/reefs.

Base data source: Reef locations are based on 500 meter resolution gridded data reflecting shallow, tropical coral reefs of the world. Organizations contributing to the data and development of the map include the Institute for Marine Remote Sensing, University of South Florida (IMaRS/USF), Institut de Recherche pour le Développement (IRD), UNEP-WCMC, The World Fish Center, and WRI. The composite data set was compiled from multiple sources, incorporating products from the Millennium Coral Reef Mapping Project prepared by IMaRS/USF and IRD.

Map projection: Lambert Cylindrical Equal-Area; Central Meridian: 160° W

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WORLD RESOURCES INSTITUTE

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Summary for Decision Makers

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Contents

Foreword

As anyone who has spent time around the ocean knows—whether diving, conducting research, or fishing—coral reefs are among the world's greatest sources of beauty and wonder. Home to over 4,000 species of fish and 800 types of coral, reefs offer an amazing panorama of underwater life.

Coral reefs supply a wide range of important benefits to communities around the world. From the fisherman in Indonesia or Tanzania who relies on local fish to feed his family, to the scientist in Panama who investigates the medicinal potential of reef-related compounds, reefs provide jobs, livelihoods, food, shelter, and protection for coastal communities and the shorelines along which they live.

Unfortunately, reefs today are facing multiple threats from many directions. 2010 was one of the warmest years on record, causing widespread damage to coral reefs. Warmer oceans lead to coral bleaching, which is becoming increasingly frequent around the globe—leaving reefs, fish, and the communities who depend on these resources at great risk. No one yet knows what the long-term impacts of this bleaching will be. But, if the ocean's waters keep warming, the outlook is grim.

Against this backdrop, the World Resources Institute has produced *Reefs at Risk Revisited,* a groundbreaking new analysis of threats to the world's coral reefs. This report builds on WRI's seminal 1998 report, *Reefs at Risk,* which served as a call to action for policymakers, scientists, nongovernmental organizations, and industry to confront one of the most pressing, though poorly understood, environmental issues. That report played a critical role in raising awareness and driving action, inspiring countless regional projects, stimulating greater funding, and providing motivation for new policies to protect marine areas and mitigate risks.

However, much has changed since 1998—including an increase in the world's population, and with it greater consumption, trade, and tourism. Rising economies in the developing world have led to more industrialization, more agricultural development, more commerce, and more and more greenhouse gas emissions. All of these factors have contributed to the need to update and refine the earlier report.

The latest report builds on the original *Reefs at Risk* in two important ways. First, the map-based assessment uses the latest global data and satellite imagery, drawing on a reef map that is 64 times more detailed than in the 1998 report. The second major new component is our greater understanding of the effects of climate change on coral reefs. As harmful as overfishing, coastal development, and other local threats are to reefs, the warming planet is quickly becoming the chief threat to the health of coral reefs around the world. Every day, we dump 90 million tons of carbon pollution into the thin shell of atmosphere surrounding our planet—roughly one-third of it goes into the ocean, increasing ocean acidification.

Coral reefs are harbingers of change. Like the proverbial “canary in the coal mine,” the degradation of coral reefs is a clear sign that our dangerous overreliance on fossil fuels is already changing Earth’s climate. Coral reefs are currently experiencing higher ocean temperatures and acidity than at any other time in at least the last 400,000 years. If we continue down this path, all corals will likely be threatened by mid-century, with 75 percent facing high to critical threat levels.

Reefs at Risk Revisited reveals a new reality about coral reefs and the increasing stresses they are under. It should serve as a wake-up call for policymakers and citizens around the world. By nature, coral reefs have proven to be resilient and can bounce back from the effects of a particular threat. But, if we fail to address the multiple threats they face, we will likely see these precious ecosystems unravel, and with them the numerous benefits that people around the globe derive from these ecological wonders. We simply cannot afford to let that happen.

HON. AL GORE
Former Vice President of the United States


PHOTO: DAVID BURDICK

Acknowledgments

The *Reefs at Risk Revisited* project would not have been possible without the encouragement and financial support provided by The Roy Disney Family Foundation, The David and Lucile Packard Foundation, Netherlands Ministry of Foreign Affairs, The Chino Cienega Foundation, U.S. Department of the Interior, U.S. Department of State, the International Coral Reef Initiative, U.S. National Oceanic and Atmospheric Administration, the National Fish and Wildlife Foundation, The Tiffany & Co. Foundation, The Henry Foundation, The Ocean Foundation, Project AWARE Foundation, and The Nature Conservancy.

Reefs at Risk Revisited is the result of a more than two year effort, involving a broad network of partners. The World Resources Institute gratefully acknowledges the many partners and colleagues who contributed to this project. (See inside front cover for full institutional names.) The full list of contributors can be found at **www.wri.org/reefs/acknowledgments.**

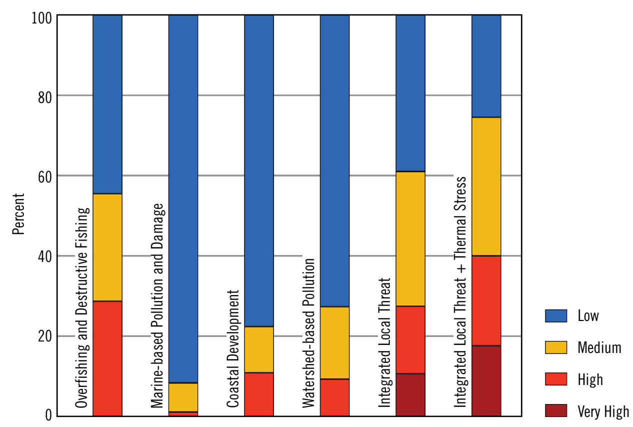
ACRONYMS

CO_2	Carbon dioxide
COTS	Crown-of-thorns starfish
DHW	Degree heating week
FAO	Food and Agriculture Organization of the United Nations
GCRMN	The Global Coral Reef Monitoring Network
GDP	Gross domestic product
GIS	Geographic Information System
ICRI	International Coral Reef Initiative
IMaRS/USF	Institute for Marine Remote Sensing, University of South Florida
IPCC	Intergovernmental Panel on Climate Change
IRD	Institut de Recherche pour le Développement
IUCN	International Union for Conservation of Nature
LDC	Least developed country
LMMAs	Locally managed marine areas
MPAs	Marine protected areas
MARPOL	International Convention for the Prevention of Pollution from Ships
NASA	U.S. National Aeronautics and Space Administration
NGOs	Nongovernmental organizations
NOAA	U.S. National Oceanic and Atmospheric Administration
ppm	Parts per million
sq km	Square kilometers
SST	Sea surface temperature
TNC	The Nature Conservancy
UNEP-WCMC	United Nations Environment Programme-World Conservation Monitoring Centre
UNFCCC	United Nations Framework Convention on Climate Change
WDPA	World Database of Protected Areas
WRI	World Resources Institute
WWF	World Wildlife Fund

Key Findings

1. **The majority of the world's coral reefs are threatened by human activities.**
   - More than 60 percent of the world's reefs are under immediate and direct threat from local sources —such as overfishing and destructive fishing, coastal development, watershed-based pollution, or marine-based pollution and damage (see map inside front cover).
   - Approximately 75 percent of the world's coral reefs are rated as threatened when local threats are combined with thermal stress. This reflects recent rising ocean temperatures, which are linked to the widespread weakening and mortality of corals due to mass coral bleaching (Figure ES-1, column 6).
   - Thirty percent of the world's reefs have experienced an increase in threats in the 10 years since the first *Reefs at Risk* analysis (1998).

FIGURE ES-1. REEFS AT RISK WORLDWIDE BY CATEGORY OF THREAT



Notes: Individual local threats are categorized as low, medium, and high. These threats are integrated to reflect cumulative stress on reefs. Reefs with multiple high individual threat scores can reach the very high threat category, which only exists for integrated threats. The fifth column, integrated local threats, reflects the four local threats combined. The right-most column also includes thermal stress during the past ten years. This figure summarizes current threats; future warming and acidification are not included.

2. **Changes in climate and ocean chemistry represent significant and growing threats.**
   - *Coral bleaching*: Rising greenhouse gas emissions are warming the atmosphere and, as a result, increasing sea surface temperatures. Mass coral bleaching, a stress response to warming waters that can weaken or kill coral, has occurred in every coral reef region. It is becoming more frequent as higher temperatures recur.
   - *Ocean acidification*: Increasing carbon dioxide in the ocean is altering ocean chemistry and making the water more acidic, which can slow coral growth rates and, ultimately, weaken coral skeletons.
   - If local and global threats are left unchecked, the percentage of threatened reefs will increase to more than 90 percent by 2030 and to nearly all reefs by 2050.

3. **Reefs are highly valuable to people around the world, providing livelihoods, food, protection, recreation, and even pharmaceuticals.**
   - *People*: Worldwide, approximately 850 million people live within 100 km of coral reefs, many of whom are likely to derive some benefits from the ecosystem services the reefs provide. More than 275 million people reside in the direct vicinity of reefs (within 30 km of reefs and less than 10 km from the coast), where livelihoods are most likely to depend on reefs and related resources.
   - *Food:* A healthy, well-managed reef in the Indian or Pacific Oceans can yield between five and fifteen tons of seafood per square kilometer (sq km) per year in perpetuity. Reef-associated fish species are an important source of protein and contribute about one-quarter of the total fish catch in developing countries.
   - *Shorelines*: Coral reefs protect 150,000 km of shorelines in more than 100 countries and territories—helping defend against storms and erosion.
   - *Tourism: A*t least ninety-four countries and territories benefit from tourism related to reefs; in twenty-three of these, reef tourism accounts for more than 15 percent of gross domestic product (GDP).

- *Disease prevention*: Many reef-dwelling species harbor the potential for forming life-saving pharmaceuticals, including treatments for cancer, HIV, malaria, and other diseases.

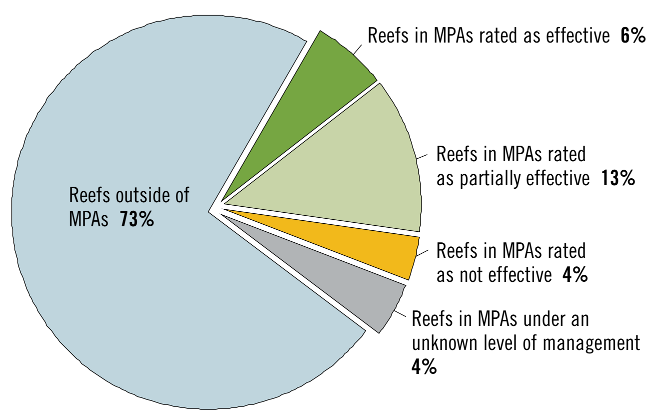
4. Degradation and loss of reefs will result in significant social and economic impacts.

- Of the twenty-seven countries and territories most vulnerable to coral reef degradation and loss, nineteen (70 percent) are small-island states.
- Nine countries—Haiti, Grenada, Philippines, Comoros, Vanuatu, Tanzania, Kiribati, Fiji, and Indonesia—are most vulnerable to the effects of coral reef degradation. Reefs in these countries face high threat levels, and coastal residents are highly dependent on reefs and have limited capacity to adapt to reef loss.

5. While more than one-quarter of the world's coral reefs are within protected areas, many of these are ineffective or only offer partial protection.

- Approximately 27 percent of the world's coral reefs are within marine protected areas (MPAs), a higher proportion than for any other marine habitat. Of the reef area inside MPAs, more than half is in Australia.
- Based on our compilation of expert-based ratings of management effectiveness, we find only 6 percent of the world's coral reefs are located in effectively managed MPAs and 13 percent are in areas rated as only partially effective for achieving management goals (Figure ES-2).
- MPA coverage tends to be in areas of lower threat, and thus less frequently reduces threats in areas of heavy human pressure.

FIGURE ES-2. CORAL REEFS BY MARINE PROTECTED AREA COVERAGE AND EFFECTIVENESS LEVEL



Note: The global area of coral reefs is 250,000 sq km (which represents 100% on this chart), including 67,350 sq km (27%) inside MPAs.

6. Policy makers, government officials, resource managers, and others need to take action to protect reefs, and to manage risks locally and globally.

- Reefs are resilient—they can recover from coral bleaching and other impacts, particularly if other threats are low.
- Reducing local pressures on reefs—overfishing, coastal development, and pollution— is the best way to "buy time" for reefs. Doing so would help reefs survive warming seas and ocean acidification while the global community works to reduce greenhouse gas emissions, particularly carbon dioxide.

Section 1. INTRODUCTION

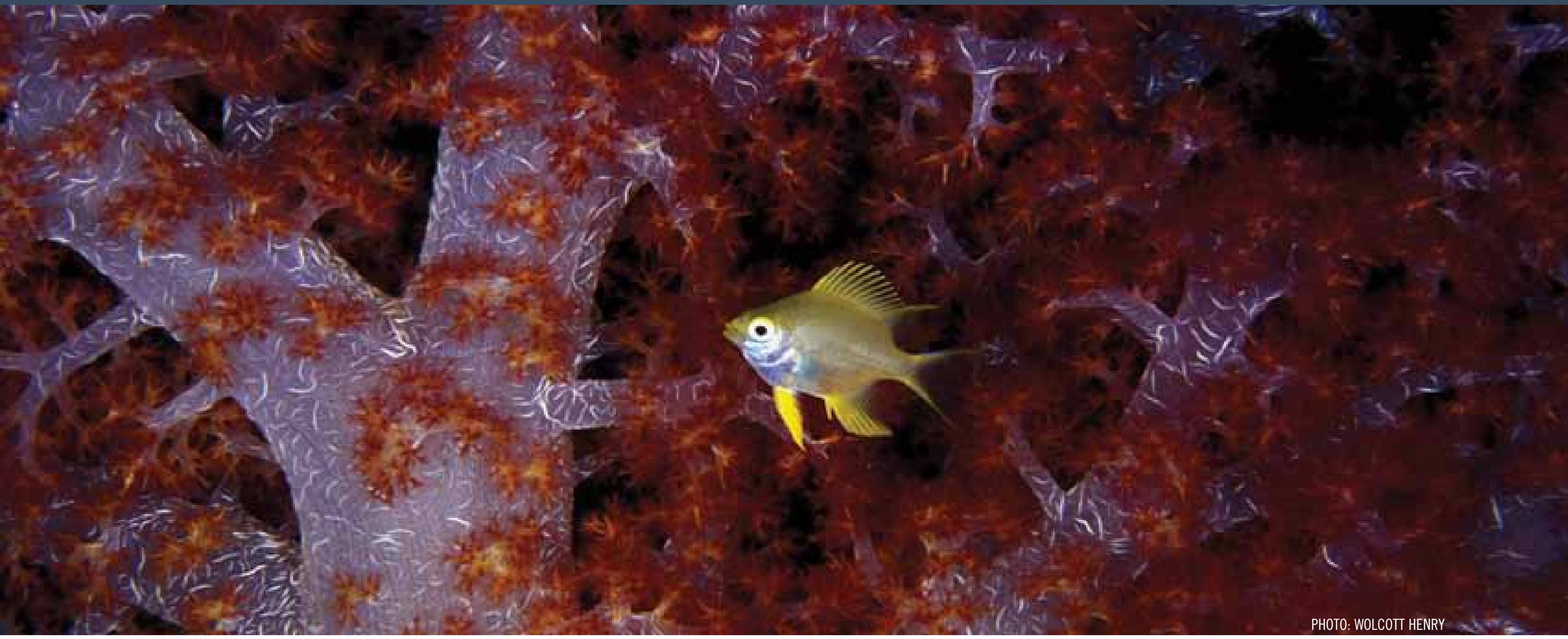


PHOTO: WOLCOTT HENRY

CORAL REEFS: VALUABLE BUT VULNERABLE

Coral reefs are among the most biologically rich and productive ecosystems on earth. They provide critical benefits to millions of people living near the coast. They are important sources of food and income, serve as nurseries for commercial fish species, attract divers and snorkelers from around the world, generate the sand on tourist beaches, and protect shorelines from the ravages of storms.

However, coral reefs face a wide and intensifying array of threats—including overfishing, coastal development, agricultural runoff, and shipping. In addition, the global threat of climate change has begun to compound these more local threats in multiple ways.

Warming seas have already caused widespread damage to reefs. High temperatures drive a stress response called coral bleaching, in which corals lose their colorful symbiotic algae, exposing their white skeletons and leaving them more vulnerable to disease and death. This phenomenon is projected to intensify in coming decades.

In addition, increasing carbon dioxide (CO_2) emissions are slowly causing the world's oceans to become more acidic. Ocean acidification reduces coral growth rates and, if unchecked, could reduce reefs' ability to maintain their physical structure.

The combination of local threats plus global threats from warming and acidification leads to increasingly degraded reefs. Signs include reduced areas of living coral, increased algal cover, reduced species diversity, and lower fish abundance. Degradation of coral is often accelerated by other local impacts from storms, infestations, and diseases.

Despite widespread recognition that coral reefs around the world are seriously threatened, information regarding which threats affect particular reefs is limited, hampering conservation efforts. Researchers have studied only a small percentage of the world's reefs; an even smaller percentage has been monitored over time. To help fill this knowledge gap, in 1998 the World Resources Institute (WRI) initiated its *Reefs at Risk* series, which seeks to develop an understanding of the location and spread of threats to coral reefs worldwide, as well as illustrate the links between human activities, human livelihoods, and coral reef ecosystems. With this knowledge, it becomes much easier to set an effective agenda for reef conservation.

PURPOSE AND GOAL OF REEFS AT RISK REVISITED

Under the *Reefs at Risk Revisited* project, WRI and its partners have developed a new, high-resolution assessment of the status of and threats to the world's coral reefs. This information is intended to raise awareness about the location and severity of threats to coral reefs and catalyze changes in policy and practice that could safeguard coral reefs and the benefits they provide to future generations.

Reefs at Risk Revisited is a high-resolution update of the original 1998 global analysis entitled *Reefs at Risk: A Map-Based Indicator of Threats to the World's Coral Reefs.*[1] *Reefs at Risk Revisited* uses a global map of coral reefs at 500-m resolution, which is sixty-four times more detailed than the 4-km map in the 1998 analysis. New data on threats are also much improved, with many sources detailing information at 1 km resolution, which is sixteen times more detailed than that used in the 1998 analysis (Box 1.2).

Like the original *Reefs at Risk*, this study evaluates threats to coral reefs from a wide range of human activities. For the first time, it also includes an assessment of climate-related threats to reefs. In addition, *Reefs at Risk Revisited* includes a global assessment of the vulnerability of nations and territories to coral reef degradation, based on their dependence on coral reefs and their capacity to adapt.

WRI led the *Reefs at Risk Revisited* analysis in collaboration with a broad partnership of more than twenty-five research, conservation, and educational organizations. Partners have provided data, offered guidance on the analytical approach, contributed to the report, and served as critical reviewers of the maps and findings (see **www.wri.org/reefs/acknowledgments** for a full list of contributors).

The outputs of *Reefs at Risk Revisited*—the report, maps, and spatial data sets—will be valuable to many users, including marine conservation practitioners, resource managers, policy makers, educators, and students. These materials are available on the *Reefs at Risk Revisited* website at **www.wri.org/reefs**.

