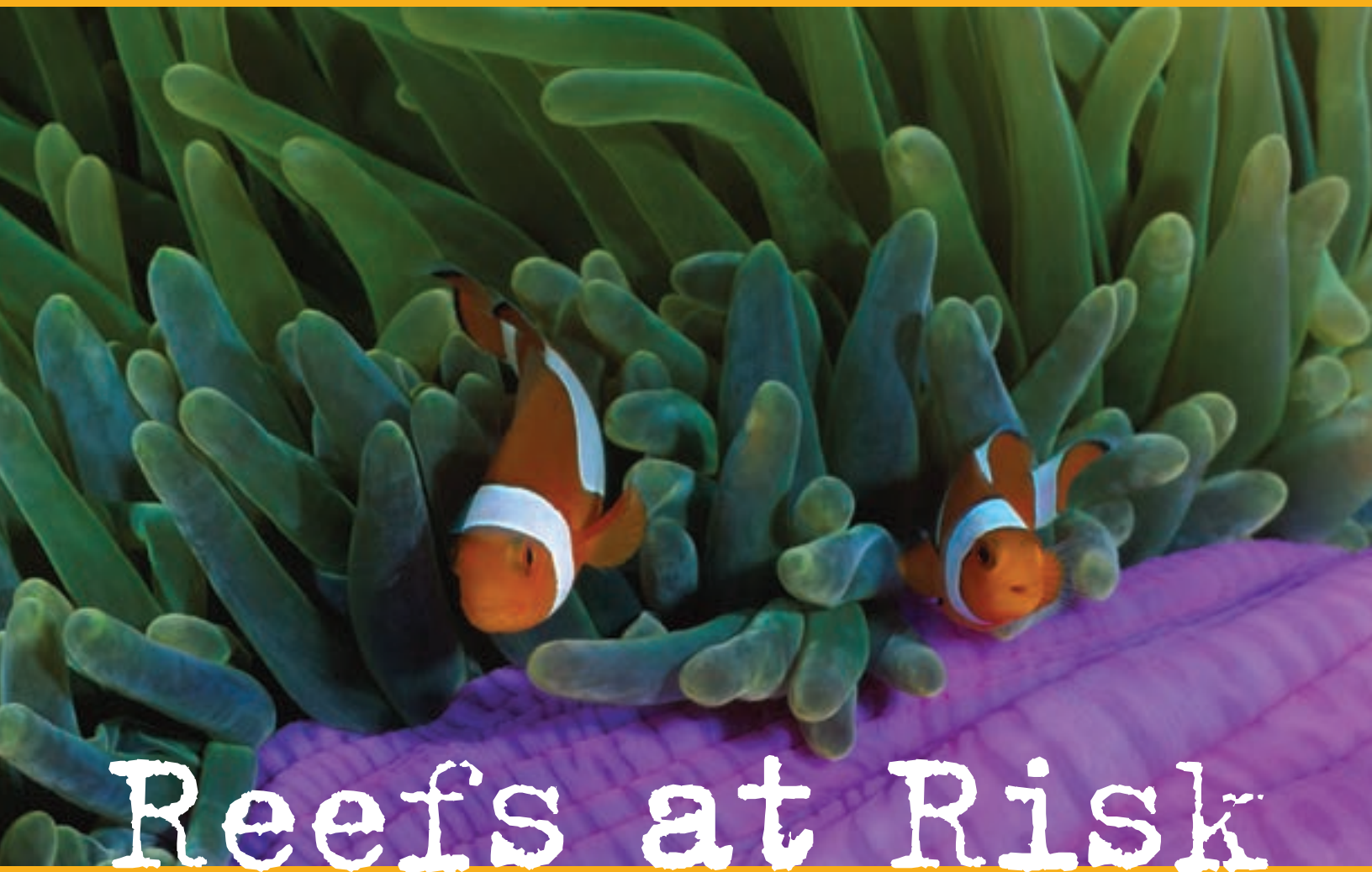

Reefs at Risk

in Southeast Asia

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Reefs at Risk in Southeast Asia

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The clownfish and anenome are two of the thousands of species found on coral reefs in Southeast Asia.

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FOREWORD

It is my pleasure to introduce this excellent report on Southeast Asian coral reefs. As an avid scuba diver and underwater photographer, I know first hand the beauty and value of coral reefs. As a former Head of State of the Philippines, I understand the reliance of Southeast Asian nations on their coastal and marine resources for food and the livelihoods of their people. I have always considered the protection and conservation of these reefs to be a high priority.

With more than 100,000 km^2 of coral reefs along the coastlines of Southeast Asia, the region has more coral reef area than any other part of the world. The reefs contain the highest coral biodiversity on the planet. This abundant endowment provides food for millions of people and generates millions of dollars in tourist revenue every year.

In the last 50 years, Southeast Asia has undergone rapid industrialization and population growth. As human populations have grown, so have pressures on the natural systems that sustain us. Economic market expansion has stimulated the construction of ports, airports, cities, and other infrastructure — often in ecologically sensitive areas. Coastal resources are being stressed at unsustainable rates. However, the exploitation is not only local in nature. The trade in live reef food fish and ornamentals has fueled regionwide overexploitation of lucrative species, often using destructive capture techniques. Many of the region's reefs have already been severely damaged.

Better information about the location of reefs and their accompanying threats is critical to alleviating the many pressures that threaten their future. Yet in most areas, resource managers lack the information they need for effective stewardship of coastal resources.

The Reefs at Risk project series is a valuable contribution to reducing this information gap. The global analysis released in 1998, *Reefs at Risk: A Map-Based Indicator of Threats to the World's Coral Reefs*, has been successful in raising awareness of the extent of human impact on coral reef ecosystems. It has also given the public useful information for evaluating relative threats around the world and identifying regions and countries most at risk. The analysis identified Southeast Asia as the region with the most threatened coral reefs.

This new analysis, *Reefs at Risk in Southeast Asia*, draws on much more detailed information and a more refined modeling approach, and it benefits from input and review by over a dozen universities and institutions within the region. The analysis highlights the value of coral reefs across the region, identifies the threats, and shows what will be lost unless current destructive activities are curtailed. The report and detailed accompanying data will be valuable to local resource managers for identifying threats and developing plans to mitigate them.