CORAL REEFS: RAIN FORESTS OF THE SEA

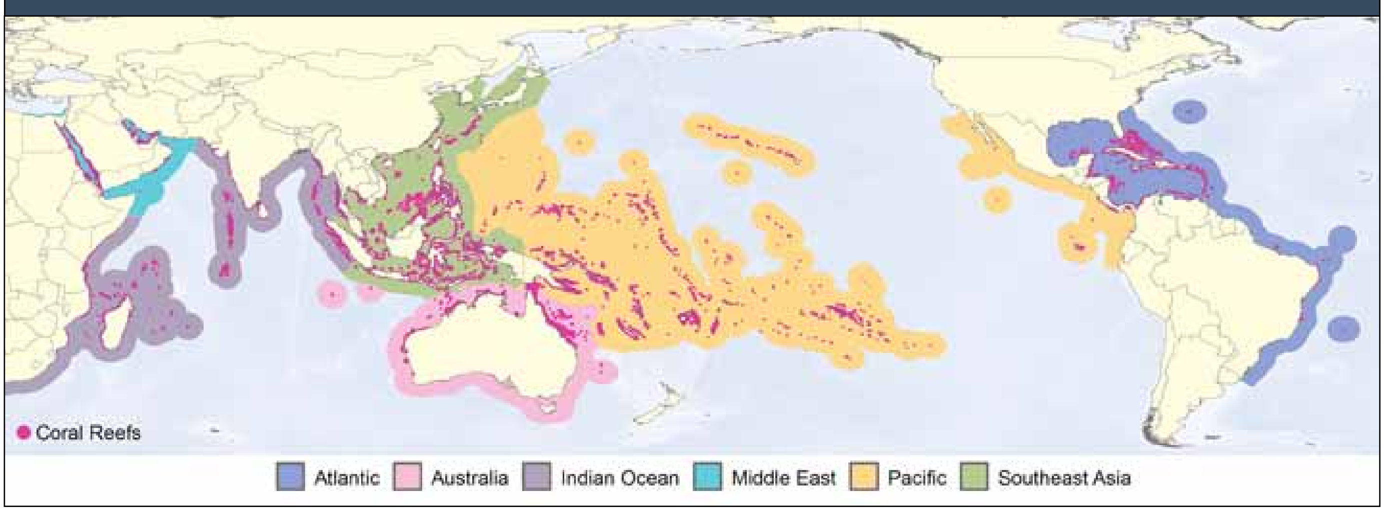
Coral reefs are one of the most productive and biologically rich ecosystems on earth. They extend over about 250,000 sq km of the ocean—less than one-tenth of one percent of the marine environment—yet they may be home to 25 percent of all known marine species.[2] About 4,000 coral reef-associated fish species and 800 species of reef-building corals have been described to date,[3] though these numbers are dwarfed by the great diversity of other marine species associated with coral reefs, including sponges, urchins, crustaceans, mollusks, and many more (Box 1.1). Figure 1.1 shows the distribution of the world's coral reefs by the regions depicted in Map 1.1.

WHY REEFS MATTER

Dynamic and highly productive, coral reefs are not only a critical habitat for numerous species, but also provide essential ecosystem services upon which millions of people depend.

- **Food and livelihoods:** One-eighth of the world's population—roughly 850 million people—live within 100 km of a coral reef and are likely to derive some benefits

MAP 1.1. MAJOR CORAL REEF REGIONS OF THE WORLD

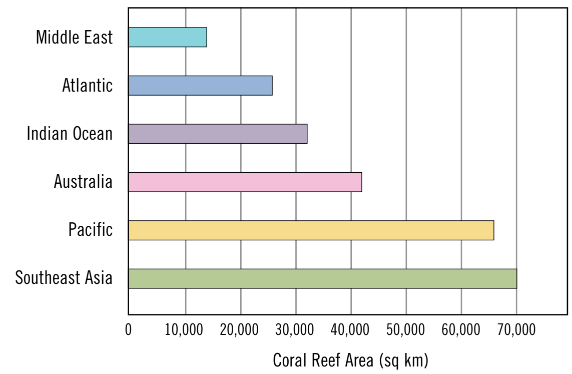


BOX 1.1. WHAT IS A CORAL REEF?

Coral reefs are physical structures built by the actions of many tiny coral animals that live in large colonies and lay down communal limestone skeletons. Over millennia, the combined mass of skeletons build up into huge reefs, some of which are visible from space. There are some 800 species of reef-building corals and they have exacting requirements, needing bright, clear, and warm waters. The individual coral animals, known as polyps, have a tubular body and central mouth ringed by stinging tentacles, which can capture food. Living within their body tissues are microscopic algae (zooxanthellae), which need sunlight to survive. The algae convert light into sugars; this energy helps to sustain their coral hosts. These same algae also provide the corals with their vibrant colors.

The complex three-dimensional surface of the reef provides a home to myriad other species. Some 4,000 fish are found here (approximately one-quarter of all marine fish species), along with a vast array of other life forms—mollusks, crustaceans, urchins, starfish, sponges, tube-worms and many more. There are perhaps a million species found in a habitat that covers a total of about 250,000 sq km[4] (roughly the area of the United Kingdom).

FIGURE 1.1. DISTRIBUTION OF CORAL REEFS BY REGION

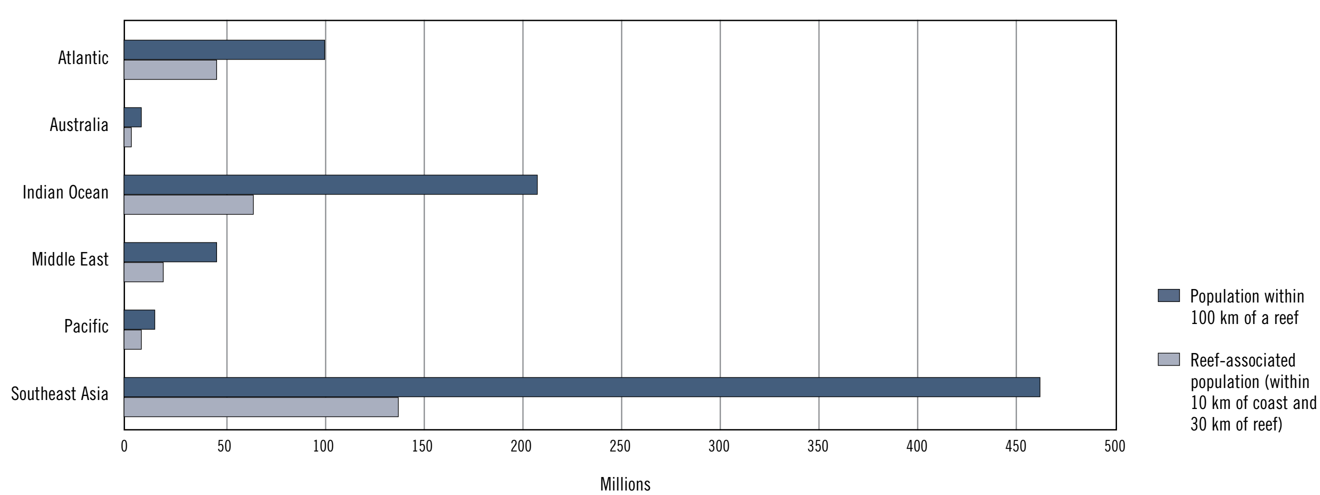


Note: Area of coral reefs (sq km) for each coral reef region of the world. The regions are shown in Map 1.1.

Sources: IMaRS/USF, IRD, NASA, UNEP-WCMC, WorldFish Center, WRI 2011.

from the ecosystem services that coral reefs provide (Figure 1.2). More than 275 million of those people live very close to reefs (less than 10 km from the coast and within 30 km of reefs.)[5] Many live in developing countries and island nations, where dependence on coral reefs for food and livelihoods is high. Reef-associated fish species are an important source of protein, contributing about one-quarter of the total fish catch on average in developing countries.[6] A healthy, well-managed reef in the Indian or Pacific Oceans can yield between five and fifteen tons of seafood per square kilometer per year, while reefs in the Atlantic and Caribbean typically have lower yields.[7,8]

FIGURE 1.2. NUMBER OF PEOPLE LIVING NEAR CORAL REEFS IN 2007



Source: WRI, using Landscan 2007 population data.

BOX 1.2. METHOD FOR ANALYZING THREATS TO REEFS

Human pressures on coral reefs are categorized throughout the report as either "local" or "global" in origin. These categories are used to distinguish between threats from human activities near reefs, which have a direct and relatively localized impact, versus threats that affect reefs indirectly, through human impacts on the global climate and ocean chemistry.

Local threats addressed in this analysis:

- Coastal development, including coastal engineering, runoff from coastal construction, sewage discharge, and impacts from unsustainable tourism.
- Watershed-based pollution, focusing on erosion and nutrient fertilizer runoff from agriculture delivered by rivers to coastal waters.
- Marine-based pollution and damage, including solid waste, nutrients, toxins from oil and gas installations and shipping, and physical damage from anchors and ship groundings.
- Overfishing and destructive fishing, including unsustainable harvesting of fish or invertebrates, and damaging fishing practices such as the use of explosives or poisons.

Global threats addressed in this analysis:

- Thermal stress, including warming sea temperatures, which can induce widespread or "mass" coral bleaching.
- Ocean acidification driven by increased CO_2 concentrations, which can reduce coral growth rates.

The report modeled each of the four local threats separately, and subsequently combined them into the *Reefs at Risk* integrated local threat index. For each local threat, an indicator was developed using data reflecting various "stressors," such as human population density and infrastructure features (including the location and size of cities, ports, and hotels), as well as more complex modeled estimates such as sediment input from rivers. The threat diminishes with distance from each stressor. Thresholds for low, medium, and high threats were developed using available information on observed impacts to coral reefs.

Local threats were modeled at WRI; data and models for global threats were obtained from external climate experts. Climate-related stressors are based on data from satellite observations of sea surface temperature, coral bleaching observations, and modeled estimates of future ocean warming and acidification. Input from coral reef scientists and climate change experts contributed to the selection of thresholds for the global threats.

Modeled outputs were further tested and calibrated against available information on coral reef condition and observed impacts on coral reefs. All threats were categorized as low, medium, or high, both to simplify the findings and to enable comparison between findings for different threats. In the presentation of findings, "threatened" refers to coral reefs classified at medium or high threat.

The analysis method is of necessity a simplification of human activities and complex natural processes. The model relies on available data and predicted relationships, but cannot capture all aspects of the dynamic interactions among people, climate, and coral reefs. Climate change science, in particular, is a relatively new field in which the complex interactions between reefs and their changing environment are not yet fully understood. The threat indicators gauge current and potential risks associated with human activities, climate change, and ocean acidification. A strength of the analysis lies in its use of globally consistent data sets to develop global indicators of human pressure on coral reefs. We purposefully use a conservative approach to the modeling, in which thresholds for threat grades are set at reasonably high levels to avoid exaggeration.

Full technical notes, including data sources and threat category thresholds, and a list of data contributors are available online at www.wri.org/reefs.

- **Tourism:** Coral reefs are vital to tourism interests in many tropical countries. They attract divers, snorkelers, and recreational fishers, and also provide much of the white sand for beaches. More than one hundred countries and territories benefit from tourism associated with coral reefs, and tourism contributes more than 30 percent of export earnings in more than twenty of these countries.[9,10]

- **Treatments for disease:** Many reef-dwelling species have developed complex chemical compounds, such as venoms and chemical defenses, to aid their survival in these highly competitive habitats. Some of these compounds have the potential to form the basis of life-saving pharmaceuticals. Explorations into the medical application of reef-related compounds to date include treatments for cancer, HIV, malaria, and other diseases.[11] Since only a small portion of reef life has been sampled, there is still vast potential for new pharmaceutically valuable discoveries.[11]

- **Shoreline protection:** Beyond their biological value, the physical structures of coral reefs protect an estimated 150,000 km of shoreline in more than one hundred countries and territories.[12] Reefs dissipate wave energy, reducing routine erosion and lessening inundation and wave damage during storms. This function protects human settlements, infrastructure, and valuable coastal ecosystems such as seagrass meadows and mangrove forests.[13,14] Some countries—especially low-lying atolls such as the Maldives, Kiribati, Tuvalu, and the Marshall Islands—have been built entirely by coral reefs and would not exist but for their protective fringe.

PHOTO: WOLCOTT HENRY

Section 2. LOCAL AND GLOBAL THREATS TO CORAL REEFS

PHOTO: MARK SPALDING

Despite their importance, coral reefs face unprecedented threats throughout most of their range. Some threats are highly visible and occur directly on reefs. For example, levels of fishing are currently unsustainable on a large proportion of the world's reefs,[8,15] and have led to localized extinctions of certain fish species, collapses and closures of fisheries, and marked ecological changes.[16-18] Many other threats are the result of human activities that occur far from the reefs. Forest clearing, crop cultivation, intensive livestock farming, and poorly planned coastal development have increased sediment and nutrient runoff into coastal waters, smothering some corals and contributing to overgrowth by algae.

Beyond these extensive and damaging local-scale impacts, reefs are increasingly at risk from the global threats associated with rising concentrations of greenhouse gases in the atmosphere. Even in areas where local stresses on reefs are relatively minimal, warming seas have caused widespread damage to reefs through mass coral bleaching, which occurs when corals become stressed and lose, en masse, the zooxanthellae that live within their tissues and normally provide their vibrant colors. Increasing concentrations of carbon dioxide (CO_2) in the atmosphere, the result of deforestation and the burning of fossil fuels, are also changing the chemistry of ocean waters. About 30 percent of the CO_2 emitted by human activities is absorbed into the surface layers of the oceans, where it reacts with water to form carbonic acid.[19] This subtle acidification has profound effects on the chemical composition of seawater, especially on the availability and solubility of mineral compounds such as calcite and aragonite, needed by corals and other organisms to build their skeletons.[20-23] Initially these changes to ocean chemistry are expected to slow the growth of corals, and may weaken their skeletons. Continued acidification will eventually halt all coral growth and begin to drive a slow dissolution of carbonate structures such as reefs.[24]

It is rare for any reef to suffer only a single threat. More often the threats are compounded. For instance, overfishing eliminates a key herbivore, while runoff from agriculture supplies nutrients that cause a bloom in macroalgae, reducing the abundance or impairing the growth of coral, ultimately reducing the competitive ability of coral communities. A reef left vulnerable by one threat can be pushed to ecological collapse by the addition of a second.[25,26]

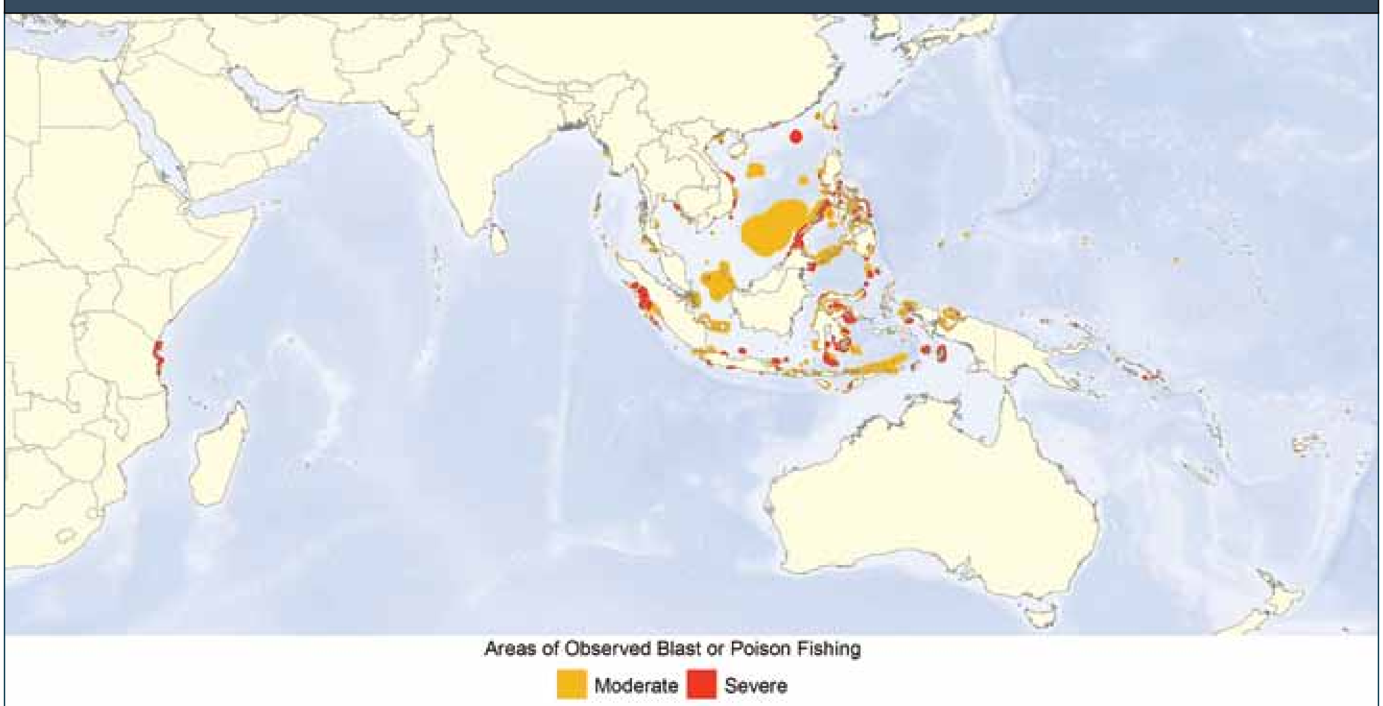
The ecological imbalance caused by these threats can leave corals more exposed to other, more "natural" types of threats. For instance, crown-of-thorns starfish (COTS), which prey on corals, occur naturally on many reefs, but outbreaks of COTS—that is, sudden, significant increases in density—are now occurring with increased frequency, often in conjunction with other threats or following coral bleaching events. Additionally, corals that are already under stress are more vulnerable to disease. Diseases are a natural feature in any ecosystem, but in terms of both prevalence and geographic distribution, coral diseases have increased in recent years.[27] The drivers are still not clearly understood, but it is probable that corals have become more susceptible to disease as a result of degraded water quality and warming seas.[28] There is strong evidence that disease outbreaks have followed coral bleaching events.[29] Given that diseases are often more problematic where corals are already under stress, management efforts such as protecting water quality, preserving functional diversity, and reducing other threats to reefs may help lessen the occurrence and impacts of disease.[30] Such efforts to reduce local threats also promote resilience in coral reefs, thus increasing the likelihood of recovery after coral bleaching.[31,32]

PRESENT THREATS TO CORAL REEFS

Our analysis indicates that more than 60 percent of the world's reefs are under immediate and direct threat from one or more local sources —overfishing and destructive fishing, coastal development, watershed-based pollution, or marine-based pollution and damage (Figure 2.1, Box 2.1 and map inside front cover).

- Of local pressures on coral reefs, **overfishing—**including destructive fishing—is the most pervasive immediate threat, affecting more than 55 percent of all reefs.
- **Destructive fishing—**the use of explosives and poisons to kill or capture fish—is common throughout Southeast Asia, as well as certain parts of the western Pacific and eastern Africa (Map 2.1).
- **Coastal development and watershed-based pollution** each threaten about 25 percent of reefs.
- **Marine-based pollution and damage** from ships is widely dispersed, threatening about 10 percent of reefs.

MAP 2.1. GLOBAL OBSERVATIONS OF BLAST AND POISON FISHING

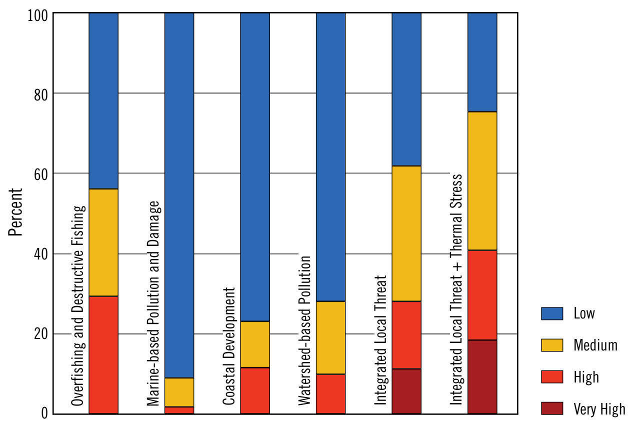


Fishing with explosives to kill or stun fish devastates the coral process. Although illegal in many countries, blast (or dynamite) fishing remains a persistent threat, particularly in Southeast Asia and East Africa, and is increasing in parts of the Western Pacific. Poison fishing is also destructive to corals. This practice typically involves using cyanide to stun and capture fish live for the lucrative live reef food fish or aquarium fish markets. The poison can bleach corals and kill polyps. Fishers often break corals to extract the stunned fish.

Note: Areas of threat shown here are based on survey observations and expert opinion.

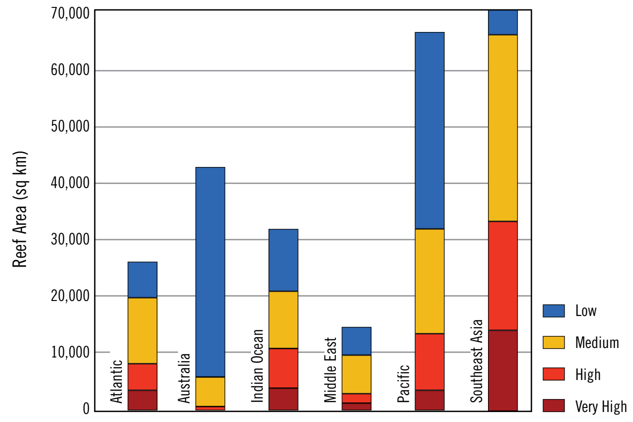
Source: WRI 2011.

FIGURE 2.1. REEFS AT RISK FROM INDIVIDUAL LOCAL THREATS AND ALL THREATS INTEGRATED



Note: The first four columns reflect individual, local threats to the world's coral reefs. The fifth column (integrated local threat) reflects the four local threats combined, while the sixth column also includes past thermal stress.

FIGURE 2.2. REEFS AT RISK FROM INTEGRATED LOCAL THREATS (by area of reef)



Note: Amount of reef area (in sq km) in each region classified by integrated local threat. Further details, including information on past thermal stress, can be seen in the regional breakdowns in Section 3.

Mapping of past thermal stress on coral reefs (1998–2007) suggests that almost 40 percent of coral reefs have experienced water temperatures warm enough to induce severe coral bleaching on at least one occasion since 1998. Approximately 75 percent of the world's coral reefs are rated as threatened when local threats are combined with thermal stress, which reflects the recent impacts of rising ocean temperatures, linked to the widespread weakening and mortality of corals due to mass coral bleaching (Figure 2.1, column 6).

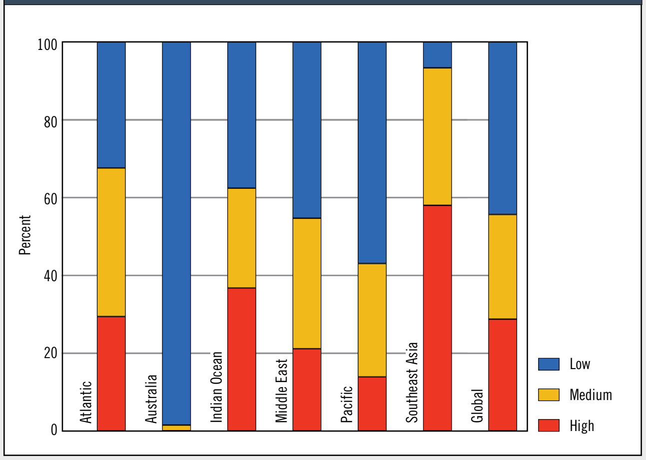
Figure 2.2 and Table 2.1 provide a summary of integrated threats to coral reefs by region. Table 2.1 also includes this information for the fifteen countries and territories with the largest coral reef area.

- The region most affected by local threats is Southeast Asia, where almost 95 percent of reefs are threatened.
- Australia is the region with the lowest percentage of threatened reefs.
- The Pacific, where about half of reefs are threatened, has had the largest increase in threat, compared with 1998 results (Box 2.2).

BOX 2.1. SUMMARY OF LOCAL THREATS TO CORAL REEFS

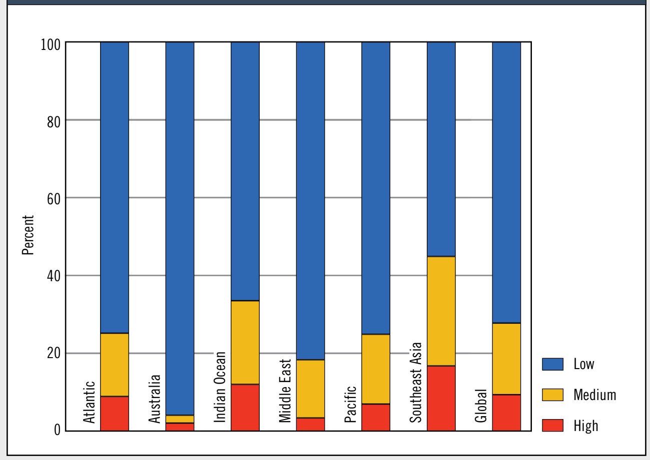
The following figures provide a comparison of local threats by region.

REEFS AT RISK FROM OVERFISHING AND DESTRUCTIVE FISHING



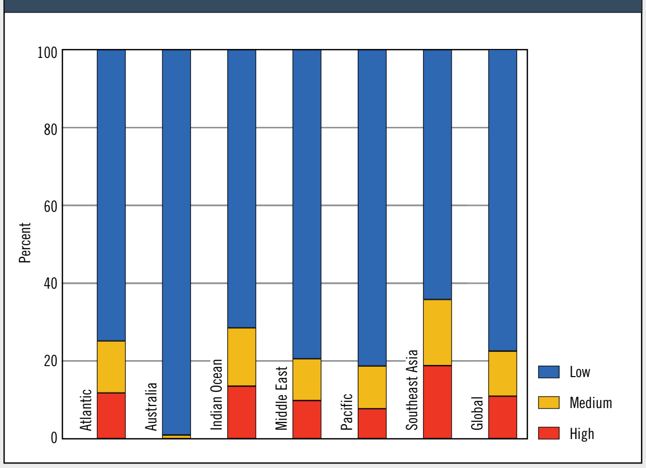
Unsustainable fishing is the most pervasive of all local threats to coral reefs. More than 55 percent of the world's reefs are threatened by overfishing and/or destructive fishing, with nearly 30 percent considered highly threatened. Reefs in Southeast Asia are most at risk, with almost 95 percent of reefs threatened.

REEFS AT RISK FROM WATERSHED-BASED POLLUTION



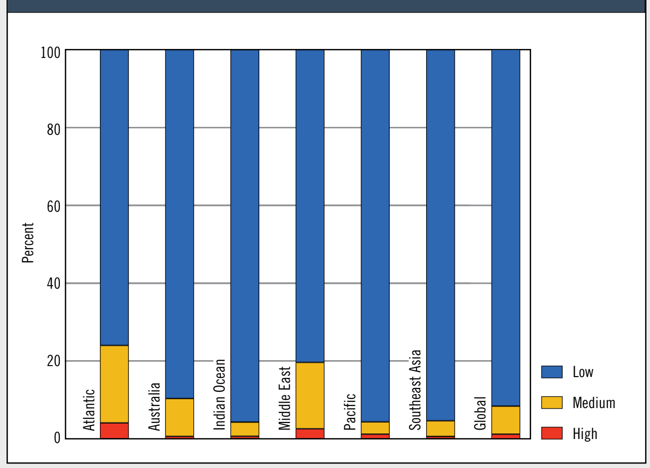
More than one-quarter of the world's reefs are threatened by watershed-based pollution (including nutrient fertilizers, sediment, pesticides, and other polluted runoff from the land), with about 10 percent highly threatened. Southeast Asia surpasses all other regions with 45 percent of reefs threatened.

REEFS AT RISK FROM COASTAL DEVELOPMENT



Development along the coast threatens almost 25 percent of the world's reefs, of which more than 10 percent face a high threat. The largest proportion of threatened reefs are in Southeast Asia, where small islands with densely populated coastlines threaten at least one-third of the region's corals.

REEFS AT RISK FROM MARINE-BASED POLLUTION AND DAMAGE



Marine-based sources of pollution and damage threaten approximately 10 percent of reefs globally, with only about 1 percent at high threat. This pressure is widely dispersed around the globe, emanating from ports and widely distributed shipping lanes. The Atlantic, Middle East, and Australia are the most threatened regions.

TABLE 2.1 INTEGRATED THREAT TO CORAL REEFS BY REGION AND COUNTRIES/TERRITORIES WITH THE HIGHEST CORAL REEF AREA

Region	Reef Area (sq km)	Reef area as percent of global	Integrated Local Threats					Severe thermal stress (1998–2007) (%)	Integrated Local + Thermal Stress Threatened (medium or higher) (%)	Coastal Population (within 30 km of reef)[b] '000	Reef Area in MPAs (%)
			Low (%)	Medium (%)	High (%)	Very High (%)	Threatened (medium or higher) (%)				
Atlantic	25,849	10	25	44	18	13	75	56	92	42,541	30
Australia[a]	42,315	17	86	13	1	<1	14	33	40	3,509	75
Indian Ocean	31,543	13	34	32	21	13	66	50	82	65,152	19
Middle East	14,399	6	35	44	13	8	65	36	76	19,041	12
Pacific	65,972	26	52	28	15	5	48	41	65	7,487	13
Southeast Asia	69,637	28	6	47	28	20	94	27	95	138,156	17
Global	**249,713**	**100**	**39**	**34**	**17**	**10**	**61**	**38**	**75**	**275,886**	**27**
Key Countries											
Australia[a]	41,942	17	86	13	1	<1	14	33	40	3,507	75
Indonesia	39,538	16	9	53	25	12	91	16	92	59,784	25
Philippines	22,484	9	2	30	34	34	98	47	99	41,283	7
Papua New Guinea	14,535	6	45	26	22	7	55	54	78	1,570	4
New Caledonia	7,450	3	63	30	6	<1	37	39	57	210	2
Solomon Islands	6,743	3	29	42	24	6	71	36	82	540	6
Fiji	6,704	3	34	34	21	10	66	54	80	690	32
French Polynesia	5,981	2	76	15	7	2	24	13	33	269	1
Maldives	5,281	2	62	33	4	1	38	74	87	357	<1
Saudi Arabia	5,273	2	39	44	11	6	61	47	73	7,223	1
Federated States of Micronesia	4,925	2	70	23	6	1	30	31	52	100	<1
Cuba	4,920	2	5	71	14	10	95	36	97	4,430	14
Bahamas	4,081	2	40	52	6	2	60	47	79	303	3
Madagascar	3,934	2	13	35	34	18	87	41	94	2,235	2
Hawaii (US)	3,834	2	83	3	6	9	17	11	28	1,209	85

Notes: a. The Australia region includes the Australian territories of Christmas Island and Cocos/Keeling Islands, whereas Australia in "Key Countries" does not.
b. Population statistics represent the human population, both within 10 km of the coast as well as within 30 km of a coral reef.

Sources:
1. **Reef area estimates:** Calculated at WRI based on 500-m resolution gridded data assembled under the *Reefs at Risk Revisited* project from Institute for Marine Remote Sensing, University of South Florida (IMaRS/USF), Institut de Recherche pour le Développement (IRD), UNEP-WCMC, The World Fish Center, and WRI (2011).
2. **Coastal population within 30 km of reef:** Derived at WRI from LandScan population data (2007) and World Vector Shoreline (2004).
3. **Number of MPAs:** Compiled at WRI from the World Database of Protected Areas (WDPA), ReefBase Pacific, The Nature Conservancy, and the Great Barrier Reef Marine Park Authority.

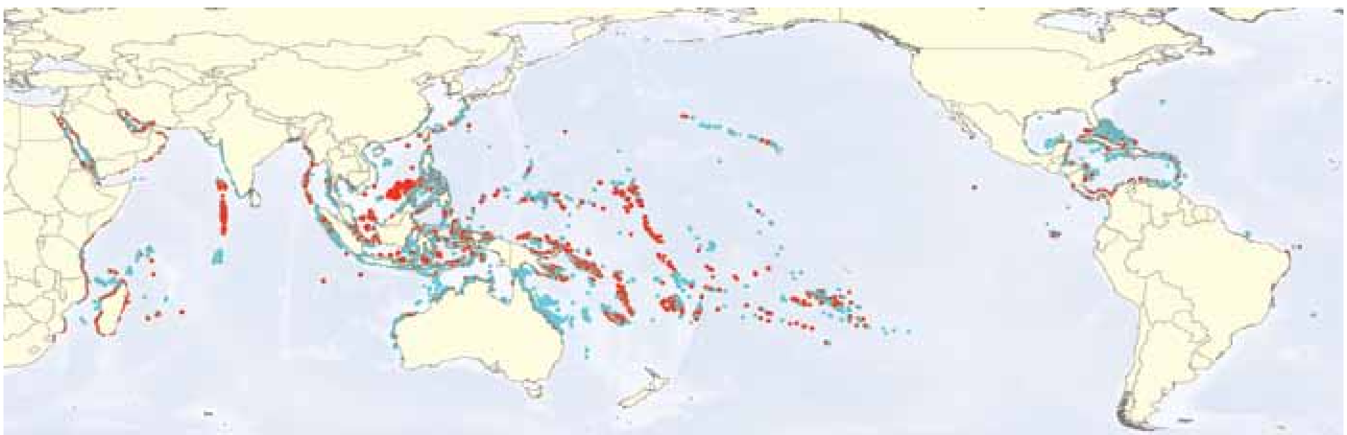
BOX 2.2. TEN YEARS OF CHANGE

Threat levels have increased dramatically over a ten-year period. Thirty percent of the world's coral reefs have experienced an increase in threat in the ten years since the first *Reefs at Risk* analysis (comparing data from 1997 and 2007), with increases in all local threat categories and in all regions

- **By local threat:** Since 1998, there has been an 80 percent increase in the threat from overfishing and destructive fishing, making it the greatest driver of pressure on reefs. This increase has been most significant in the Pacific and Indian Ocean regions. The change is largely due to the growth in coastal populations living near reefs. Pressure on reefs from coastal development, watershed-based pollution, and marine-based pollution and damage has also increased dramatically above 1998 levels.
- **By region:** In the Pacific and Indian oceans, many reefs formerly classified as low threat are now threatened, largely reflecting increased overfishing. In the Middle East, Southeast Asia, and the Atlantic, extensive areas of reefs have been pushed from medium threat into higher threat categories through a combination of local threats. Australia had the smallest increase in local pressure on reefs over the ten-year period.

Map 2.2 shows the locations where the level of integrated local threat to coral reefs increased between 1998 and 2007.

MAP 2.2. CHANGE IN LOCAL THREAT BETWEEN 1998 AND 2007



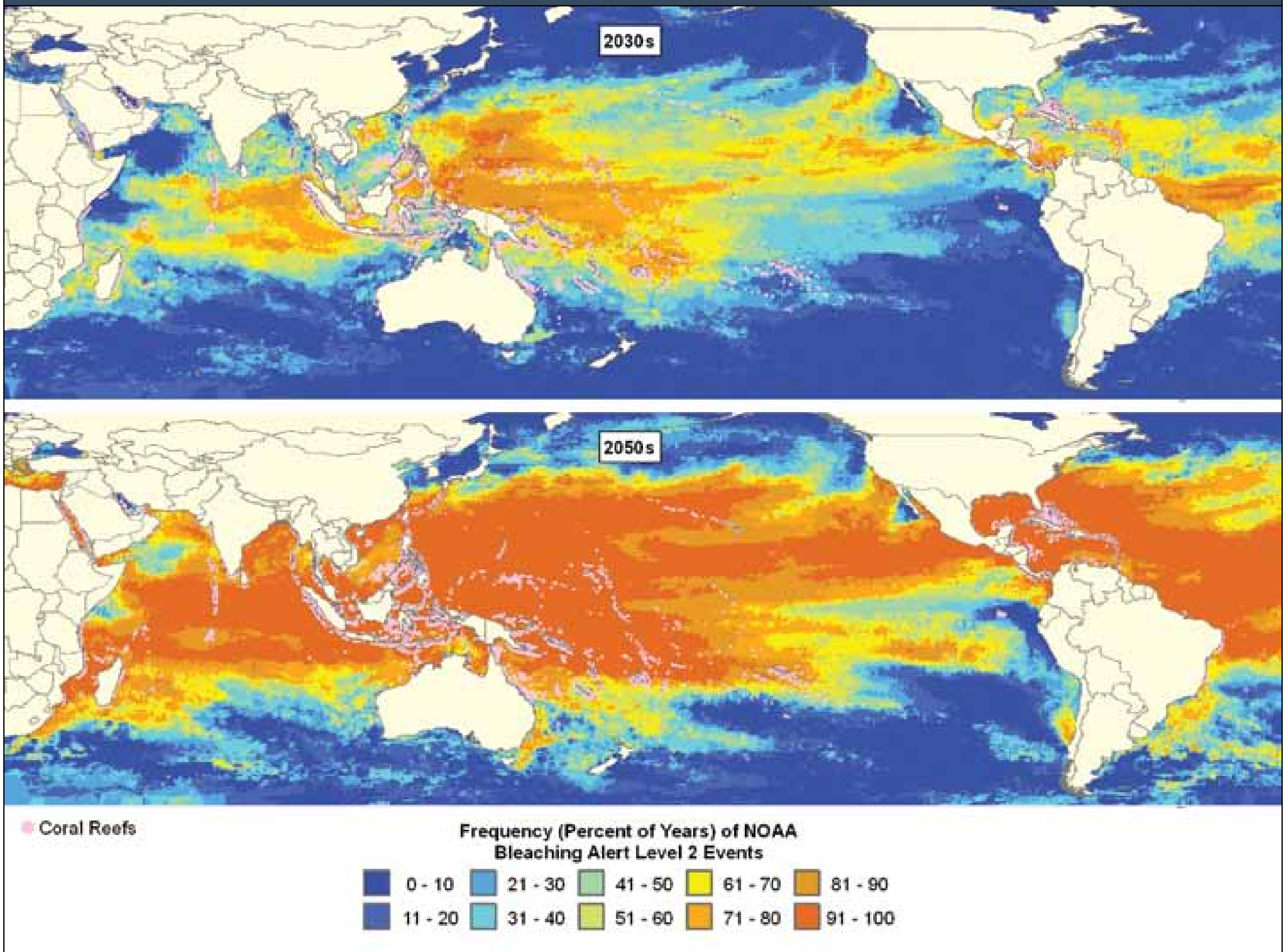
Note: These results use the 1998 modeling methodology and new coral reef data.