A commitment to sustainable development was a hallmark of my tenure as President of the Philippines. I continue to believe in the idea that development must be planned to minimize impacts in environmentally sensitive areas. We already have many laws to protect coral reefs — from bans on fishing with explosives and poisons to restrictions on fishing and criteria for coastal development. Enforcement of existing regulations is a first step toward protecting these resources. This report shows that it is in a country's economic self-interest to protect and properly manage its coastal resources for both current and future generations. I urge governments, policy makers, the private sector, and coastal communities to read it and seriously consider its recommendations.

FIDEL RAMOS | *President of the Philippines, 1992-1998*

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PHOTO: WOLCOTT HENRY

This report is dedicated to the memory of Don McAllister. Don had an undying love for the world's oceans and devoted his life to raising awareness about the wonders of the marine realm and promoting conservation of marine and coastal ecosystems. His tireless efforts and prolific writing will long be appreciated.

KEY FINDINGS

BIOLOGICAL ENDOWMENT

Southeast Asia contains nearly 100,000 km^2 of coral reefs, almost 34 percent of the world total. With over 600 of the almost 800 reef-building coral species, these reefs have the highest levels of marine biodiversity on earth. Southeast Asia is also the global center of biodiversity for coral reef fish, mollusks, and crustaceans. The region contains 51 of the world's 70 mangrove species and 23 of the 50 seagrass species.

ECONOMIC VALUE

The economic value associated with coral reefs in Southeast Asia is substantial. The value of the region's sustainable coral reef fisheries alone is US$2.4 billion per year. In addition, coral reefs are vital to food security, employment, tourism, pharmaceutical research, and shoreline protection. The coral reefs of Indonesia and the Philippines provide annual economic benefits estimated at US$1.6 billion and US$1.1 billion per year, respectively.

THREATS TO REEFS

The heavy reliance on marine resources across Southeast Asia has resulted in the overexploitation and degradation of many coral reefs, particularly those near major population centers. The main threats include overfishing, destructive fishing practices, and sedimentation and pollution from land-based sources. Human activities now threaten an estimated 88 percent of Southeast Asia's coral reefs, jeopardizing their biological and economic value to society. For 50 percent of these reefs, the level of threat is "high" or "very high." Only 12 percent of reefs are at low risk.

The Reefs at Risk project estimates that about 64 percent of the region's reefs are threatened by overfishing, and 56 percent are threatened by destructive fishing techniques. In addition, dredging, landfilling, mining of sand and coral, coastal construction, discharge of sewage and other activities associated with coastal development threaten about 25 percent of the region's coral reefs. Sediment and pollution from deforestation and agricultural activities threaten an estimated 20 percent of the region's reefs.

Over 90 percent of the coral reefs in Cambodia, Singapore, Taiwan, the Philippines, Vietnam, China, and the Spratly Islands are threatened, and over 85 percent of the reefs of Malaysia and Indonesia are threatened. Indonesia and the Philippines together possess 77 percent of the region's coral reefs and nearly 80 percent of all threatened reefs in the region.

Logging, destructive fishing practices, overfishing, and other activities that are damaging to coral reefs may be lucrative to individuals in the short-term. However, the net economic losses to society from diminished coastal protection, tourism and sustainable fisheries usually outweigh the short-term benefits. Over a 20-year period, current levels of blast fishing, overfishing, and sedimentation could cost Indonesia and the Philippines more than US$2.6 billion and US$2.5 billion, respectively.

Global climate change is also a significant threat to coral reefs in Southeast Asia. Elevated sea-surface temperatures have resulted in more severe and more frequent coral bleaching. The 1997–98 El Niño Southern Oscillation (ENSO) event triggered the largest worldwide coral bleaching event ever recorded. In Southeast Asia, an estimated 18 percent of the region's coral reefs were damaged or destroyed.

MANAGEMENT

Effective management is key to maintaining coastal resources, but, is inadequate across much of the region. Some 646 marine protected areas (MPAs) include an estimated 8 percent of the region's coral reefs. Of the 332 MPAs whose management effectiveness could be determined, only 14 percent were rated as effectively managed, 48 percent have partially effective management, and 38 percent have inadequate management.

THE LACK OF INFORMATION

Despite widespread recognition that coral reefs are severely threatened, information about the status and nature of the threats to specific reef areas is limited. This lack of information inhibits effective decisionmaking concerning coastal resources. The Reefs at Risk project was developed to address this deficiency by creating standardized indicators that raise awareness about threats to coral reefs and highlight the linkages between human activity and coral reef condition.

CHAPTER 1. INTRODUCTION

PHOTO: WOLCOTT HENRY

Corals are found from the icy waters of the Arctic and Antarctic to the balmy, crystal-clear seas of the tropics. Yet coral reefs, with their majestic walls and enormous limestone skeletons, are found only in the swath of oceans around the equator. In this tropical band, biology, chemistry, and climate meet the exacting balance required for the survival of reef-building corals. Reef-building corals thrive in this delicate equilibrium, creating one of the most productive and diverse ecosystems in the world. Southeast Asia is the heart of this incredible diversity, holding more than 77 percent of the almost 800 reef-building coral species that have been described by scientists.

People have coexisted with coral reef ecosystems in Southeast Asia for thousands of years. With more than 350 million people living within 50 km of the coast,[1] coral reefs are important not only in local communities' cultures, but are also critical to the economic health of these nations. Coral reef fisheries, in particular, are a vital source of food and employment. Fisheries dedicated to the live food fish trade, the ornamental trade, and local subsistence economies generate billions of dollars each year. The total annual net benefit of sustainable coral reef fisheries across Southeast Asia is estimated to be US$2.4 billion per year.

In addition to fisheries, coral reefs provide many other exceptionally valuable services. Their beauty draws millions of tourists from around the world each year. Corals themselves possess a yet untold value as biochemical material for pharmaceuticals and other products. Reefs also facilitate the growth of mangroves and seagrasses, provide sheltering habitat essential to a variety of marine species, and help prevent shoreline erosion. The coral reefs in the Malacca Straits alone have a total assessed economic value of US$563 million for tourism, shoreline protection, fishery resources, and their research potential.[2]

Despite their worth, coral reefs in Southeast Asia and throughout the world face unprecedented threat from human activities. The population explosion during the last 50 years is driving many of the current pressures and is creating elevated, often unsustainable demand on both the terrestrial and marine resources of the region. These pressures are jeopardizing the incredible value of coral reefs, whose loss would have significant economic impacts for the region.

The most prevalent threat to coral reefs in Southeast Asia is overexploitation. Rapid population growth has vastly increased fishing pressure on reefs across the region. Lacking other sources of income, fishers have no incentive to leave the industry

BOX 1. WHAT IS A CORAL REEF?

During the last several centuries and even today, corals have been mistaken for rocks or plants despite the fact that they are animals. In their simplest form, corals may only have a single polyp that has a tube-like body with a mouth on top that is surrounded by a ring of tentacles. In many coral species, these individual polyps form numerous, identical clones in dense formations called colonies.

Although all coral species can use stinging tentacles to catch prey, most tropical corals obtain a large proportion of their food from a unique symbiosis. Living within the tissues of corals are thousands of microscopic algae called zooxanthellae, which derive energy directly from sunlight through photosynthesis. Corals can obtain much of their energy and oxygen requirements directly from zooxanthellae. In return, the algae receive shelter from predators and use the carbon dioxide produced by the corals in their metabolic processes. This tight association is highly efficient, allowing corals to survive and grow even in nutrient-poor waters. The success of this relationship can be seen in the great diversity and ancient lineage of corals, which first evolved over 200 million years ago.

Many corals lay down some form of skeleton to support their simple bodies. Soft corals and fan corals have skeletons made of protein. However, those that build reefs are a subset of corals that lay down skeletons of calcium carbonate or limestone. These corals are mostly from the family Scleractinia and are sometimes known as hermatypic or reef-building. Today, almost 800 species of scleractinian corals have been described. Some reefs consist of small patches of coral and associated species, but others can be giant structures tens of kilometers wide.

Although corals may dominate specific zones of reefs, seagrasses and other organisms are also essential components of reef structures. Stress from storms, added nutrients, and increased sedimentation can cause naturally coral-dominated zones to be replaced with algae. When algae overtake former coral zones, it is often a sign that the reef is unhealthy. Healthy coral reefs constitute the most diverse of all known marine ecosystems, with a greater array of life forms than any other ecosystem on the planet.

or reduce fishing pressure. In addition, the enticing profits to be made in the live reef food fish and aquarium trades have led to widespread target species overfishing by both local and foreign vessels and to the proliferation of destructive fishing techniques. Practices like blast and poison fishing not only destroy the natural resource base for future fishing, but also have detrimental effects across the ecosystem. Even without these destructive methods, current fishing levels and methods are unsustainable in most areas. If fishing in Southeast Asia is not reduced to more sustainable levels, both coral reefs and food security will be further imperiled.

High levels of development and land-use changes in the last 20 years have also been major threats to coral reefs in the region. Massive deforestation and the construction of roads, airports, channels, ports, and buildings, including tourist resorts, have substantially increased sediment and nutrient loads in coastal areas. Increased sediments can smother corals, and added nutrients can cause the coral to become overgrown with algae. A major challenge for the region in the coming years will be to restrict growth or manage development in ecologically sensitive areas before further degradation occurs.

One of the least understood threats to coral reefs is coral bleaching, a stress response that is often correlated to elevated sea surface temperatures and global climate change. The 1997–98 El Niño Southern Oscillation (ENSO) was the strongest on record, triggering massive coral bleaching throughout the Pacific and Indian Oceans.[3] Worldwide economic losses from this event are estimated between US$700 million to US$8 billion over the next 20 years.[4]

The cumulative threats of overexploitation, land-use changes, pollution, and coastal development, coupled with the effects of global climate change, foretell an uncertain future for Southeast Asia's coral reefs. Despite widespread recognition that coral reefs are severely threatened, information regarding particular threats to specific reefs is limited. Only a small percentage of reefs have ever been studied, and an even smaller number have been monitored over time using consistent methods.[5] In addition, these data are rarely consolidated in a central

PHOTOS: TONI PARRAS

Most corals are made up of thousands of tiny polyps, like those pictured above. Over 600 species of hard coral are found within Southeast Asia, growing in an incredible array of shapes and colors.

repository where copies would be widely accessible.

This lack of information inhibits effective decisionmaking concerning coastal resources. The Reefs at Risk in Southeast Asia (RRSEA) project was designed to address this information deficiency through an extensive data compilation and improvement effort. Understanding which human activities negatively impact which reefs is key to future conservation and planning efforts. The goal of the RRSEA project is to raise awareness about threats to coral reefs and provide resource managers with specific information and tools to manage coastal habitats in Southeast Asia more effectively.

ABOUT THE PROJECT

The Reefs at Risk in Southeast Asia project is a follow-up to the global Reefs at Risk analysis completed in 1998.[6] The global analysis identified Southeast Asia as the region with both the highest level of biodiversity and the greatest degree of threat to its reefs. RRSEA began in 1999 with the objective of refining the original data and model for the region and providing a tool for analyzing the impacts of human activities on coral reefs. The new analysis is 16 times more detailed than the global study and incorporates innovations like the consideration of natural vulnerability, management effectiveness of protected areas, and economic data. RRSEA was implemented in collaboration with more than 20 partner institutions in the region.

This two-year collaborative effort has resulted in the compilation and integration of far more information than can be presented in this report, which is designed as a summary of the project. Additional information is available at www.wri.org/wri/reefsatrisk. Included on the RRSEA website is information about particular reefs, tourism, management, biodiversity, monitoring, and more. In addition, all datasets are available for downloading.

RRSEA is the first in a series of regional analyses. A similar project focusing on Caribbean reefs, Reefs at Risk in the Caribbean, was initiated in 2001.

THE SOUTHEAST ASIA REGION

The region included in this study is larger than what is traditionally considered Southeast Asia, stretching from 30°N to 11°S latitude, including coral reefs as far north as Japan, Taiwan, and China and as far west as Myanmar and the Andaman Islands of India. It includes only small portions of China and Japan but the entirety of the other nations traditionally considered part of Southeast Asia. Throughout this study, the term Southeast Asia refers to this area, which possesses almost 34 percent of the world's coral reefs. Table 1 presents some important geographic and socioeconomic characteristics of the countries included in the RRSEA analysis.

PHOTO: WOLCOTT HENRY

Nudibranchs are one of the many amazing lifeforms found on coral reefs.