FUTURE THREATS TO CORAL REEFS

Population growth, increased demand for fish and agricultural products, and further development along coasts will escalate pressures on coral reefs. However, the single greatest growing threat to coral reefs is the rapid increase in greenhouse gases in the atmosphere, including carbon dioxide (CO_2), methane, nitrous oxide, and halocarbons, with CO_2 contributing the most to both warming and acidification. Since preindustrial times, atmospheric concentrations of all greenhouse gases have increased significantly. In terms of CO_2-equivalents, total greenhouse gas emissions increased by 70 percent between 1970 and 2004.[33]

Mass coral bleaching, a stress response to abnormally warm waters across wide expanses of coral reefs, is becoming more frequent, more intense, and more widespread as water temperatures rise.[34-36] Severe or prolonged bleaching events can kill corals outright, while less extreme events can weaken corals by reducing their growth rates and reproductive potential, and leave them more vulnerable to disease. While corals can recover from bleaching, studies have found that other local stressors—such as pollution—can diminish their resilience.[37-40]

MAP 2.3. FREQUENCY OF FUTURE BLEACHING EVENTS IN THE 2030s AND 2050s



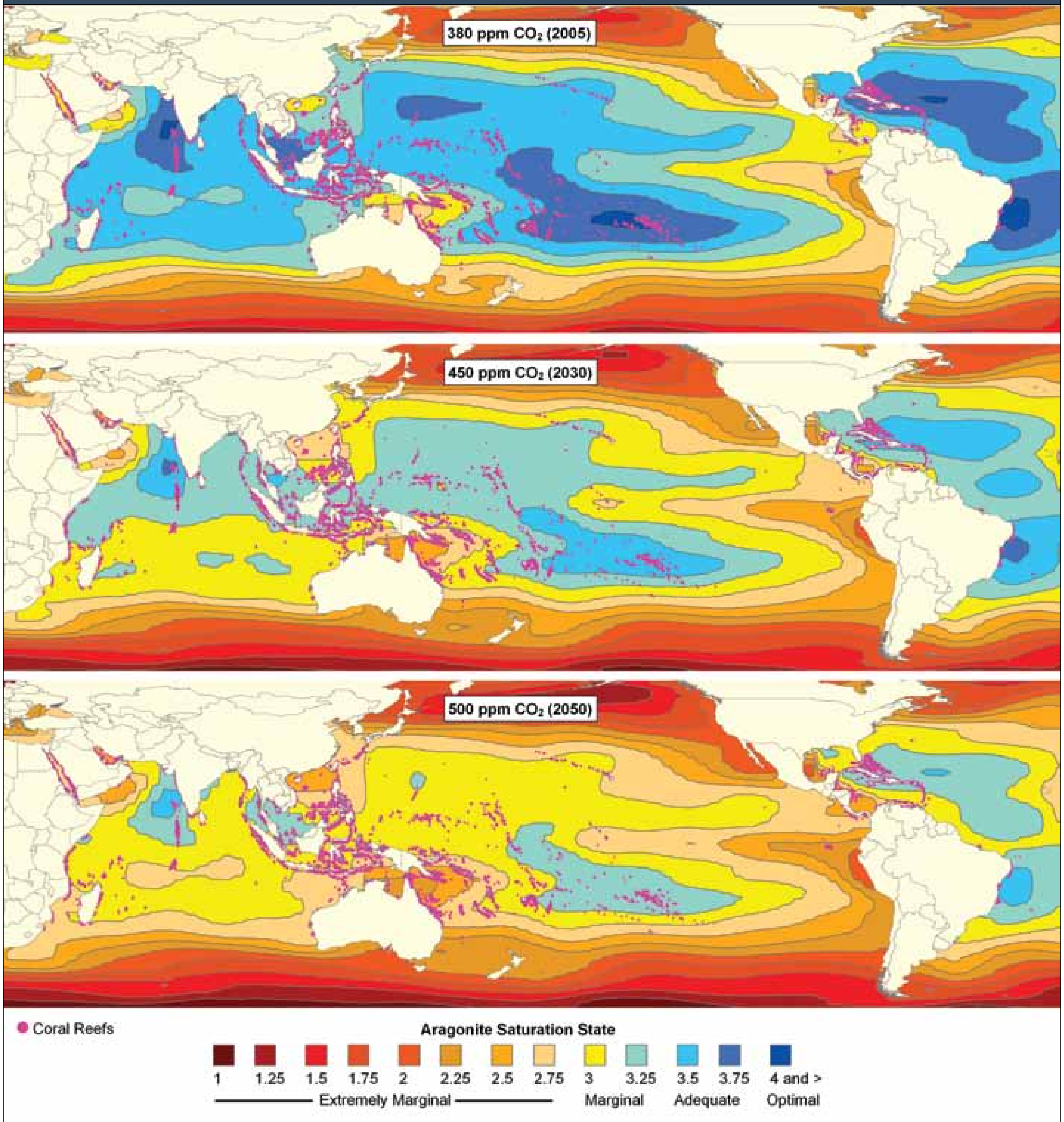
Note: Frequency of future bleaching events in the 2030s and 2050s, as represented by the percentage of years in each decade where a NOAA Bleaching Alert Level 2 is predicted to occur. Predictions are based on an IPCC A1B ("business-as-usual") emissions scenario and adjusted to account for historical temperature variability, but not adjusted by any other resistance or resilience factors.

Source: Adapted from S.D. Donner. 2009. "Coping with Commitment: Projected thermal stress on coral reefs under different future scenarios." *PLoS ONE* 4(6): e5712.

Under a "business-as-usual" emissions scenario, our projections suggest that roughly half of the world's reefs will experience thermal stress sufficient to induce severe bleaching in at least five out of ten years during the 2030s. During the 2050s, this percentage is expected to grow to more than 95 percent (Map 2.3). These projections assume that greenhouse gas emissions continue on current trajectories and local threats are not addressed. Although coral reefs can recover from infrequent and mild bleaching, this degree of high, regular stress presents a significant risk of irreversible damage.

In addition, increasing CO_2 emissions are dissolving into the oceans and changing the chemical composition of seawater. Increased CO_2 elevates the acidity of seawater and reduces the saturation state of aragonite, the mineral corals use to build their skeletons. Increased acidity means less aragonite available to corals, meaning slower coral growth. The best available modeling suggests that by 2030, fewer than half of the world's reefs will be in areas where aragonite levels are adequate for coral growth; that is, where the aragonite saturation state is 3.25 or higher. By 2050, only about 15 percent of reefs will be in areas where aragonite levels are adequate for growth (Map 2.4).

MAP 2.4. THREAT TO CORAL REEFS FROM OCEAN ACIDIFICATION IN THE PRESENT, 2030, AND 2050



Note: Estimated aragonite saturation state for CO_2 stabilization levels of 380 ppm, 450 ppm, and 500 ppm, which correspond approximately to the years 2005, 2030, and 2050 under the IPCC A1B (business-as-usual) emissions scenario.

Source: Adapted from Cao, L. and K. Caldeira. 2008. "Atmospheric CO_2 Stabilization and Ocean Acidification." *Geophysical Research Letters* 35: L19609.

THREAT IN 2030

By the 2030s, our estimates predict:

- More than 90 percent of the world's reefs will be threatened by local human activities, warming, and acidification, with nearly 60 percent facing high, very high, or critical threat levels.
- Thirty percent of reefs will shift from low threat to medium or higher threat specifically due to climate or ocean chemistry changes.
- An additional 45 percent of reefs that were already impacted by local threats will shift to a higher threat level by the 2030s due to climate or ocean chemistry changes (Figure 2.3).
- Thermal stress will play a larger role in elevating threat levels than acidification by 2030, though about half of all reefs will be threatened by both conditions.

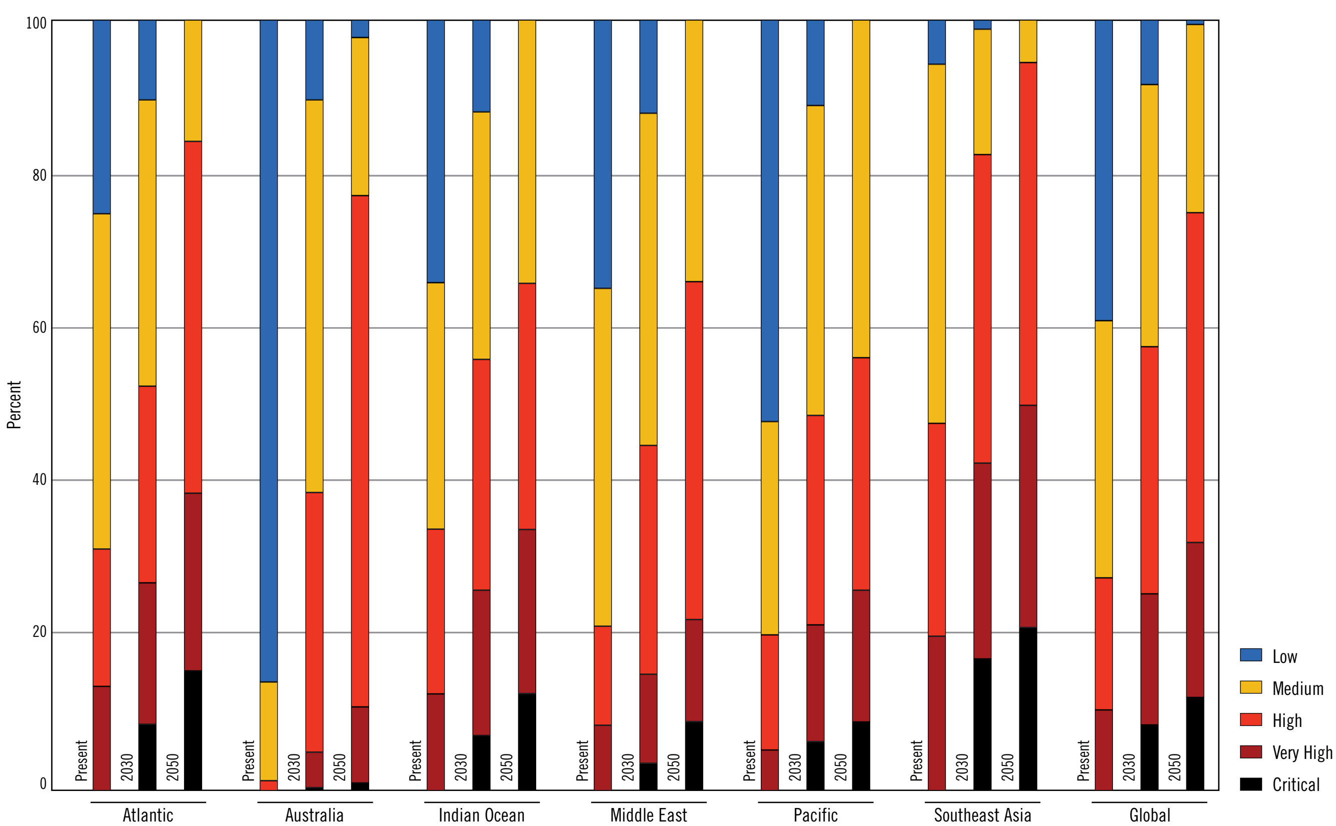
As shown in Figure 2.3 and Map 2.5b, the predictions for thermal stress and acidification in the 2030s have the most dramatic effect on the reefs in Australia and the Pacific, pushing many reefs from low to threatened categories. In addition, climate-related threats in parts of Southeast Asia will compound already high local threat levels in that region.

THREAT IN 2050

By the 2050s, our estimates predict that almost no reefs will be under low threat and only about one-quarter will be under medium threat, with the remaining 75 percent at a high, very high, or critical threat levels (Figure 2.3). A few small areas of reef are projected to remain under low threat in Australia and the South Pacific (Map 2.5c).

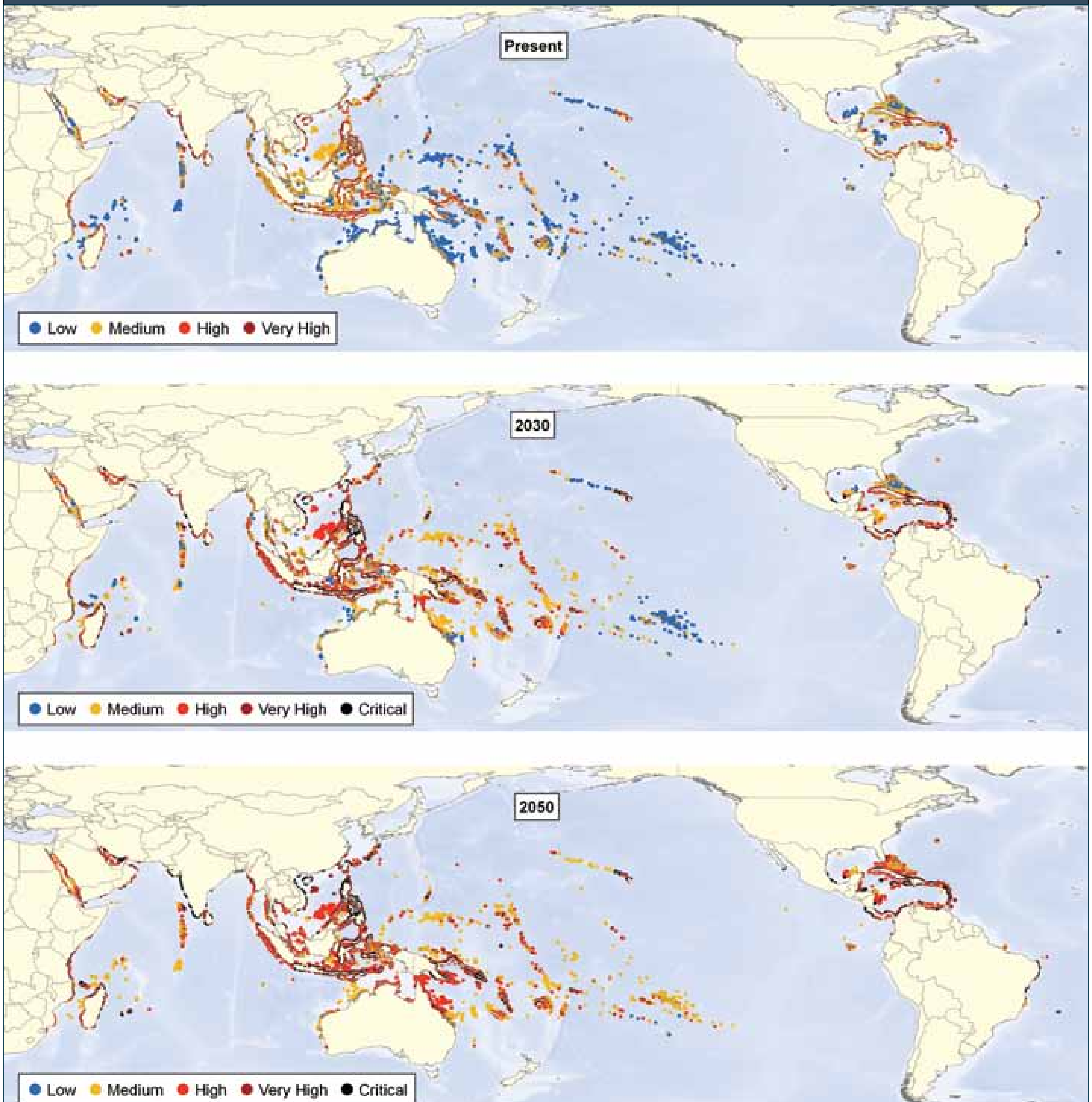
It is important to note that these projections assume that current local threats remain constant in the future, and do not account for potential changes in human pressure,

FIGURE 2.3 REEFS AT RISK PROJECTIONS: PRESENT, 2030, AND 2050



Note: "Present" represents the Reefs at Risk integrated local threat index, without past thermal stress considered. Estimated threats in 2030 and 2050 use the present local threat index as a base and also include projections of future thermal stress and ocean acidification. The 2030 and 2050 projections assume that current local threats remain constant in the future, and do not account for potential changes in human pressure, management, or policy, which could influence overall threat ratings.

MAP 2.5. a, b, and c. REEFS AT RISK IN THE PRESENT, 2030, AND 2050



Note: Map 2.5.a shows reefs classified by present integrated threat from local activities. Maps 2.5b and 2.5c show reefs classified by integrated local threat combined with projections of thermal stress and ocean acidification for 2030 and 2050, respectively. Method: Reefs are assigned their threat category from the integrated local threat index as a starting point. The threat is raised one level if reefs are at high threat from either thermal stress or ocean acidification, or if they are at medium threat for both. If reefs are at high threat for both thermal stress and acidification, the threat classification is increased by two levels. The analysis assumes no increase in future local pressure on reefs, and no reduction in local threats due to improvements in management.

management, or policy, which could influence overall threat ratings. If future population growth, coastal development, and agricultural expansion were considered, the projections of the threat to reefs would be even higher.

Moreover, it is important to remember that the results presented here are projections and are not foregone conclusions. This analysis highlights the urgent need for global action to curtail greenhouse gas emissions, in parallel with local actions to lessen the immediate pressures on coral reefs. Controlling local threats to coral reefs will be critical to ensuring their resilience and survival in the face of heavy human pressure in coastal regions, and growing threats from climate change and ocean acidification.

REEF STORY

Chagos Archipelago: A Case Study in Rapid Reef Recovery

The Chagos Archipelago in the central Indian Ocean is a group of atolls, submerged atolls, and reefs scattered throughout an area of 60,000 sq km. The archipelago is home to the most geographically isolated reef system in the Indian Ocean, in terms of both distance and ocean current patterns. Local human influence is low, as most of the archipelago is uninhabited; only the military base on the atoll Diego Garcia is populated. In April 2010, the British government designated the entire Chagos Archipelago as a marine protected area. Prior to this designation, most islands and surrounding reefs were nature reserves with restricted access.

The reef system of Chagos lost more than 80 percent of its shallow corals and almost all its soft corals during the 1998 mass bleaching event.[41] The reefs also suffered extensive bleaching in 2003 and 2005, but in neither of these more recent cases was there subsequent mass mortality such as in 1998.

Recovery from the bleaching event of 1998, including recruitment of juvenile corals and recolonization, has been rapid— more so than many other locations equally affected by the 1998 event—and this has been attributed to the lack of direct or local human impacts in Chagos. Regeneration of coral cover has been greatest in shallow waters, and in deeper waters, three-dimensional structures and complexity have shown rapid recovery.[39]

Today, the number of reefs around the world without direct human impacts is extremely small, so Chagos represents the rare case where scientists can examine effects of global climate change in the absence of human influence. The recovery of corals in Chagos—in comparison to other sites in the region under greater human pressures—therefore highlights the importance of local management efforts to reduce these pressures.

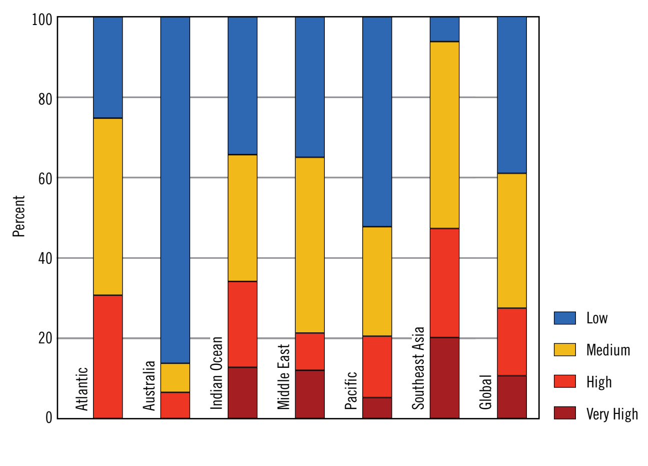
Story provided by Charles Sheppard of the University of Warwick.
For more stories about reefs around the world, visit: www.wri.org/reefs/stories.

Section 3. REGIONAL SUMMARIES

PHOTO: STEVE LINFIELD

At a global scale, the threats facing the world's coral reefs present a considerable challenge to human society. However, it is only by understanding the root causes and impacts of these threats in specific locations that we can begin to develop coherent responses. The key drivers of threats, the current condition and future risk to reefs, and the management measures used to protect reefs are highly variable from place to place. This section explores reef distribution, status, and threats in each of six major coral reef regions.

FIGURE 3.1. REEFS AT RISK FROM INTEGRATED LOCAL THREATS BY REGION

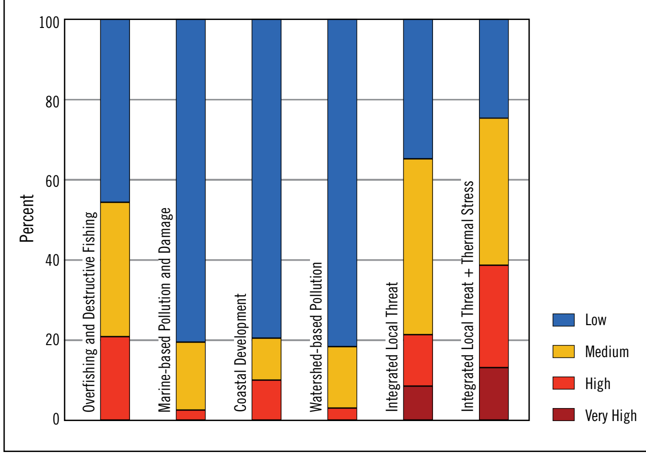


Note: Integrated local threats consist of the four local threats—overfishing and destructive fishing, marine pollution and damage, coastal development, and watershed-based pollution.