TABLE 1. BASIC GEOGRAPHIC AND ECONOMIC INDICATORS[a]

COUNTRY	COASTLINE LENGTH (KM)	POPULATION (2000) (THOUSANDS)	PER CAPITA GDP (1997) (CURRENT US$)	PER CAPITA FISH CONSUMPTION (1997) (KG/YR)	FISH PROTEIN AS A PERCENTAGE OF TOTAL PROTEIN SUPPLY (1997)	FISH PROTEIN AS A PERCENTAGE OF TOTAL ANIMAL PROTEIN (1997)
Indonesia	95,181	212,107	1,124	18	10	53
Philippines	33,900	75,967	1,156	30	20	43
Spratly and Paracel Islands	N/A	N/A	N/A	N/A	N/A	N/A
Malaysia	9,323	22,244	4,873	56	20	35
Japan[b]	N/A	N/A	42,719	66	25	46
Thailand	7,066	61,399	2,957	34	19	42
Myanmar	14,708	45,611	N/A	18	6	45
Vietnam	11,409	79,832	315	17	9	39
China[b]	N/A	N/A	671	26	8	24
Taiwan	2,007	N/A	N/A	39	11	22
Brunei Darussalam	269	328	N/A	21	7	14
Singapore	268	3,567	28,619	34	9	17
Cambodia	1,127	11,168	303	9	5	28

SOURCES:

1. Coastal length: Derived from "World Vector Shoreline," United States Defense Mapping Agency, 1989. L. Pruett and J. Cimino, "Global Maritime Boundaries Database (GMBD), Veridian-MRJ Technology Solutions," in Burke et al. *Pilot Analysis of Global Ecosystems: Coastal Ecosystems* (Washington, DC: WRI, 2001). This standardized estimate is different from previously published estimates for many countries.
2. Population: United Nations (U.N.) Population Division, "Annual Populations 1950-2050 (The 1998 Revision)," on diskette (New York: U.N., 1999).
3. Per Capita Gross Domestic Product (GDP): The World Bank, "World Development Indicators 1999," on CD-ROM (Washington, DC: Development Data Group, The World Bank, 1999).
4. Per Capita Fish Consumption and Fish Protein as Percentage of Total Protein and Animal Protein: Edmondo Laureti, compiler, "Fish and Fishery Products: World Apparent Consumption Statistics Based on Food Balance Sheets (1961-1997)," FAO Fisheries Circular 821, Revision 5 (Rome: FAO, 1999).

NOTES:

a. Countries are ordered by reef area, as in Table 2.

b. Because most of the coastline and population of Japan and China are outside of the RRSEA study area, coastline and population data are not included for these countries.

N/A = not available

CHAPTER 2. BIODIVERSITY OF SOUTHEAST ASIAN CORAL REEFS

PHOTO: WOLCOTT HENRY

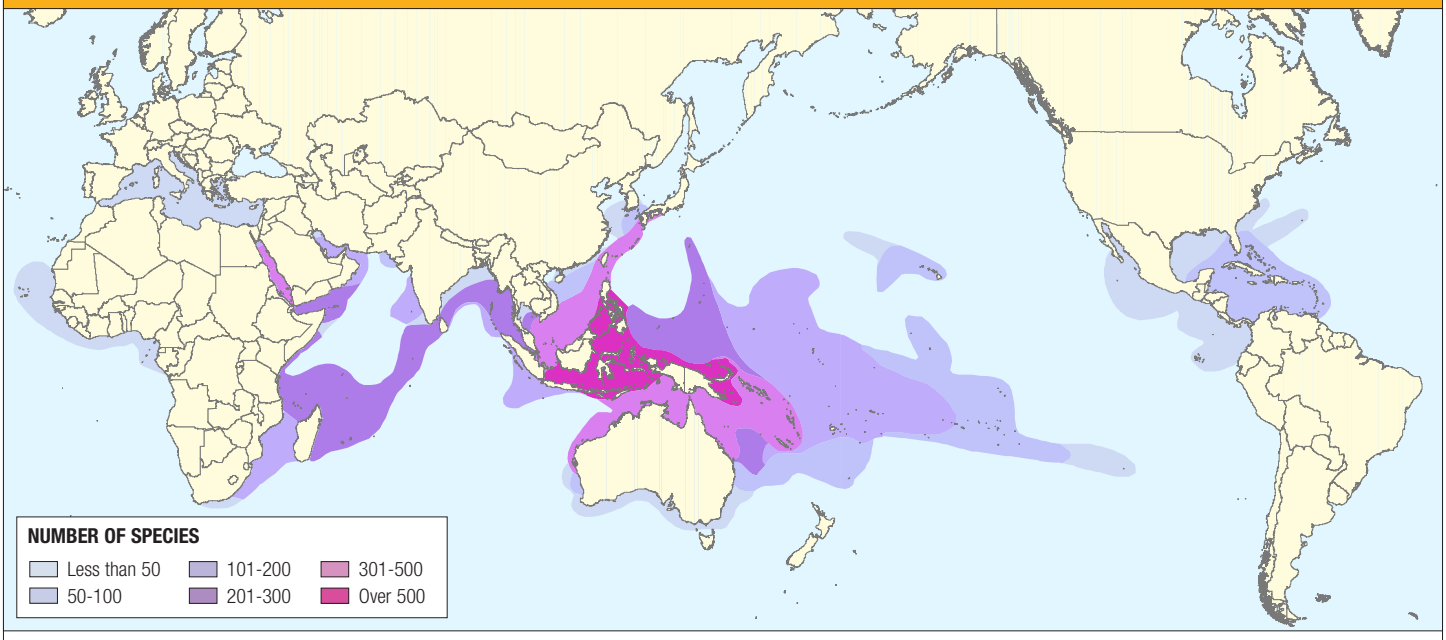
Southeast Asia's coral reefs have the highest degree of biodiversity of all the world's coral reefs. This extraordinary diversity generates high productivity, providing food for millions of people within the region and beyond. Scientists are just beginning to understand the potential diversity of coral reefs; it is estimated that only 10 percent of marine species associated with coral reefs have been identified and described.[7]

THE EPICENTER OF GLOBAL MARINE BIODIVERSITY

Scientists have found more coral species around a single island in Southeast Asia than have been identified for the entire Caribbean.[8] Map 1, which shows coral reef diversity worldwide, illustrates the high concentration of species in the region, particularly in the broad Indo-Malayan Triangle, stretching from the Philippines to the southern islands of Indonesia and encompassing all of Java east to New Guinea. This extraordinary diversity has built up over geological timescales, but it is maintained through the wide array of physical conditions—salinity, wave exposure, depth, temperature, and turbidity—found across Southeast Asia that fulfill the requirements of a broad range of species.[9] The region contains more than 600 of the nearly 800 reef-building coral species (Scleractinia) found worldwide.[10] *(See Map 1.)*

The diversity of coral reefs is not limited to coral species. Over 1,650 fish species have been recorded in eastern Indonesia alone, the majority of which are associated with reefs.[11] This same diversity is also found in related coastal ecosystems. Southeast Asia contains over 61,000 km^2 of mangroves, approximately 35 percent of the world's total. It holds nearly 75 percent of the world's mangrove species and over 45 percent of seagrass species.[12] *(See Box 2 and Table 2.)*

MAP 1. PATTERNS OF DIVERSITY IN REEF-BUILDING SCLERACTINIAN CORALS



Source: J.E.N. Veron and Mary Stafford-Smith. *Corals of the World* (Cape Ferguson: AIMS,2000).

BOX 2. RELATED ECOSYSTEMS: MANGROVES AND SEAGRASSES

In addition to coral reefs, two other coastal ecosystems are commonly found in tropical areas — mangrove forests and seagrass beds. Mangrove forests grow in the intertidal range, lining considerable areas of the coasts of Southeast Asia. Farther offshore, groups of flowering plants known as seagrasses form extensive "meadows" over soft sediments. In many areas, the typical coastal profile moves from mangroves to shallow waters with seagrass beds to offshore coral reefs. Mangroves, seagrasses, and coral reefs can all occur in isolation, but research has shown substantial interaction among the ecosystems where they exist together.

These interactions are both physical and biological. Mangroves and seagrasses bind soft sediments, facilitating coral reef development in areas that might otherwise have too much silt for coral growth. Mangrove and seagrass ecosystems are also highly productive and play a significant role in the health of some fisheries. They not only support substantial fisheries within their waters, but they also help maintain many commercially important offshore species that utilize mangrove or seagrass areas as spawning and nursery grounds. Like coral reefs, mangroves protect coastal communities by stabilizing sediments and preventing shoreline erosion. In turn, reefs buffer wave impacts, helping to minimize erosion of the soft sediments that mangroves and seagrasses need to grow.

Mangroves and seagrasses are being destroyed by many of the same activities that threaten coral reefs. Land reclamation, pollution, sedimentation, dredging, and trawling can all damage seagrass beds. Clearcutting for timber, fuelwood, and the creation of aquaculture farms particularly endangers mangroves.[a] Recent estimates indicate that by the early 1990s both Malaysia and Myanmar had lost almost 75 percent of their original mangrove cover; Thailand had lost 84 percent; and Vietnam 37 percent. Older estimates have suggested that by the late 1980s, the Philippines had lost 67 percent of its mangroves, Brunei 20 percent, and Indonesia 55 percent.[b] The lack of adequate maps thwarts efforts to calculate seagrass losses accurately.

a. M.D. Spalding, F. Blasco, and C.D. Field, eds., *World Mangrove Atlas* (Okinawa: The International Society for Mangrove Ecosystems, 1997).
b. L. Burke et al., *Pilot Analysis of Global Ecosystems: Coastal Ecosystems* (Washington, DC: WRI, 2001), p. 19.

TABLE 2. CORAL, MANGROVE, AND SEAGRASS BIODIVERSITY IN SOUTHEAST ASIA

COUNTRY	REEF AREA (KM^2)[a]	PREDICTED CORAL DIVERSITY[b]	MANGROVE AREA (KM^2)	NO. OF MANGROVE SPECIES	NO. OF SEAGRASS SPECIES[c]
Indonesia	51,000	581	42,550	45	13
Philippines	26,000	561	1,610	30	19
Spratly and Paracel Islands	5,700	362	N/A	N/A	N/A
Malaysia	4,000	>550[d]	6,420	36	12
Japan	2,600	420	4	11	8
Thailand	1,800	357	2,640	35	15
Myanmar	1,700	270	3,790	24	3
Vietnam	1,100	355	2,530	29	9
China	900	150	340	23	N/A
Taiwan	700	389	340	23	5
Brunei Darussalam	200	N/A	170	29	4
Singapore	50	186	6	31	11
Cambodia	40	272	850	5	1
Regional Total	**95,790**	**N/A**	**61,250**	**51**	**23**

SOURCES:

1. Reef area estimates: calculated by WRI based on 1 km resolution gridded data sets assembled under the RRSEA project, rounded to two significant digits.
2. Predicted coral diversity: J.E.N. Veron and Mary Stafford-Smith, *Corals of the World* (Cape Ferguson: Australian Institute of Marine Science, 2000), subsequently revised by J.E.N. Veron.
3. Mangrove area and number of mangrove species: largely derived from M.D. Spalding, F. Blasco, and C.D. Field, eds., *World Mangrove Atlas* (Okinawa: The International Society for Mangrove Ecosystems, 1997), with updates by M.D. Spalding.
4. Number of seagrass species: World Conservation Monitoring Centre, unpublished data.

NOTES:

a. Ownership of large areas of reefs in the South China Sea is disputed by two or more nations. These areas include the Spratly and Paracel Islands, which have been treated separately in this analysis.
b. These data represent predicted numbers of species by country. They are estimates, rather than observed species counts and are based on predicted species distributions. The estimates are a sum of all predicted species, so they may be exaggerated for some countries.
c. This database is still under development and estimates are likely to be conservative.
d. Predicted coral diversity is 367 for Peninsular (West) Malaysia and 550 for East Malaysia.
N/A = not available

PHOTO: MARK SPALDING

Mangrove roots trap sediments, reducing silt in water, and thereby enhancing areas for coral reef development.

SETTING PRIORITIES FOR CONSERVATION

Few coral reef areas in Southeast Asia remain unaffected by human activities. In the past, reefs in remote locations were relatively pristine. However, isolation is no longer a guarantee of good reef condition, as evidenced by the degradation of reefs in the Morotai Islands (North Maluku).[13] Even reefs in good condition like the Spratly Islands, Tubbataha, and eastern Indonesia are threatened by human activities such as destructive fishing practices. The reefs that are still largely unaffected by people may be particularly important to the survival of species and the recovery of neighboring areas. Relatively "pristine" reefs not only harbor a diverse suite of corals and fish, but they also provide an important source of larvae for degraded reefs.

PHOTO: WOLCOTT HENRY

The eggs and larvae of corals and fish can be carried by currents hundreds of kilometers, making them important potential genetic sources for other locations.