MIDDLE EAST

- The seas of the Middle East are home to about 6 percent of the world's coral reefs (14,000 sq km).
- Approximately 19 million people live on the coast within 30 km of a coral reef.
- In this region, 65 percent of reefs are at risk from local threats, with more than 20 percent under high or very high threat.
- All four threats add significant pressure, with marine-based pollution from shipping and offshore oil and gas development threatening a greater percentage of reefs in this region than any other.
- The highest concentration of threats is in the Persian Gulf.
- In Bahrain, Djibouti, Iran, Kuwait, Qatar, and Yemen, more than 95 percent of reefs are threatened.

FIGURE 3.2. REEFS AT RISK IN THE MIDDLE EAST

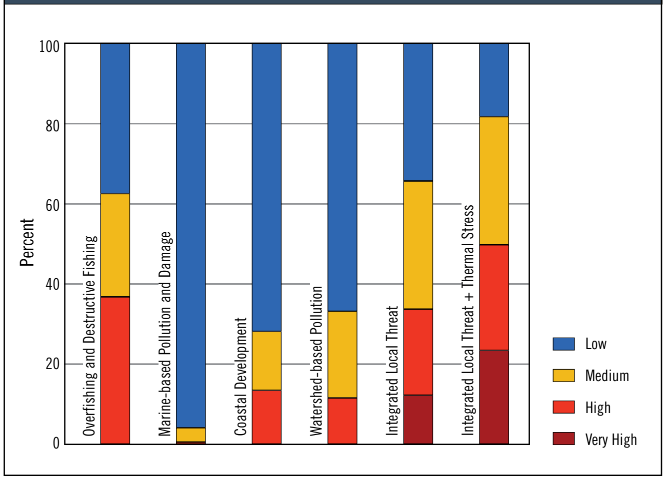


MAP 3.1. REEFS AT RISK IN THE MIDDLE EAST

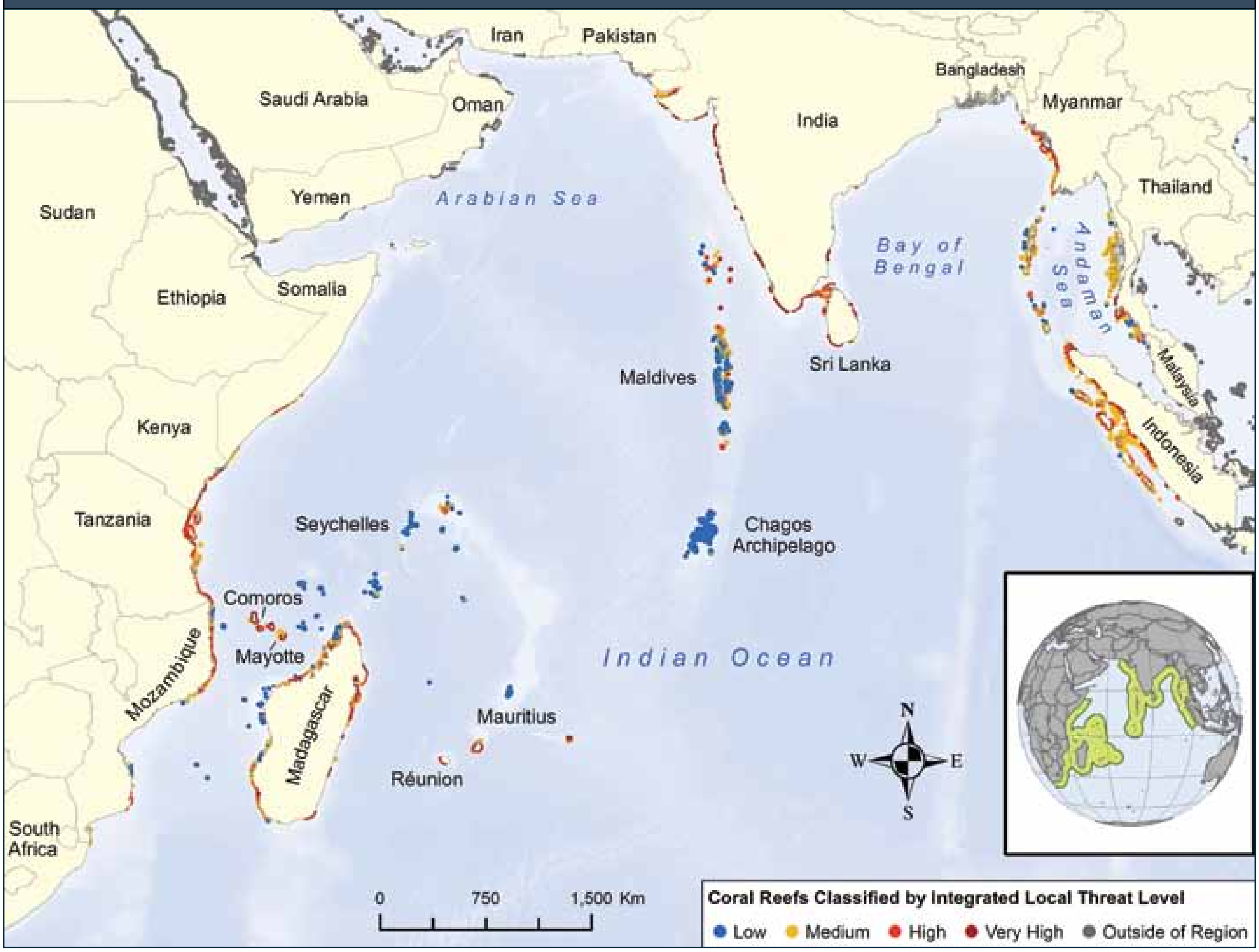
INDIAN OCEAN

- The Indian Ocean basin contains 13 percent of the world's coral reefs (31,500 sq km).
- More than 65 million people live on the coast within 30 km of a coral reef.
- About 65 percent of reefs are threatened by local activities, with nearly 35 percent under high or very high threat.
- Overfishing is the most widespread threat in the region, but land-based pollution and coastal development also elevate overall pressure.
- Along continental shores, more than 90 percent of reefs are threatened. The threat is generally lower around the oceanic islands. The Maldives, the Chagos Archipelago, and the Seychelles have the largest area of reefs under low threat.

FIGURE 3.3. REEFS AT RISK IN THE INDIAN OCEAN



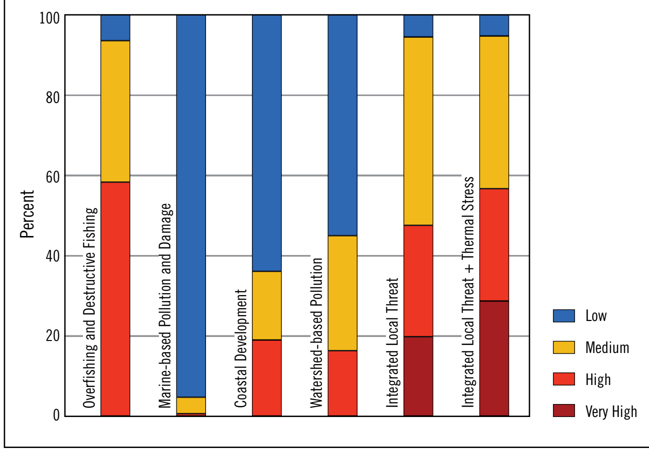
MAP 3.2. REEFS AT RISK IN THE INDIAN OCEAN



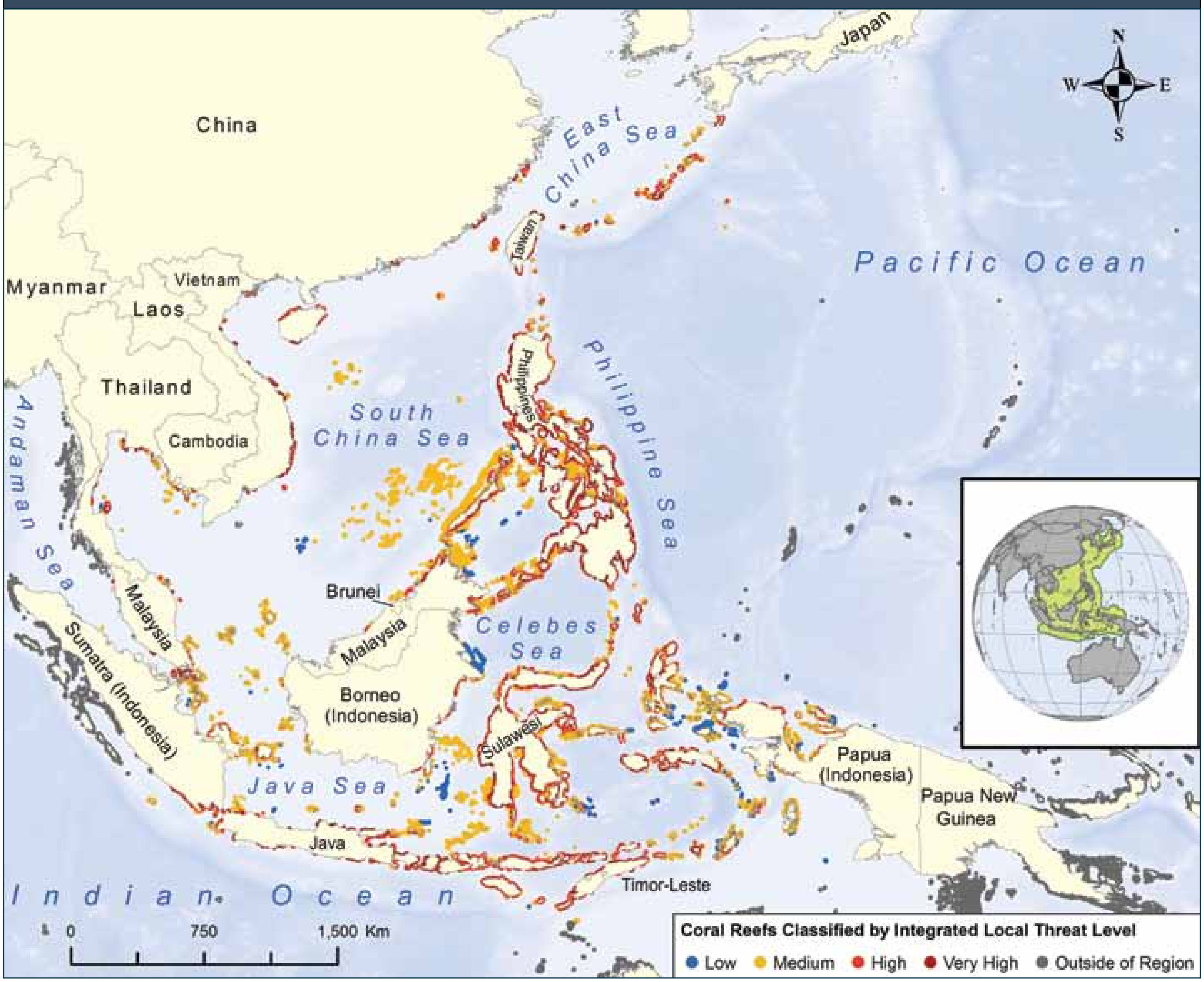
SOUTHEAST ASIA

- Southeast Asia has the most extensive and diverse coral reefs in the world—about 28 percent of the global total (almost 70,000 sq km).
- More than 138 million people live on the coast within 30 km of a coral reef, which is more than every other coral reef region combined.
- The reefs in this region are the most threatened in the world: nearly 95 percent of reefs are threatened, and about 50 percent are in the high or very high threat categories.
- Overfishing and destructive fishing drive much of the threat in this region, although watershed-based pollution and coastal development are also significant.
- The threat is particularly high in the Philippines and central Indonesia.

FIGURE 3.4. REEFS AT RISK IN SOUTHEAST ASIA



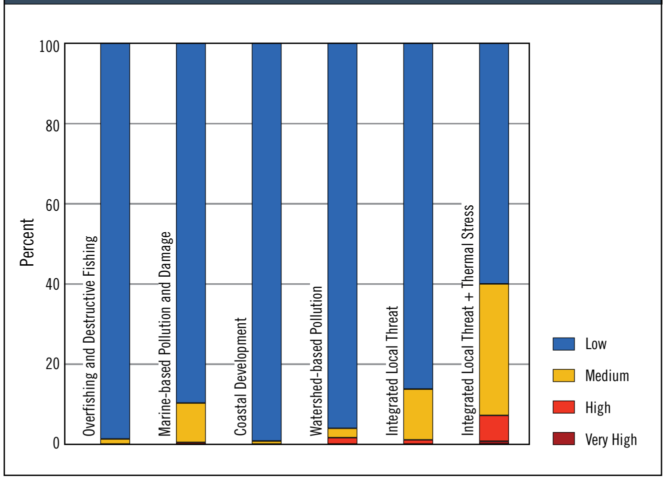
MAP 3.3. REEFS AT RISK IN SOUTHEAST ASIA



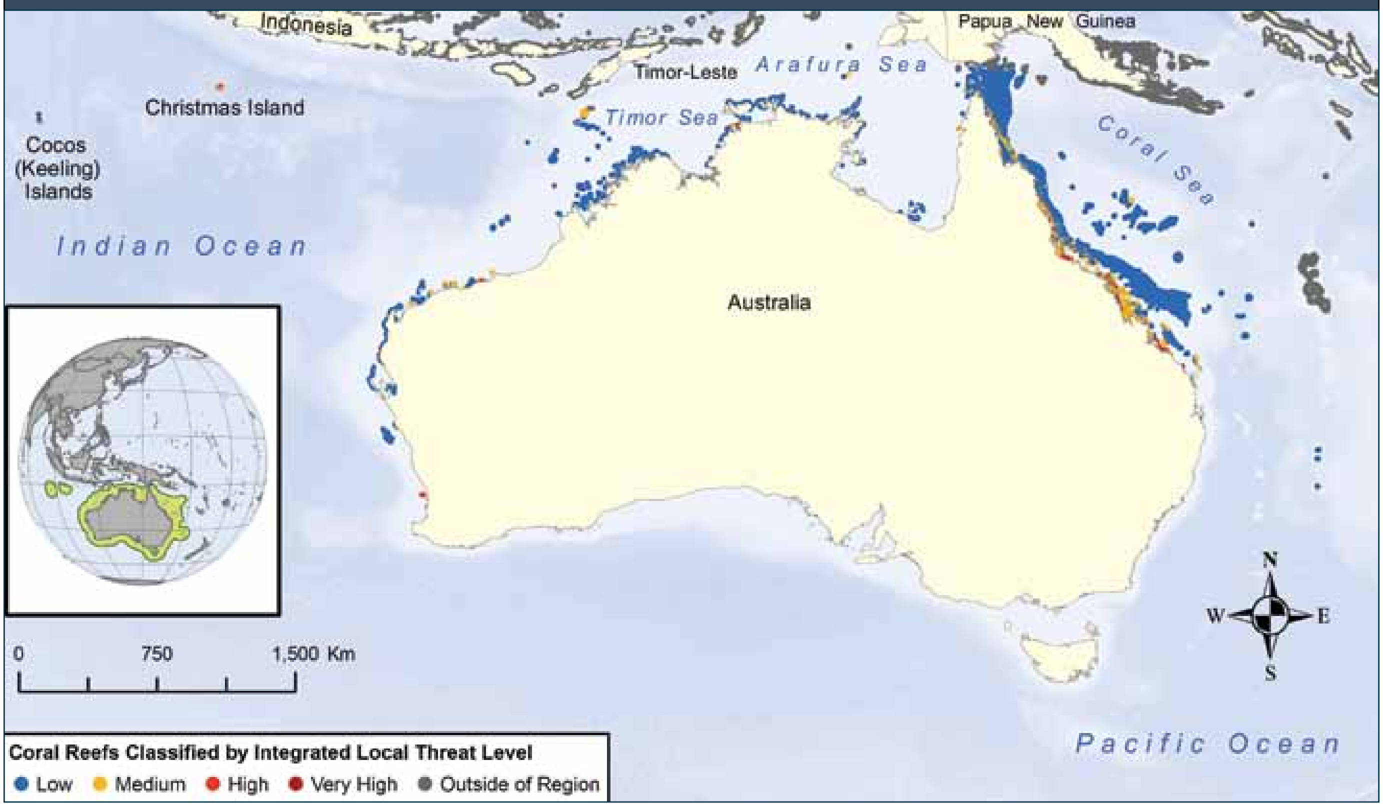
AUSTRALIA

- Australia has more coral reefs than any other single nation—approximately 42,000 sq km (17 percent of the global total), most of which are part of the Great Barrier Reef off Australia's northeastern shore.
- About 3.5 million people live on the coast within 30 km of a coral reef, which is the lowest coastal population density of any region.
- Australia's reefs have the smallest percentage of threatened reefs of any region, with an estimated 14 percent threatened by local activities and just over 1 percent at high or very high threat.
- Our analysis identifies both marine-based pollution and watershed-based pollution as the dominant threats, but vast areas of reef are remote from such impacts.