Active management and protection are key to maintaining the ecological integrity of the region. Priority areas should include not only places that have high species richness, but also locations that contain a broad diversity of habitat types or unique species or assemblages. The location of protected areas should also consider factors of connectivity between reefs. *(See Box 3.)*

Many conservation organizations are developing and applying prioritization schemes for marine conservation, typically focusing on biodiversity. The Reefs at Risk Threat index makes it possible to integrate socioeconomic considerations and human pressures in prioritization efforts.

BOX 3. LARVAL CONNECTIVITY

Maintaining and restoring natural biodiversity to degraded reefs relies on the availability of new juveniles. Almost all reef organisms have a larval phase; the larvae can drift through the ocean, often for days or weeks. In the majority of cases, the larvae settle on the reef where they were produced.[a] Yet, ocean currents can sweep some larvae over considerable distances to new reefs. In this way, they may be critical to genetic flow and the repopulation of damaged reefs. Identifying reefs that are "larval storehouses," particularly "source" reefs that lie upstream of others in the main current flow, is part of the emerging study of larval connectivity. Such information has important implications for proposed marine protected area networks, reef rehabilitation projects, and fisheries management.[b]

Regional-scale patterns of larval connectivity are not well understood. Many larvae do not reach other reefs because they face unfavorable currents or cannot survive because of pollutants or a lack of nutrients. Studies on the mantis shrimp, *Haptosquilla pulchella*, in 11 reef systems of central Indonesia have shown highly distinctive genetic structures on either side of the Makassar Strait, where currents run north and south but not crosswise.[c] Thus reefs on one side of the Strait probably cannot be relied on to reestablish populations on the other side. However, there is evidence that larval sources from the South China Sea[d] and the Northern Philippines[e] supply the surrounding reefs.

Few, if any, existing management regimes consider larval connectivity during planning. This shortcoming may leave certain reefs vulnerable to degradation even when they are officially protected.

a. S.E. Swearer et al., "Larval Retention and Recruitment in an Island Population of a Coral-Reef Fish," *Nature* 402 (1999): 799-802.
b. J.A.H. Benzie, "Genetic Structure of Marine Organisms and Southeast Asian Biogeography," in R. Hall and J.D. Holloway, eds., *Biogeography and Geological Evolution of Southeast Asia* (Leiden, The Netherlands: Backhuys Publishers, 1998).
c. P.H. Barber et al., "A Marine Wallace's Line?" *Nature* 406 (2000): 692-93.
d. J.W. McManus, "The Spratly Islands: A Marine Park?" *Ambio* 23 (1994): 181-86.
e. J.E.N. Veron, *Corals in Space and Time: The Biogeography and Evolution of the Scleractinia* (Sydney: University of New South Wales Press, 1995); J.E.N. Veron and P.R. Minchin, "Correlations Between Sea Temperature, Circulation Patterns, and the Distribution of Hermatypic Corals of Japan," *Continental Shelf Research* 12 (1992): 835-57.

CHAPTER 3. ESTIMATING HUMAN THREATS TO CORAL REEFS: THE REEFS AT RISK INDEX

PHOTO: EDMUND GREEN

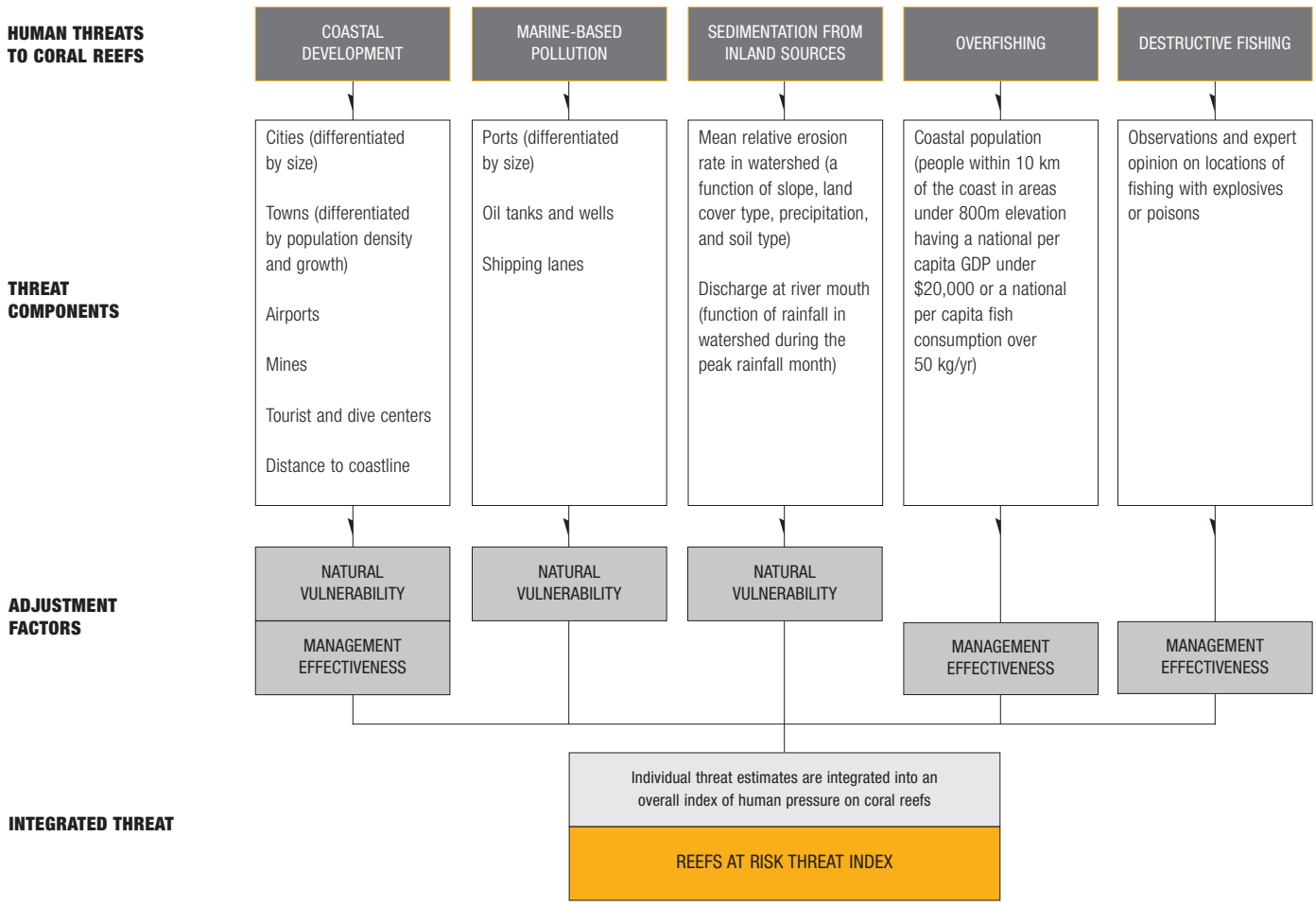
Across Southeast Asia, monitoring capacity varies widely among countries, resulting in uneven and often uncomparable information about reef conditions.[14] The RRSEA model aims to create standardized indicators that raise awareness about threats to coral reefs, identify areas most at risk, and highlight the linkages between human activity and coral reef condition.

PRINCIPLES

The model produces map-based indicators of human pressure on coral reefs from five broad categories: coastal development, overfishing, destructive fishing, marine pollution, and sedimentation and pollution from inland activities. The modeling approach involves identifying component sources of stress that can be mapped for each threat category. These "stressors" include simple population and infrastructure features such as cities, ports, and oil rigs as well as more complex modeled layers of riverine inputs. Once these components have been selected, model rules are developed for translating them into measures of threat. These guidelines typically involve the development of distance-based rules by which the level of threat declines with distance from the location of a stressor. Each threat estimate for the five categories is developed with considerable input from scientists in the region and is calibrated against available information from observed impacts to coral reefs or from satellite imagery. With some variation, this process is similar for each of the five threat categories. *(Figure 1 provides an overview of the threat categories and stressors. See Appendix 1 for more details on the modeling methodology.)*

The RRSEA model accounts for the effects of management and incorporates natural features that influence how human pressures impact coral reef ecosystems. Natural features such as depth, degree of embayment, fetch, and tidal range that affect flushing rates were integrated into the model to estimate how

FIGURE 1. OVERVIEW OF REEFS AT RISK THREAT MODEL



susceptible a reef may be to pollution or sedimentation. The threat estimates for coastal development, marine-based pollution, and inland pollution and sedimentation were adjusted for natural vulnerability. Similarly, the threat estimates for overfishing, destructive fishing, and coastal development were adjusted to take into account how effective management mitigates those threats. The threat estimates from the five adjusted threat indicators were then combined to create a map of integrated threat for the region — the Reefs at Risk Threat Index.

The index is designed to highlight areas where, in the absence of good management, coral reef degradation might be occurring or where it is likely to happen in the near future given ongoing levels of human activity. The index provides a regionally consistent indicator of human pressure on coral reefs that serves as a proxy guide to coral reef condition across Southeast Asia.

PHOTO: UNIVERSITY OF THE PHILIPPINES, MARINE SCIENCE INSTITUTE

Scientists and managers from across the region contributed to the RRSEA database and model development.

PHOTOS: LAURETTA BURKE

Sewage discharge from a coastal development coupled with intense visitor pressure have killed large sections of this reef.

LIMITATIONS

Pressures associated with elevated sea-surface temperature (SST) anomalies and coral bleaching have not been incorporated into the model. At this time, the data are too coarse and local heterogeneity is so strong that predicting the impact of SSTs on the condition of coral reefs is not possible. However, the general threats from bleaching are discussed in Chapter 4.

By their very nature, model predictions are not perfect. The RRSEA model is a simplification of human activities and complex natural processes. The threat indicators gauge current and potential risks associated with human activities, not actual reef condition. Consequently, the model relies upon available data and predicted relationships but cannot capture all aspects of the dynamic relationships between people and coral reefs across Southeast Asia. Reefs classified as low risk are not necessarily healthy. In fact, some scientists argue that all reefs in the region have already been adversely affected by human activity.[15] The model inevitably underestimates threat in some areas and overestimates it in others. Because the model does not capture threats from commercial overfishing, including trawling, and cannot predict sediment plumes in areas with small watersheds, it probably underestimates threat in these two categories. Some reefs classified as threatened may be relatively pristine owing to physical factors or management mitigation not identified in the model. For instance, all tourism centers or settlements of a specific size do not exact the same pressure, but the model treats them uniformly.

The picture of reef health in Southeast Asia is extraordinarily dynamic. New development projects are constantly underway. Land use in the region changes from year to year because of agricultural conversion, massive fires, and logging. The RRSEA analysis used regionally consistent datasets even when better national-level data were available in order to gain a more consistent regional portrait. The maps presented in this report are only static images of the pressure on reefs. Conditions on individual reefs may be different from the threat presented on the maps.

CHAPTER 4. THREATS TO CORAL REEFS IN SOUTHEAST ASIA

PHOTO: REEFBASE / T. HEEGER

The coral reefs of Southeast Asia are the most threatened in the world. Like all reefs, they suffer occasional impacts from storms and other natural phenomena. However, burgeoning human populations in the region are putting coral reefs under unprecedented pressure. Stresses can be chronic, such as routine discharge of sewage, frequent sedimentation, and long-term overfishing at unsustainable levels. They can also be acute, as in the case of blast fishing or a month of unusually warm water temperatures. Although coral reefs can adapt to chronic stresses in some cases, ongoing pressure prevents recovery from acute stresses and can result in lower levels of biodiversity.[16] In the past 20 years, coral bleaching associated with anomalous sea-surface temperatures has also become a new major threat. This chapter examines the five threats included in the Reefs at Risk model and discusses the broad trends of coral bleaching in the region. *(See Appendix 1 for additional detail on the model.)*