FIGURE 3.5. REEFS AT RISK IN AUSTRALIA



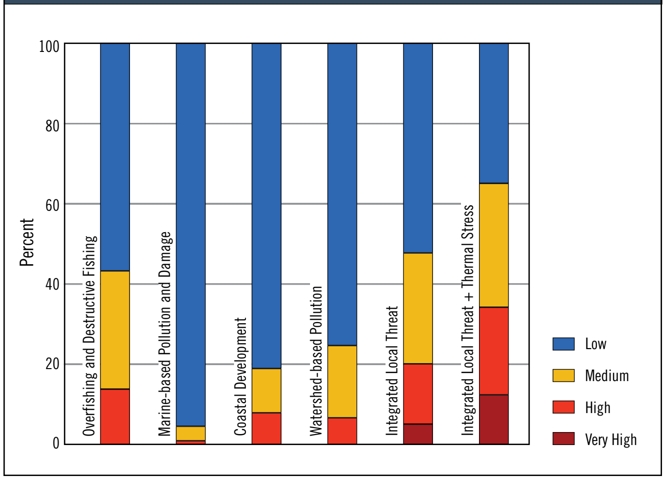
MAP 3.4. REEFS AT RISK IN AUSTRALIA



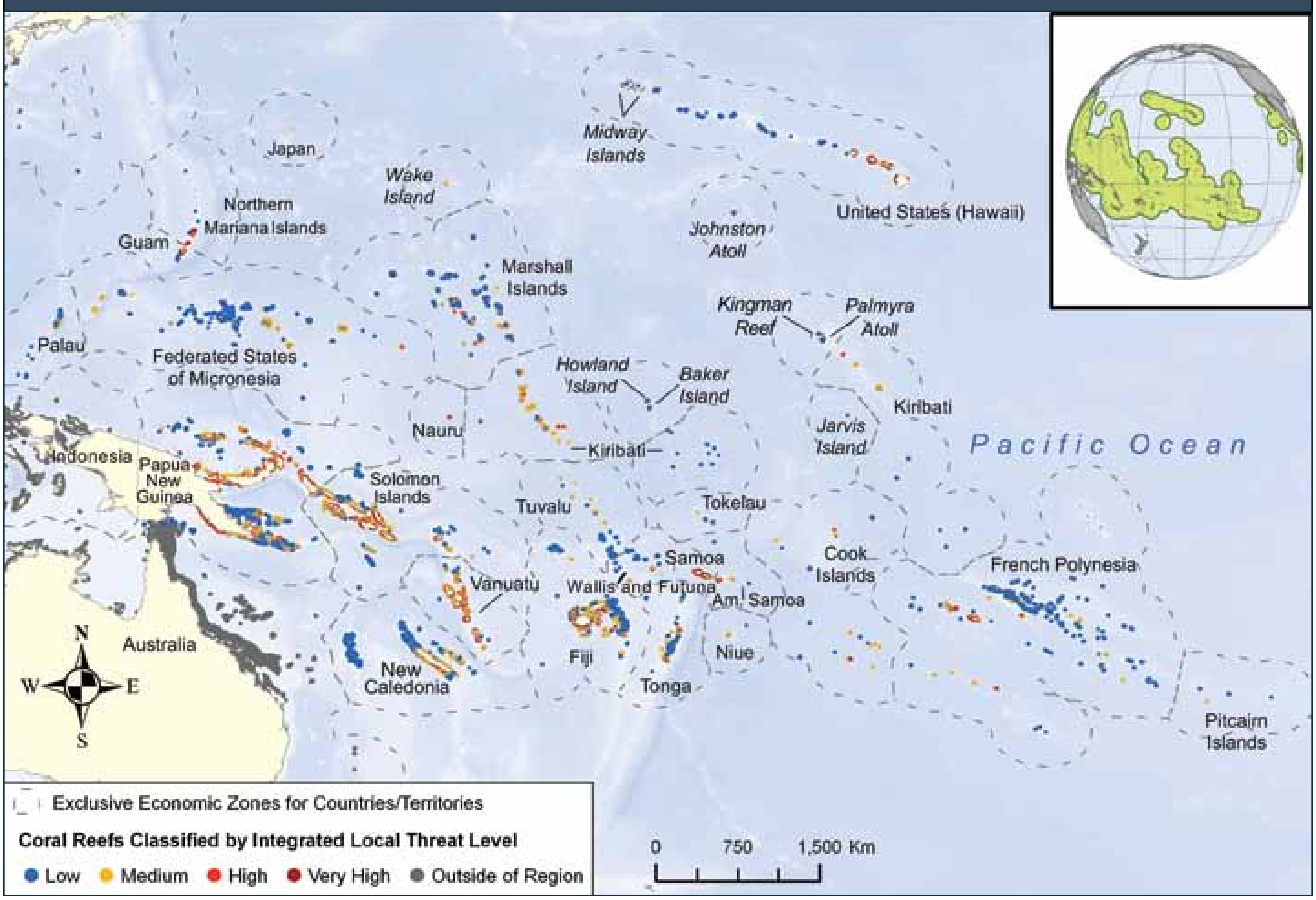
PACIFIC

- Spanning almost half the globe, the Pacific contains more than a quarter of the world's reefs—nearly 66,000 sq km.
- About 7.5 million people live on the coast within 30 km of a coral reef in the Pacific, representing 50 percent of the total population of the region.
- Although the wider Pacific region has long enjoyed relatively low pressure on coastal resources, almost 50 percent of reefs are currently considered threatened, with about 20 percent rated as high or very high.
- Overfishing and runoff from land-based sources are the predominant threats, though coastal development is also a major pressure in some areas.
- The more remote atoll reefs in archipelagos of French Polynesia, the Federated States of Micronesia, Hawaii (United States), and the Marshall Islands have some of the lowest overall threat ratings, but threats are high in these same countries/territories around the more developed islands.

FIGURE 3.6. REEFS AT RISK IN THE PACIFIC



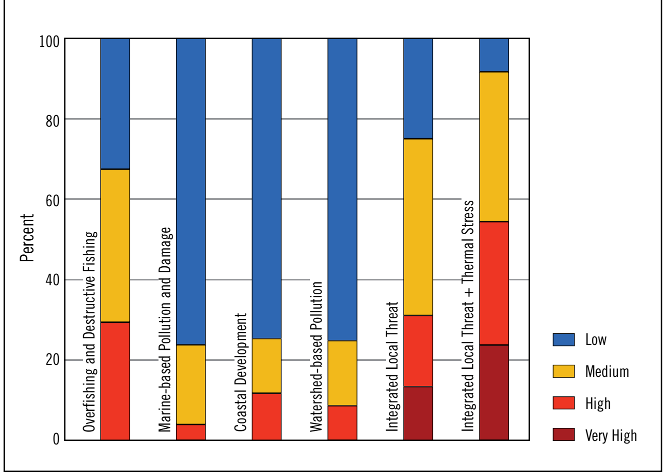
MAP 3.5. REEFS AT RISK IN THE WESTERN PACIFIC



ATLANTIC/CARIBBEAN

- The Atlantic/Caribbean region includes about 10 percent (26,000 sq km) of the world's coral reefs.
- About 43 million people live on the coast within 30 km of a reef, many of whom reside in densely populated small-island nations.
- More than 75 percent of reefs are threatened, with more than 30 percent in the high or very high threat category.
- Overfishing is the most pervasive threat, but marine-based pollution and damage, coastal development, and watershed-based pollution also pose significant threats.
- In more than twenty countries or territories in the region—including Florida (United States), Haiti, the Dominican Republic, and Jamaica—all reefs are rated as threatened.
- The Bahamas, Mexico, and Nicaragua have the largest areas of reef rated as low threat.

FIGURE 3.7. REEFS AT RISK IN THE ATLANTIC/CARIBBEAN



- Many reefs in this region have already been severely degraded by the combined impacts of the threats themselves and the influence of stressors such as coral disease and bleaching.

MAP 3.6. REEFS AT RISK IN THE ATLANTIC/CARIBBEAN

Section 4. SOCIAL AND ECONOMIC IMPLICATIONS OF REEF LOSS


PHOTO: JOSHUA CINNER, ARC CENTER OF EXCELLENCE

In many nations, coral reef ecosystem services—including fisheries, tourism, and shoreline protection—are critically important to people's livelihoods, food security, and well-being. As a result, threats to reefs not only endanger ecosystems and marine species, but also directly threaten the communities and nations that depend upon them. The relative social and economic importance of reefs is further increased by the fact that many reef-dependent people live in poverty, and have limited capacity to adapt to impacts of reef degradation. For many reef nations, a shift toward more sustainable use of coral reef resources may offer valuable opportunities for poverty reduction and economic development.

This section builds on the findings of the threat analysis by examining where identified threats to reefs may have the most serious social and economic consequences for reef nations. We represent a country's vulnerability to reef degradation and loss as the combination of three components: (1) exposure to reef threats, (2) dependence on reef ecosystem services (that is, social and economic sensitivity to reef loss), and (3) the capacity to adapt to the potential impacts of reef loss (Box 4.1).[42-44]

REEF DEPENDENCE

Hundreds of millions of people worldwide rely on reef resources.[45-47] Global estimates of the economic values attributed to reef ecosystem services range from tens to hundreds of billions of dollars annually (Box 4.2). Yet these numbers provide only a broad overview of the importance of reefs to economies, livelihoods, and cultures. To capture the multidimensional nature of people's reliance on reefs, we break down reef dependence into six indicators that are important at the national scale:

- **Reef-associated population:** Worldwide, roughly 850 million people live within 100 km of coral reefs, and are likely to derive some benefits from the ecosystem services they provide.[48] More than 275 million people reside in the direct vicinity of coral reefs (within 30 km of reefs and less than 10 km from the coast), where livelihoods are most likely to depend on reefs and related resources.
- **Fisheries employment:** Fisheries are one of most direct forms of human dependence on reefs, providing vital food, income, and employment. They also play an important role in poverty alleviation.[46] In absolute numbers, the greatest numbers of people who fish on reefs are found in populous Asian nations such as Indonesia and the Philippines. While relative to total population, two-thirds of countries and territories with highest participation in reef fisheries are in the Pacific.

BOX 4.1. ASSESSING VULNERABILITY: ANALYTICAL APPROACH

The three components of vulnerability to degradation and loss of reefs are outlined in Table 4.1, with the national-level indicators used to assess them. We focused mainly at the national level, and included 108 countries, territories, and subnational regions (e.g., states) in the study. Where data were unavailable, we interpolated values based on countries or territories within the same region that were culturally and economically similar.

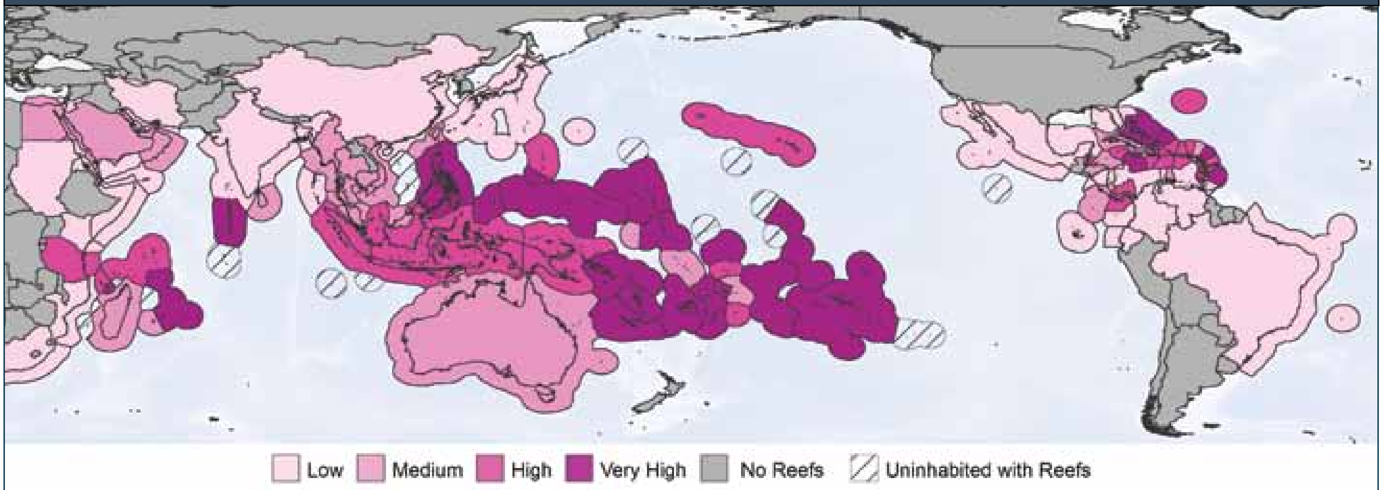
TABLE 4.1 VULNERABILITY ANALYSIS COMPONENTS, INDICATORS, AND VARIABLES

Component	Indicator	Variable
Exposure	Threats to coral reefs	• Reefs at Risk integrated local threat index weighted by ratio of reef area to land area
Reef dependence	Reef-associated population	• Number of coastal people within 30 km of reefs • Coastal people within 30 km of reefs as a proportion of national population
	Reef fisheries employment	• Number of reef fishers • Reef fishers as a proportion of national population
	Reef-associated exports	• Value of reef-associated exports as a proportion of total export value
	Nutritional dependence on fish and seafood	• Per capita annual consumption of fish and seafood
	Reef-associated tourism	• Ratio of registered dive shops to annual tourist arrivals, scaled by annual tourist receipts as a proportion of GDP
	Shoreline protection	• Index of coastal protection by reefs (combining coastline within proximity of reefs, and reef distance from shore)
Adaptive Capacity	Economic resources	• Gross domestic product (GDP) + remittances (payments received from migrant workers abroad) per capita
	Education	• Adult literacy rate • Combined ratio of enrollment in primary, secondary, and tertiary education
	Health	• Average life expectancy
	Governance	• Average of worldwide governance indicators (World Bank) • Fisheries subsidies that encourage resource conservation and management, as a proportion of fisheries value
	Access to markets	• Proportion of population within 25 km of market centers (> 5,000 people)
	Agricultural resources	• Agricultural land area per agricultural worker

- **Nutritional dependence:** Healthy reefs provide an abundant variety of foods, many of which are inexpensive sources of high-quality animal protein. In some places—particularly small, isolated islands with limited resources and trade—reefs may be the only such source. Across reef nations and territories, people consume a per capita average of 29 kg of fish and seafood each year, as compared to the global average of 18 kg.[49]
- **Export value:** Exports of reef-derived species and products represent important sources of revenue for tropical economies. In twenty-one countries and territories, reef-associated exports are valued at more than 1 percent of total exports, and in six cases, at more than 15 percent of total exports.
- **Tourism:** At least ninety-six countries and territories benefit from reef tourism.[50] In twenty-three countries and territories, reef tourism accounts for more than 15 percent of GDP.[51] Spending by divers, snorkelers, beachgoers, and recreational fishers supports a range of businesses (including dive shops, hotels, restaurants, and transportation), and in some places directly contributes to the management costs of marine parks and other types of marine protected areas (MPAs).
- **Shoreline protection:** Coral reefs play a valuable role in buffering coastal communities and infrastructure from the physical impacts of wave action and storms, thereby reducing coastal erosion and lessening wave-induced flooding. More than 150,000 km of shoreline in 106 countries and territories receives some protection from reefs.[52] In seventeen small islands, more than 80 percent of the coastline is estimated to be protected by reefs.

Combining all six indicators reveals several geographic clusters of particularly strong dependence on reefs (Map 4.1). More than half of the countries and territories with

MAP 4.1. SOCIAL AND ECONOMIC DEPENDENCE ON CORAL REEFS



Notes: Reef dependence is based on reef-associated population, reef fisheries employment, nutritional dependence on fish and seafood, reef-associated export value, reef tourism, and shoreline protection from reefs. Eighty-one countries, twenty-one island territories, and six subnational regions (Florida, Hawaii, Hong Kong SAR, Peninsular Malaysia, Sabah, and Sarawak) were assessed, and are categorized according to quartiles. Reef territories that are only inhabited by military or scientific personnel are not included.

very high reef dependence are located in the Pacific, including French Polynesia, which globally has the highest dependence on reefs. One-third of very high reef-dependent countries and territories are in the Caribbean, including Grenada, Curaçao, and the Bahamas. Nearly all of the most strongly reef-dependent nations are small-island states.

In ten cases, dependence is high or very high on all six indicators: the Cook Islands, Fiji, Jamaica, the Maldives, the Marshall Islands, New Caledonia, the Philippines, Solomon Islands, Samoa, and Tonga.

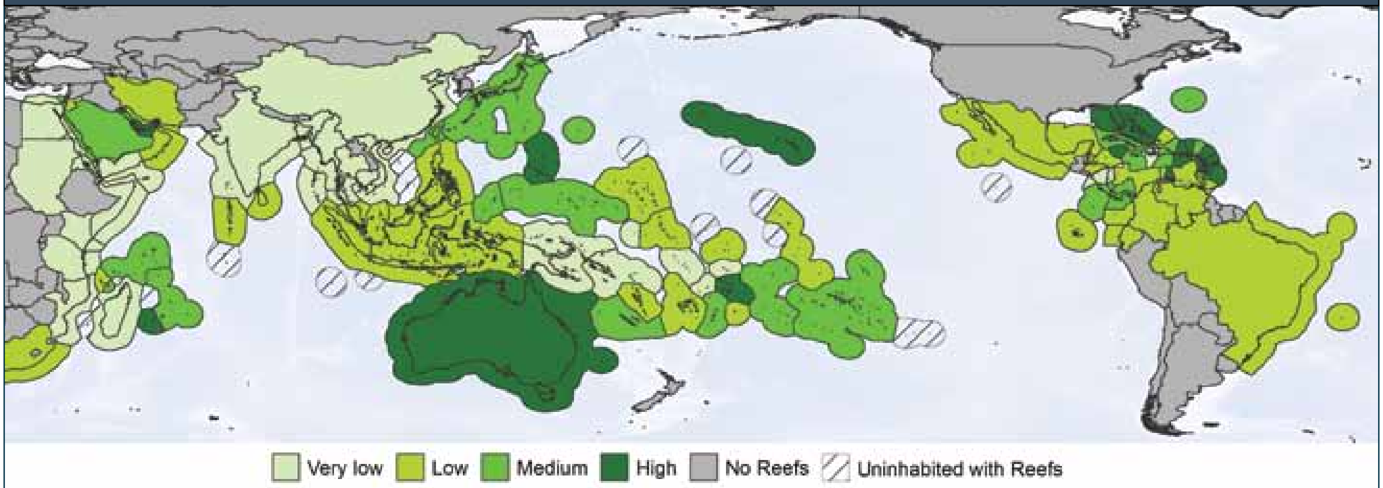
PHOTO: ASENACA DIKOILA VALEMI/REEFBASE

ADAPTIVE CAPACITY

Adaptive capacity is the ability to cope with, adapt to, or recover from the effects of changes.[53] For nations faced with reef degradation and loss, adaptive capacity includes the resources, skills, and tools available for planning and responding to the effects of the resulting losses of reef ecosystem services. Like reef dependence, adaptive capacity is complex and cannot be directly measured. We therefore separate adaptive capacity into six national-scale indicators that are relevant to reef-dependent regions. We use two types of indicators: (1) those that describe general aspects of human and economic development, including economic resources, education, health, and governance; and (2) those that are more specific to the case of potential reef loss, including access to markets (for trading food and goods not derived from reefs) and agricultural resources (a proxy for the availability of non-reef natural resources to provide food and livelihoods).[54]

When these six indicators are combined, we find that adaptive capacity is most limited for nations with a relatively recent history of conflict, such as Somalia, Mozambique, Eritrea, Sudan, and Timor-Leste (Map 4.2). Most of the reef countries classified as least developed countries (LDCs) fall within the lowest category of adaptive capacity, including the five countries listed above and others such as Bangladesh, Tanzania, Yemen, and Haiti.[55] Not surprisingly,

MAP 4.2. CAPACITY OF REEF NATIONS AND TERRITORIES TO ADAPT TO REEF DEGRADATION AND LOSS



Notes: Adaptive capacity is based on economic resources, education, health, governance, access to markets, and agricultural resources. Eighty-one countries, twenty-one island territories, and six subnational regions (Florida, Hawaii, Hong Kong SAR, Peninsular Malaysia, Sabah, and Sarawak) were assessed, and are categorized according to quartiles.

adaptive capacity is typically greatest among countries characterized by high levels of economic development and resources (for example, the United States and Singapore), including oil-producing nations (such as Brunei and Qatar) and Caribbean islands engaged in offshore finance (such as the British Virgin Islands and Cayman Islands).

SOCIAL AND ECONOMIC VULNERABILITY

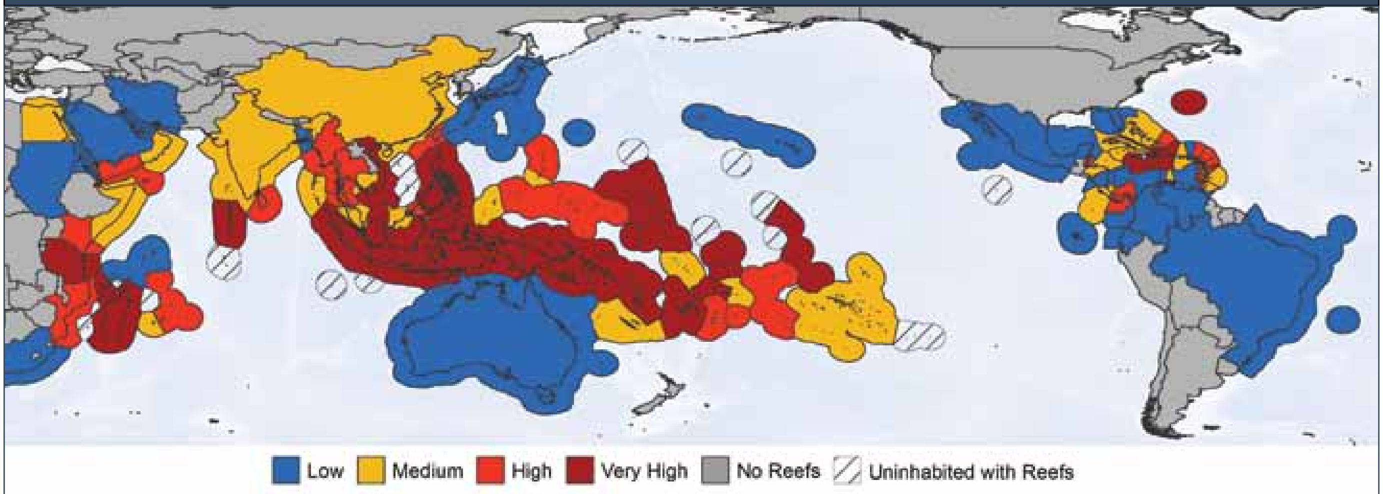
Combining the three components of vulnerability (exposure to reef threats, dependence on reef ecosystem services, and adaptive capacity) reveals that the countries and territories that are most vulnerable to the degradation and loss of reefs are spread throughout the world's tropical regions (Map 4.3). More than one-third of very highly vulnerable countries and territories are in the Caribbean, one-fifth are in Eastern Africa and the Western Indian Ocean, and smaller numbers are found in the Pacific, Southeast Asia, and South Asia. Among the twenty-seven countries and territories rated as very highly vulnerable, the majority (nineteen) are small-island states.

The most vulnerable countries and territories reflect different underlying combinations of the three components (Figure 4.1). Each of these types of vulnerability has different implications for the likely consequences of reef loss; identifying them provides a useful starting point for setting priorities for resource management and development action to minimize potential impacts. It may also provide an opportunity for countries that are not considered highly vulnerable to plan how best to avoid potential pitfalls in the future.

Nine countries (Comoros, Fiji, Grenada, Haiti, Indonesia, Kiribati, Philippines, Tanzania, and Vanuatu) lie in a position of serious immediate social and economic vulnerability, with high to very high exposure and reef dependence, and low to medium adaptive capacity. These nations represent key priorities for concerted national and local efforts to reduce reef dependence and build adaptive capacity, alongside reducing immediate threats to reefs. These efforts should ideally be integrated within the broader national development context. Recognizing the needs of reef-dependent communities within other ongoing development initiatives may bring opportunities for reducing their vulnerability to future reef loss, as well as identifying the role that sustainable use of reef resources can play in poverty reduction and economic development.

For six island countries and territories (the Maldives, the Marshall Islands, Papua New Guinea, Solomon Islands, Tokelau, and Wallis and Futuna), where exposure to reef threats is not yet extreme at the national scale, strong reliance on reefs and limited capacity to adapt suggest that if pressures on reefs increase, serious social and economic impacts may result. This situation may offer a window of opportunity to build secure management

MAP 4.3. SOCIAL AND ECONOMIC VULNERABILITY OF COUNTRIES AND TERRITORIES TO REEF LOSS



Notes: Vulnerability is based on exposure to reef threats, reef-dependence, and adaptive capacity. Eighty-one countries, twenty-one island territories, and six subnational regions (Florida, Hawaii, Hong Kong SAR, Peninsular Malaysia, Sabah, and Sarawak) were assessed, and are categorized according to quartiles.

frameworks to protect reefs, shift some human dependence away from reefs, and strengthen local and national capacity. The window may be limited, however, given that large-scale threats such as climate change (which is not included within the exposure index) may also have serious consequences on reefs.

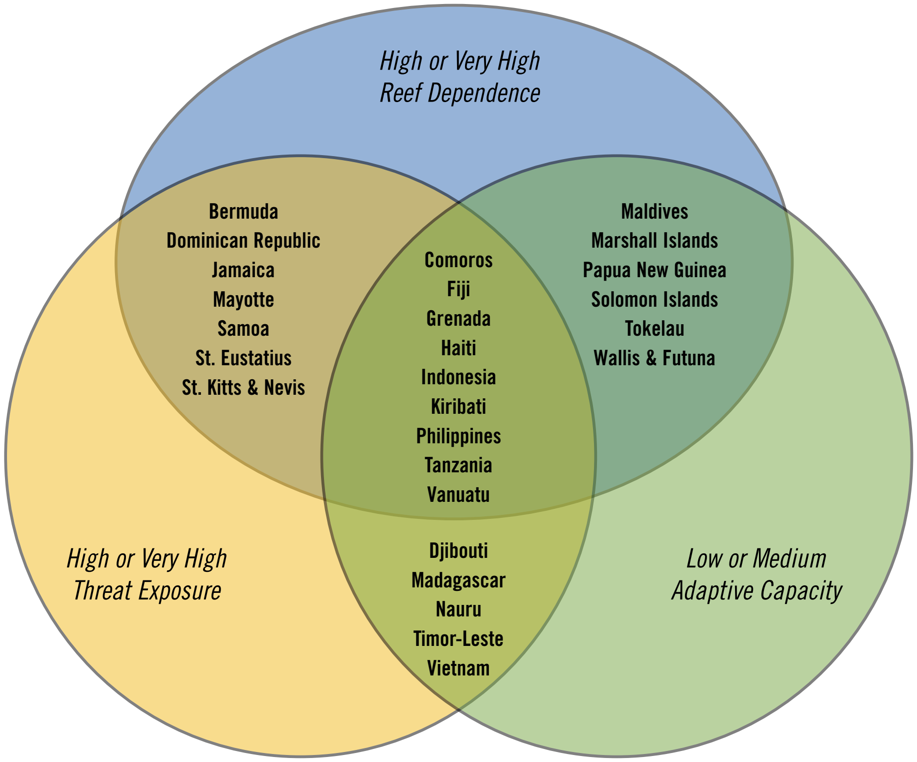
Seven very highly vulnerable countries and territories (Bermuda, the Dominican Republic, Jamaica, Mayotte, Samoa, St. Eustatius, and St. Kitts and Nevis) have reefs that are highly or very highly exposed to threats and depend heavily on reef ecosystem services, but also have high or very high adaptive capacity.[56] While relatively high adaptive capacities are likely to help buffer potential impacts on reef-dependent people, ultimately the extent of their vulnerability to reef loss will depend on how effectively resources and skills are directed toward reducing reef threats and dependence.

PHOTO: AMY V. UHRIN

In five reef nations (Djibouti, Madagascar, Nauru, Timor-Leste, Vietnam), very high vulnerability stems from serious threats to reefs and limited adaptive capacity, despite only moderate national-scale dependence upon reefs. This combination of drivers suggests that while social and economic impacts of reef loss may be serious for some local areas, these effects are likely to be less significant on a national scale. In these countries, vulnerability may be reduced most effectively by targeting efforts to reduce threats to reefs and build capacity at local scales, raising government awareness about regions where reef dependence is particularly high, and paying attention to cases where this dependence may increase.

Globally, the extent of humans' reef dependence is enormous. Threats to reefs have the potential to bring significant hardship to many vulnerable coastal communities and nations. Ultimately, reducing vulnerability depends on management to reduce or eliminate local threats to reefs, and also requires measures to shift human dependence—at least partially—away from reefs. This need will become even greater as climate change impacts on reef ecosystems become more frequent and severe.

FIGURE 4.1. DRIVERS OF VULNERABILITY IN VERY HIGHLY VULNERABLE NATIONS AND TERRITORIES



Note: Only the twenty-seven very highly vulnerable countries and territories are shown.

Efforts to reduce reef dependence are extremely challenging. Planning and prioritizing at local scales are hindered by a lack of information about dependence on specific reef ecosystem services (for example, dietary consumption, numbers of subsistence fishers) in many areas. Even where reef dependence is well-understood, past efforts to develop alternative livelihoods in coastal areas have frequently proven unsuccessful.[57] Activities such as agriculture, aquaculture, tourism, or trade may represent viable alternatives, but will only be sustainable where their development takes into account local aspirations, needs, perceptions, and cultural ties to coral reefs.[58] For millions of reef-dependent people, it is critical that such efforts succeed.

PHOTO: KAREN KOLTES

BOX 4.2. ECONOMIC VALUE OF CORAL REEFS

Economic valuation is a tool that can aid decision making by quantifying ecosystem services, such as those provided by coral reefs, in monetary terms. In traditional markets, ecosystem services are often overlooked or unaccounted for, an omission that regularly leads to decisions favoring short-term economic gains at the expense of longer-term benefits. Economic valuation provides more complete information on the economic consequences of decisions that lead to degradation and loss of natural resources, as well as the short- and long-term costs and benefits of environmental protection.

CORAL REEF VALUES

Many studies have quantified the value of one or more ecosystem services provided by coral reefs. These studies vary widely in terms of spatial scale (from global to local), method used, and type of value estimated. Some assessments focus on the annual benefits coming from reefs, and some estimate total value over a number of years. Still others focus on the change in value as an ecosystem is altered.

Of the many ecosystem services provided by coral reefs, reef-related fisheries, tourism, and shoreline protection are among the most widely studied because their prices are traceable in markets and are thus relatively easy to calculate. We provide examples of values in Table 4.2. The economic benefits derived from coral reefs vary considerably by site, depending on the size of tourism markets, the importance and productivity of fisheries, level of coastal development, and the distance to major population centers.

VALUATION OF LOSSES DUE TO DEGRADATION

Although many economic valuation studies have focused on estimating the benefits of coral reef ecosystem services, some studies have also focused on changes in value—that is, what an economy stands to lose if a reef is degraded. For example, *Reefs at Risk in the Caribbean* (2004) estimated that by 2015, the projected degradation of Caribbean reefs from human activities such as overfishing and pollution could result in annual losses of US$95 million to US$140 million in net revenues from coral reef-associated fisheries, and US$100 million to US$300 million in reduced tourism revenue. In addition, degradation of reefs could lead to annual losses of US$140 million to US$420 million from reduced coastal protection within the next fifty years.[59] Other studies estimate that Australia's economy could lose US$2.2 billion to US$5.3 billion over the next nineteen years due to global climate change degrading the Great Barrier Reef,[60] while Indonesia could lose US$1.9 billion over 20 years due to overfishing.[61]

POLICY AND MANAGEMENT APPLICATIONS

The goal of economic valuation is to influence decisions that will promote conservation and sustainable management of reefs. By quantifying the economic benefits or losses likely to occur due to degradation of reefs, it is possible to tap public and private funding for coastal management, gain access to new markets, initiate payments for ecosystem services, and charge polluters for damages.

Despite the usefulness of economic valuation, there are still many challenges to its practical application. In particular, although global-scale valuation studies are frequently cited, they are often misleading due to the difficulty of aggregating values and constraints on data at the global level. Furthermore, economic valuation can produce only a partial estimate of total ecosystem value, as our limited technical, economic, and ecological knowledge prevents us from ever truly identifying, calculating, and ranking all of an ecosystem's values. Valuation studies also contain a range of assumptions and limitations, which must be taken into account during the decision-making process. Economic valuation can inform policy decisions, but valuations tend to be most useful when developed with a particular policy application in mind.

TABLE 4.2 SAMPLE VALUES: ANNUAL NET BENEFITS FROM CORAL REEF-RELATED GOODS AND SERVICES (US$, 2010)

Extent of Study	Tourism	Coral-reef Fisheries	Shoreline Protection
Global[a]	$11.5 billion	$6.8 billion	$10.7 billion
Caribbean (Regional)[b]	$2.7 billion	$395 million	$944 million to $2.8 billion
Philippines & Indonesia[c]	$258 million	$2.2 billion	$782 million
Belize (National)[d]	$143.1 million to $186.5 million**	$13.8 million to $14.8 million**	$127.2 to $190.8 million
Guam (National)[e]	$100.3 million**	$4.2 million**	$8.9 million
Hawaii (Subnational)[f]	$371.3 million	$3.0 million	Not evaluated

* All estimates have been converted to US$ 2010.
** Estimates of the value of coral reef-associated fisheries and tourism for Belize and Guam are gross values, while all other numbers in the table are net benefits, which take costs into account.

Cesar, H., L. Burke, and L. Pet-Soede.2003. *The Economics of Worldwide Coral Reef Degradation*. Zeist, Netherlands: Cesar Environmental Economics Consulting (CEEC).
Burke, L., and J. Maidens. 2004. *Reefs at Risk in the Caribbean*. Washington, DC: World Resources Institute.
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Cooper, E., L. Burke, and N. Bood. 2008. *Coastal Capital: Belize The Economic contribution of Belize's coral reefs and mangroves*. Washington, DC: World Resources Institute.
Haider, W. et al. 2007. *The economic value of Guam's coral reefs*. Mangilao, Guam: University of Guam Marine Laboratory.
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Section 5. SUSTAINING AND MANAGING CORAL REEFS FOR THE FUTURE

PHOTO: MARK SPALDING

Despite an overall picture of rising levels of stress and of failing health and productivity on many of the world's coral reefs, people *can* live sustainably alongside reefs, deriving considerable benefits from them. The challenges, as societies grow and technologies change, are to understand the limits to sustainability and to manage human activities to remain within these limits.

This chapter focuses on the role of managed areas—notably marine protected areas (MPAs) and locally managed marine areas (LMMAs)—in protecting coral reefs. Such areas are the most widely used tools in coral reef management and conservation, and are the only tools for which sufficient data were available to conduct a global analysis. The chapter first briefly discusses the role of MPAs in reef management, and then presents the first-ever global assessment of reef coverage in managed areas, including an assessment of their effectiveness.

REEF PROTECTION APPROACHES

Beyond marine managed areas, there exists a broad range of other management approaches that support reef health and resilience. Numerous fisheries management tools—defining fishing grounds, catch limits, gears, fishing seasons, or the capture of individual species—are often applied independently from MPAs. Other management measures deal with marine-based threats; for example, through controls on discharge from ships, shipping lanes, and anchoring in sensitive areas. Land-based sources of sediment and pollution are managed through coastal zone planning and enforcement, sewage treatment, and integrated watershed management to reduce erosion and nutrient runoff from agriculture. A number of these approaches are touched on again in Section 6, which presents overall recommendations for reef conservation.

Communications, education, capacity building and economic incentives are all critical elements of reef protection, both for improving stakeholders' understanding of risks, and for ensuring sustained application of management measures. In many cases, simply informing communities of alternative management approaches can help, by raising awareness of coral reef goods and services and techniques to improve management of reef resources. Training reef resource users in improved management techniques can help ensure sustainable practices, and can help build local capacity for essential tasks such as monitoring fish stocks and reef condition. As for economic incentives, development of alternative livelihoods or direct financial interventions for reef protection are often critical to promoting

PHOTO: ARC CENTRE OF EXCELLENCE FOR CORAL REEF STUDIES

change. Financial interventions could include payments for ecosystem services, where local communities—as the owners or stewards of the reef ecosystem—are paid in cash or kind as compensation for adopting improved management practices that promote the continued provision of coral reef goods and services.

Marine Protected Areas

MPAs are one of the most widely used management tools in reef conservation. Simply defined, an MPA is any marine area that is actively managed for conservation.[62] Such a definition is broad. At one end of the scale, it includes areas with just a few restrictions on fishing or other potentially harmful activities, even without a strict legal framework. At the other, it extends to sites with comprehensive protections targeting multiple activities, including recreational boating, fishing, pollution, and coastal development.

The most consistent feature of MPAs is the provision of some control over fishing, although relatively few offer complete protection as "no-take" areas. Many MPAs place other restrictions on activities such as boat anchoring, tourism use, or pollution. In addition, they are valuable for research, education, and raising awareness about the importance of an area. Where sites extend into adjacent terrestrial areas, they may provide additional benefits, such as limiting coastal development or other damaging types of land use. Even ineffective sites offer a basis on which future, more effective, management can be built.

At their most effective, MPAs are able to maintain healthy coral reefs even while surrounding areas are degraded. They support recovery of areas that may have been overfished or affected by other threats, and they build resilient reef communities that can recover more quickly than non-protected sites from a variety of threats, including diseases and coral bleaching.[63-67] Of course, such areas are not immune from impacts. In most cases they offer only a proportional reduction in impacts, and degradation within MPAs is still a major problem.[68-70]

Locally Managed Marine Areas

The trend toward ownership of marine space or resources at local levels has led, in many areas, to more comprehensive management strategies. Locally managed marine areas (LMMAs) are marine areas that are "largely or wholly managed at a local level" by individuals or groups who are based nearby.[71] Such areas are managed for sustainable use rather than conservation *per se*, but most restrict resource use, and many contain permanent, temporary, or seasonal fishery closures. In this way, LMMAs in their entirety are similar to many MPAs with no-take zones or wider areas of restricted use.

The best examples of LMMAs are in the Pacific region, where most reefs were held in customary tenure by adjacent villages for centuries. Recent decades have seen more formal legal recognition of traditional ownership in countries such as Fiji, the Solomon Islands, and Vanuatu.[7] Such local management also facilitates the rapid transmission of ideas between neighboring communities and islands; for example, there has been a rapid proliferation of small no-take reserves in LMMAs across parts of Vanuatu.[71-74]

Scaled-up across multiple locations and communities, LMMAs could prove as important for coral reef conservation as the designation of very large-scale MPAs are in remote areas where local threats are minimal. For the sake of simplicity, references to MPAs for the remainder of this chapter also include LMMAs.

REEF STORY

Fiji: Local Management Yields Multiple Benefits at the Namena Marine Reserve

The Namena Marine Reserve surrounds the 1.6 km-long island of Namenalala and one of Fiji's most pristine reef ecosystems—the Namena Barrier Reef. In the mid-1980s, community members began noticing drastic declines in fish populations on the reef due to intensive commercial fishing. As a result, local chiefs and community leaders led a movement to ban commercial fishing that ultimately resulted in the establishment of a locally managed marine area (LMMA) network. The network consists of thirteen small, traditional closures and three large, district-wide no-take areas. To replace the income lost from the sale of commercial fishing licenses, the community introduced a user-based fee system collected from tourists who visit the reserve to swim, snorkel, or dive. The tourism revenue supports both the management of the reserve and a scholarship fund for local children. Managing the LMMA emphasizes an ecosystem-based approach, while also protecting traditional fishing practices. The reefs are recovering, providing an invaluable lesson in how community action combined with management knowledge can provide multiple benefits. See full story online at www.wri.org/reefs/stories.

TABLE 5.1 REGIONAL COVERAGE OF CORAL REEFS BY MPAS AND MPA EFFECTIVENESS

REGION	No. of MPAs	Reef Area in MPAs (sq km)	Total Reef Area (sq km)	Reefs in MPAs (%)	Sites rated	Proportion of rated sites (%)		
						Effective	Partial	Not effective
Atlantic	617	7,630	25,850	30	310	12	26	61
Australia	171	31,650	42,310	75	27	44	52	4
Indian Ocean	330	6,060	31,540	19	192	29	46	25
Middle East	41	1,680	14,400	12	27	33	37	30
Pacific	921	8,690	65,970	13	252	18	57	25
Southeast Asia	599	11,650	69,640	17	339	2	29	69
Global Total	**2,679**	**67,350**	**249,710**	**27**	**1,147**	**15**	**38**	**47**

The global coverage of MPAs

There are an estimated 2,679 coral reef protected areas worldwide, encompassing approximately 27 percent of the world's coral reefs (Table 5.1).[75] There is considerable geographic variation in this coverage: while more than three-quarters of Australia's coral reefs are within MPAs, outside of Australia the area of protected reefs drops to only 17 percent.

While these overall protection figures are high—few other marine or terrestrial habitats have more than one-quarter of their extent within protected areas—there is still cause for concern:

- First, most of the remaining 73 percent of coral reefs lie outside any formal management framework.
- Second, not all MPAs are effective in reducing human threats or impacts. Some sites, often described as "paper parks," are ineffective simply because the management framework is ignored or not enforced. In others, the regulations, even if fully and effectively implemented, are insufficient to address the threats within their borders. For example, a site that forbids the use of lobster traps, but permits catching lobsters by hand, may be just as thoroughly depleted of lobsters and suffer as much physical damage from divers as if the trap restrictions were not in place.

MAP 5.1. MARINE PROTECTED AREAS IN CORAL REEF REGIONS CLASSIFIED ACCORDING TO MANAGEMENT EFFECTIVENESS RATING

Notes: MPAs for coral reef regions were rated by regional experts according to their effectiveness level using a three-category scheme: (1) MPAs rated as "effective" were managed sufficiently well that local threats were not undermining natural ecosystem function; (2) MPAs rated as "partially effective" were managed such that local threats were significantly lower than adjacent non-managed sites, but there may still be some detrimental effects on ecosystem function; and (3) MPAs rated as "not effective" were unmanaged, or management was insufficient to reduce local threats in any meaningful way.

- Third, MPAs are rarely placed in areas where threats to reefs are greatest. This is highlighted by the recent creation of a number of very large MPAs in remote areas, where there are few or no local people and where threats are very low. Such MPAs are clearly important as potential regional strongholds, refuges, and seeding grounds for recovery, but do very little to mitigate current, urgent, local threats elsewhere.

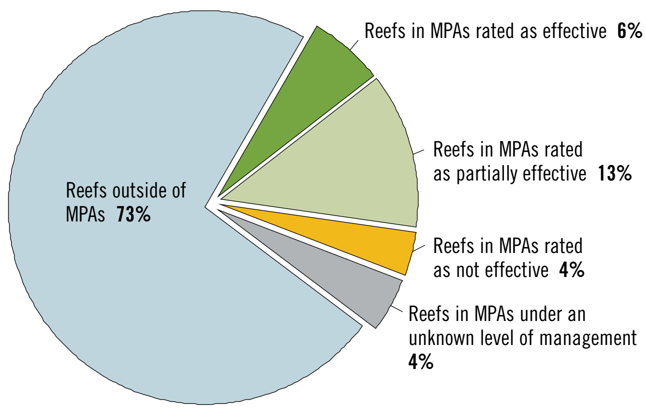

PHOTO: STACY JUPITER

A further problem is that many reefs are affected by threats that originate far away, particularly pollutants and sediments from poor land-use practices or coastal development in areas outside the MPA boundaries. While healthy reefs within MPAs may be more resilient to such stresses, MPAs alone are unlikely to provide sufficient protection, and other management approaches may be required to deal with these issues. In a few cases, MPAs have made considerable progress by engaging with adjacent communities to improve land management and reduce pollution and sediment runoff in adjacent areas.[76]

MANAGEMENT EFFECTIVENESS AND CORAL REEFS

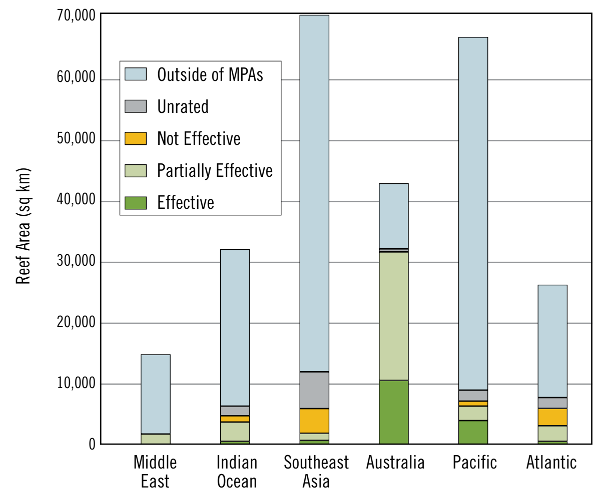
There is no single agreed-upon framework to assess how well MPAs reduce threats, although considerable resources are now available to support such assessments.[77] For this work, we undertook a rapid review—with a limited scope—to try to assess the effectiveness of MPA sites at reducing the threat of overfishing in as many sites as possible.[78] Our interest was to capture the ecological effectiveness of sites. Sites might thus be classed as ineffective or partially effective either (1) because of the failure of implementation, *or* (2) because the regulatory and management regime allowed for some ecological impacts. We obtained scores from regional experts for 1,147 sites (Map 5.1). These sites represent

FIGURE 5.1. CORAL REEFS BY MARINE PROTECTED AREA COVERAGE AND EFFECTIVENESS LEVEL



Note: The global area of coral reefs is 250,000 sq km (which represents 100% on this chart), including 67,350 sq km (27%) inside MPAs.

FIGURE 5.2. REEF AREA BY MPA COVERAGE AND EFFECTIVENESS



about 43 percent of our documented MPAs, but cover 83 percent of all reefs in MPAs by area (as we have scores for most of the larger MPAs). These results are summarized by region in Table 5.1.

Our analysis revealed that nearly half by number (47 percent) of the 1,147 coral reef MPAs for which we have ratings are considered ineffective in reducing overfishing. Furthermore, the proportion of ineffective sites is highest in the most threatened regions of world: 61 percent of MPAs in the Atlantic and 69 percent of MPAs in Southeast Asia are rated as ineffective.

Looked at by area of reef coverage rather than number of sites, these statistics are slightly more optimistic. We find that, by area, 6 percent of the world's reefs are located in MPAs rated as effectively managed and 13 percent are located in areas rated as partially effective. Four percent of reefs are in areas rated as ineffective, and 4 percent are in unrated areas. Figure 5.1 presents a global overview of coverage and effectiveness level, and Figure 5.2 provides a summary for each region.

Australia dominates the statistics, with three-quarters of reefs falling inside MPAs. This of course skews the global averages considerably; outside of Australia only 17 percent of reefs are inside MPAs. Of particular concern are the statistics for Southeast Asia, where only 3 percent of reefs are located within effective or partially effective MPAs.

In comparing the locations of MPAs with our modeled threat of overfishing, we found that MPAs did not have a large influence on reducing this threat. MPAs, particularly large sites, are located disproportionately in areas of low fishing pressure, and management effectiveness tends to be lower in areas of high fishing pressure. These results highlight the need for additional MPA coverage, especially in areas with high local pressures, and additional resources allocated to improve the effectiveness of existing MPAs in managing to reduce fishing pressure.

Section 6. CONCLUSIONS AND RECOMMENDATIONS

PHOTO: STEVE LINDFIELD

This report presents a deeply troubling picture of the world's coral reefs. Local human activities already threaten the majority of reefs in most regions, and the accelerating impacts of global climate change are compounding these problems. The extent and severity of threats to reefs, in combination with the critically important ecosystem services they provide, point to an urgent need for action to mitigate both local and global threats to coral reefs.

The report offers reasons for hope: reefs around the world have shown a capacity to rebound from even extreme damage, while active management is protecting reefs and aiding recovery in some areas. However, we need to improve, quickly and comprehensively, existing efforts to protect reefs and the services they provide humanity. It is encouraging that our collective ability to do so has become stronger, with new management tools, increased public understanding, better communications, and more active local engagement. We hope this new report will spur further action to save these critical ecosystems.

The array of measures to deal with the many threats to reefs must be comprehensive. Local threats must be tackled head-on with direct management interventions, while efforts to quickly and significantly reduce greenhouse gas emissions are of paramount concern not only for reefs, but for nature and humanity as a whole. At the same time, we may be able to "buy time" for coral reefs in the face of climate change, through local-scale measures to increase reef resilience to climate-related threats.

Toward these aims, we recommend the following specific actions involving a broad range of people at the local, national, regional, and international scales:

- **Mitigate threats from local human activities.**
  - *Reduce unsustainable fishing* by addressing the underlying social and economic drivers of overfishing; establishing sustainable fisheries management policies and practices; reducing excess fishing capacity and removing inefficient subsidies that encourage overfishing; enforcing fishing regulations; halting destructive fishing; improving and expanding MPAs to maximize benefits; and involving stakeholders in resource management.
  - *Manage coastal development* by implementing coastal zone planning and enforcement to encourage sound land development; protecting coastal vegetation; implementing erosion-control measures during construction; improving sewage treatment; linking marine and terrestrial protected areas; and developing tourism in sustainable ways.

Mangroves are vital nursery areas for fish, and they filter water and sediments coming off the land. Their maintenance or restoration can be a critical component of coral reef conservation.

- *Reduce watershed-based pollution* by reducing sediment and nutrient delivery to coastal waters through improved agriculture, livestock, and mining practices; minimizing industrial and urban runoff; and protecting and restoring riparian vegetation (plants along rivers and streams).
- *Reduce marine-based pollution and damage* by reducing at-sea disposal of waste from vessels; increasing regulation of ballast discharge from ships; designating safe shipping lanes and boating areas; managing offshore oil and gas activities; and using MPAs to protect reefs and adjacent waters.

■ **Enhance local-scale reef resilience.** A growing body of evidence has shown that by reducing local threats (including overfishing, nutrients, and sediment pollution), reefs may be able to recover more quickly from coral bleaching. Strategic planning to enhance local-scale reef resilience should target critical areas, building networks of protected areas that include different parts of the reef system, as well as including areas critical for future reef replenishment. Such efforts may represent an opportunity to "buy time" for reefs, until global greenhouse gas emissions can be curbed (Box 6.1).

■ **Develop integrated management efforts at ecosystem scales.** Plans that are agreed to by critically important sectors and stakeholders and that consider the relationships between ecosystems and human uses are most likely to avoid waste, repetition, and potential conflicts with other interventions and maximize potential benefits. For reefs, relevant approaches include ecosystem-based management, integrated coastal management, ocean zoning, and watershed management.

■ **Scale up efforts through international collaboration.** At all scales, we need political will and economic commitment to reduce local pressures on reefs and promote reef resilience in the face of a changing climate. It is also critical to replicate successful local and national approaches, and work internationally, using tools such as transboundary collaboration and regional agreements, improved international regulations to govern trade in reef products, and international agreements such as the UN Convention on the Law of the Sea, which helps regulate fishing, and the International Convention on the Prevention of Pollution from Ships (MARPOL), which regulates pollution from ships.

■ **Support climate change efforts.** Reef scientists recommend not only a stabilization of atmospheric CO_2 and other greenhouse gas concentrations, but also a slight reduction from our current level of 388 ppm (2010) to 350 ppm, if large-scale degradation of reefs is to be avoided. Attaining this challenging target will take time, and require immense global efforts. Individuals and civil society, NGOs, scientists, engineers, economists, businesses, national governments, and the international community all have a role to play to address this enormous and unprecedented global threat.

The complete closure of even small areas to fishing (no-take areas) can lead to rapid reef recovery, as well as to improved fishing in surrounding areas.

- **Build consensus and capacity.** Closing the gap between knowledge and results depends on action within the following key areas:
  - *Involve local stakeholders* in the decision making and management of reef resources.
  - *Train and build capacity* of reef stakeholders to manage and protect reefs, understand and argue for their value, spread awareness, and reduce vulnerability in reef-dependent regions.
  - *Conduct scientific research* to build understanding of how particular reefs are affected by local activities and climate change and how different stressors may act in combination to affect reef species; to explore factors that confer resilience to reef systems and species; to assess the extent of human dependence on specific reef ecosystem services; and to determine the potential for coastal communities to adapt to expected change.
  - *Conduct and publicize economic valuation* to highlight the value of reefs and the losses associated with reef degradation, and to aid in assessing the longer-term costs and benefits of particular management and development plans.
  - *Educate and communicate knowledge* to inform communities, government agencies, donors, and the general public about how current activities threaten reefs and why action is needed to save them, and to highlight examples of replicable conservation success.

BOX 6.1. BUILDING REEF RESILIENCE IN THE FACE OF CLIMATE CHANGE

While no direct management intervention can prevent damage to coral reefs from climate change, a large body of evidence shows that incorporating principles of reef resilience into management strategies can help. Such measures include the following:

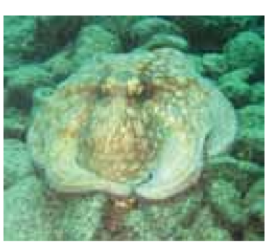
- Identify and protect areas of reef that are naturally likely to suffer less damage from climate change (i.e., areas of reef resistant to coral bleaching).
- Design management interventions to reduce local threats and improve reef condition, which will reduce climate-related impacts and/or hasten recovery after bleaching (i.e., enhance reef resilience).
- Establish MPA networks that include representation of all reef zones and habitats to reasonable extents.
- Protect critical areas, such as fish spawning locations.
- Design MPA networks to take advantage of reproductive connectivity (the flow of larvae) of reef ecosystems to maximize replenishment and regeneration following impacts.

  - *Provide support to policy makers and planners* in making long-term decisions that will affect the survival of coral reefs, as well as enhancing the ability of coastal communities to adapt to environmental changes and reef degradation.

- **Individual action.** Regardless of whether you live near or far from a coral reef, you can take action to help coral reefs:
  - *If you live near coral reefs:*
    - Follow local laws and regulations designed to protect reefs and reef species.
    - If you fish, do it sustainably, avoiding rare species, juveniles, breeding animals, and spawning aggregations.
    - Avoid causing physical damage to reefs with boat anchors, or by trampling or touching reefs.
    - Minimize your indirect impacts on reefs by choosing sustainably caught seafood and reducing household waste and pollution that reaches the marine environment.

- Help improve reef protection by working with others in your area to establish stronger conservation measures, participating in consultation processes for planned coastal or watershed development projects, and supporting local organizations that take care of reefs.
- Tell your political representatives why protecting coral reefs is important.

- *If you visit coral reefs:*
  - Choose sustainably managed, eco-conscious tourism providers.
  - Dive and snorkel carefully, to avoid physically damaging reefs.
  - Tell people if you see them doing something harmful to reefs.
  - Visit and make contributions to MPAs to support management efforts.
  - Avoid buying souvenirs made from corals and other marine species.
- *Wherever you are*:
  - Choose sustainably caught seafood.
  - Avoid buying marine species that are threatened or may have been caught or farmed unsustainably.
  - Help to prioritize coral reefs, the environment, and climate change issues within your government
  - Support NGOs that conserve coral reefs and encourage sustainable development in reef regions.
  - Educate through example, showing your family, friends, and peers why reefs are important to you.
  - Reduce your carbon footprint.



Whichever of these you do, encourage others to do the same.

Education and communication are essential to identifying appropriate solutions and building stakeholder support.

CONCLUSION

Coral reefs are vital to coastal communities and nations around the world. They are a source of inspiration to many more. The threats to the world's coral reefs, however, are serious and growing. This summary has portrayed the precarious state of coral reefs globally, encroached upon from all sides by numerous threats. In the face of such pressures, it is critical that we focus on practical, immediate responses, such as those highlighted above, to reduce and to reverse these threats. We are at a critical juncture. We know what is needed. Action now could ensure that coral reefs remain, and that they continue to provide food, livelihoods, and inspiration to hundreds of millions of people now, and for generations into the future.

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72. T. R. McClanahan, M. J. Marnane, J. E. Cinner, and W. E. Kiene. 2006. "A Comparison of Marine Protected Areas and Alternative Approaches to Coral-Reef Management." *Current Biology* 16 (14): 1408–1413.

73. C. Y. Bartlett, K. Pakoa, and C. Manua. 2009. "Marine reserve phenomenon in the Pacific islands." *Marine Policy* 33 (4): 99–104.

74. H. Govan. 2009. "Achieving the potential of locally managed marine areas in the South Pacific." *SPC Traditional Marine Resource Management and Knowledge Information Bulletin* 25:16–25.

75. For *Reefs at Risk Revisited*, we compiled a new global data set of MPAs near coral reefs. Our definition of a coral reef MPA includes all sites that overlap with coral reefs on the maps (1,712 sites), but also those that are known (from a variety of sources) to contain reefs. The primary source for this information is the *World Database of Protected Areas* (WDPA), which provided the majority of sites. In addition, *Reef Base* provided information on over 600 LMMAs for Pacific Islands and in the Phillipines. The Nature Conservancy provided data on over 100 additional sites on Indonesia, while reviewers provided about 50 additional sites.

76. Great Barrier Reef Marine Park Authority. 2009. *Great Barrier Reef Outlook Report 2009*. Townsville: Great Barrier Reef Marine Park Authority.

77. A number of studies have attempted to develop tools for assessing "management effectiveness," although to date such measures have only been applied to a small proportion of sites. These include: M. Hocking, D. Stolton, and N. Dudley. 2000. *Evaluating Effectiveness: a Framework for Assessing the Management of Protected Areas*. Gland, Switzerland: IUCN-World Conservation Union; and R.S. Pomeroy, J.E. Parks, and L.M. Watson. 2004. *How is you MPA doing? A guidebook of natural and social indicators for evaluating marine protected areas management effectiveness*. Gland, Switzerland: IUCN, WWF and NOAA.

78. Unlike some broader measures of management effectiveness, our primary interest was in ecological effectiveness. Given the challenges in any such survey, we reduced our focus simply to the consideration of the impact of an MPA on the threat of overfishing. Building on earlier work undertaken in the regional *Reefs at Risk* analyses for the Caribbean and Southeast Asia, as well as input from a number of other experts and a literature review, sites were scored using a three-point scale: (1) Effective, where the site is managed sufficiently well that in situ threats are not undermining natural ecosystem function; (2) Partially effective, where the site is managed such that in situ threats are significantly lower than adjacent non-managed sites, but there may still be some detrimental effects on ecosystem function; and (3) Ineffective, where the site is unmanaged, or management is insufficient to reduce in situ threats in any meaningful way. Given that the sampling drew on field knowledge by regional experts rather than field practitioners, there is likely to be a sampling bias toward better-known sites, with perhaps a higher proportion of effective sites than would be found overall.

PHOTO: STACY JUPITER

THE REEFS AT RISK SERIES

Reefs at Risk Revisited is part of a series that began in 1998 with the release of the first global analysis, *Reefs at Risk: A Map-Based Indicator of Threats to the World's Coral Reefs*. Two region-specific publications followed with *Reefs at Risk in Southeast Asia* (2002) and *Reefs at Risk in the Caribbean* (2004). These regional studies incorporated more detailed data and refined the modeling approach for mapping the impact of human activities on reefs. *Reefs at Risk Revisited*—an updated, enhanced global report—has drawn upon the improved methodology of the regional studies, more detailed global data sets, and new developments in mapping technology and coral reef science. The *Reefs at Risk Revisited* project was a multi-year, collaborative effort that involved more than 25 partner institutions (see inside front cover). The project has compiled far more data, maps, and statistics than can be presented in this report. This additional information is available at **www.wri.org/reefs** and on the accompanying *Reefs at Risk Revisited* data disk.

The **World Resources Institute (WRI)** is an environmental think tank that goes beyond research to create practical ways to protect the earth and improve people's lives. WRI's work in coastal ecosystems includes the Reefs at Risk series, as well as the Coastal Capital project, which supports sustainable management of coral reefs and mangroves by quantifying their economic value. (www.wri.org)

The Nature Conservancy (TNC) is a leading conservation organization working around the world to protect ecologically important lands and waters for nature and people. The Conservancy and its more than one million members have protected more than 480,000 sq km of land and engage in more than 100 marine conservation projects. The Conservancy is actively working on coral reef conservation in 24 countries, including the Caribbean and the Coral Triangle. (www.nature.org)

WorldFish Center is an international, nonprofit, nongovernmental organization dedicated to reducing poverty and hunger by improving fisheries and aquaculture. Working in partnership with a wide range of agencies and research institutions, WorldFish carries out research to improve small-scale fisheries and aquaculture. Its work on coral reefs includes ReefBase, the global information system on coral reefs. (www.worldfishcenter.org)

International Coral Reef Action Network (ICRAN) is a global network of coral reef science and conservation organizations working together and with local stakeholders to improve the management of coral reef ecosystems. ICRAN facilitates the exchange and replication of good practices in coral reef management throughout the world's major coral reef regions. (www.icran.org)

United Nations Environment Programme-World Conservation Monitoring Centre (UNEP-WCMC) is an internationally recognized center for the synthesis, analysis, and dissemination of global biodiversity knowledge. UNEP-WCMC provides authoritative, strategic, and timely information on critical marine and coastal habitats for conventions, countries, organizations, and companies to use in the development and implementation of their policies and decisions. (www.unep-wcmc.org)

Global Coral Reef Monitoring Network (GCRMN) is an operational unit of the International Coral Reef Initiative (ICRI) charged with coordinating research and monitoring of coral reefs. The network, with many partners, reports on ecological and socioeconomic monitoring and produces Status of Coral Reefs of the World reports covering more than 80 countries and states. (www.gcrmn.org)

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