COASTAL DEVELOPMENT

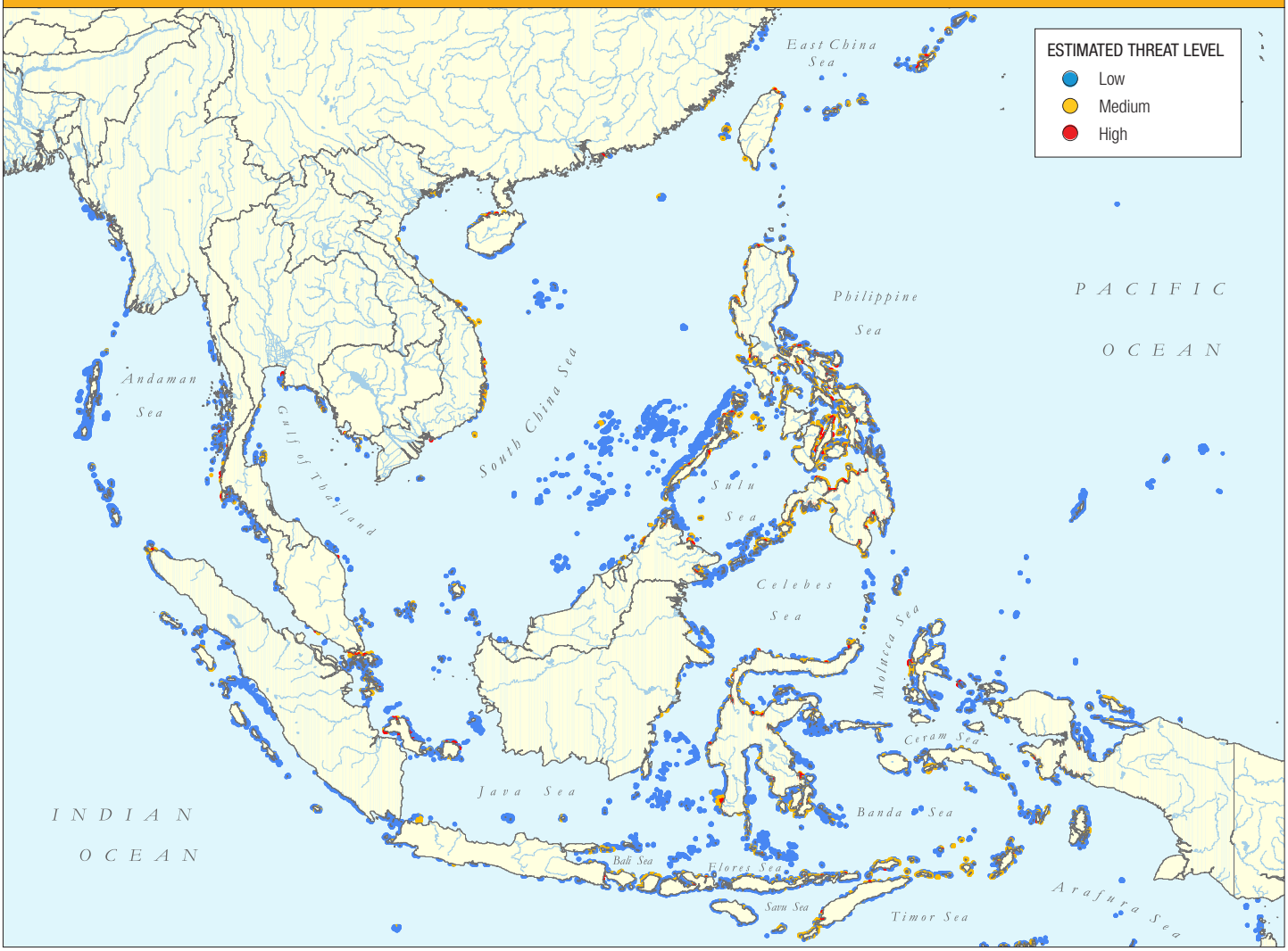
The growing populations, expanding industrial economies, and emerging tourism markets in Southeast Asia drive the demand for the construction of new infrastructure in the coastal zone. Coastal development can result in direct or indirect pressures on coral reefs—both of which can be devastating to coral health.

Some development projects result in the outright obliteration of coral reefs through removal of reef substrate and increased sedimentation. Dredging harbors and channels to improve navigation often requires some reef substrate removal. Land reclamation to build airports, housing developments, malls, and hotels is also on the rise in the region, often without regard to environmental impacts. Singapore, for example, has lost an estimated 60 percent of its coral reefs through land reclamation.[17] Corals are also being used in building materials and for extracting lime for cement production. However, removing portions of the reef structure generally results in greater erosion and sedimentation.[18]

Coral reefs can also be significantly damaged by the indirect impacts of development along the coastline. Construction in coastal areas generally results in increased sedimentation and nutrient runoff, reducing water clarity. Removal of mangroves and seagrasses, which filter nutrients and trap sediments, often exacerbates the problem. If sediment levels are high enough, zooxanthellae may not get enough light to photosynthesize and feed corals, reducing growth or causing coral bleaching and death.

Because many coastal communities in Southeast Asia lack adequate sewage treatment systems, population growth often results in the release of high levels of nitrogen and phosphorus

MAP 2. REEFS THREATENED BY COASTAL DEVELOPMENT



MODELING THE THREAT FROM COASTAL DEVELOPMENT

The threats to reefs from coastal development were assessed based on distance from population centers; the size of these centers; population growth in the area; and distance from airports, mines, tourist resorts, dive centers and the coastline. Tourism development (including dive centers) can provide incentives for conservation, but it may also have negative ramifications such as reef trampling, coral removal, and sewage discharge. The above components were aggregated into a map layer reflecting the threat from coastal development, which was then adjusted by indicators of natural vulnerability and management effectiveness.[19]

COASTAL DEVELOPMENT RESULTS FOR SOUTHEAST ASIA

The RRSEA model considers a coral reef threatened if it scores medium or higher threat in the Reefs at Risk model. According to the RRSEA analysis, about 25 percent of coral reefs in Southeast Asia are threatened by coastal development, with five percent under high threat. The coral reefs of Singapore, Vietnam, Taiwan, the Philippines, and Japan are the most threatened by coastal development, each with over 40 percent of their coral reefs at medium or high threat.

onto reefs. Lack of infrastructure is widespread; in fact, no major coastal city in Indonesia had a sewage treatment system in place as of 1998.[20] Nutrients in sewage can trigger major shifts in reef communities, allowing algae to overgrow and smother corals. Algae-dominated reefs have lower fish diversity and represent a significant loss in value. Irresponsible tourism development contributes to these problems through increased garbage disposal, sewage effluent outflows, and land-use changes. If tourism is not developed responsibly, it can destroy the very ecosystems tourists come to see.

For more information on tourism development in Southeast Asia, see www.wri.org/wri/reefsatrisk.

As coastal areas are developed, a variety of measures can be undertaken to minimize impacts on the environment. Integrated coastal planning can help avoid dredging or building near sensitive and valuable habitats. Sewage treatment facilities, particularly for planned developments, will ease nutrient loads in surrounding waters. Indeed, considering whether development is compatible with the capacity of the local area will help to ensure that the value of the resource base is not wasted.

PHOTO: JOHN MCMANUS

Proper planning and implementation of coastal development is vital to reducing impacts on coastal habitats.

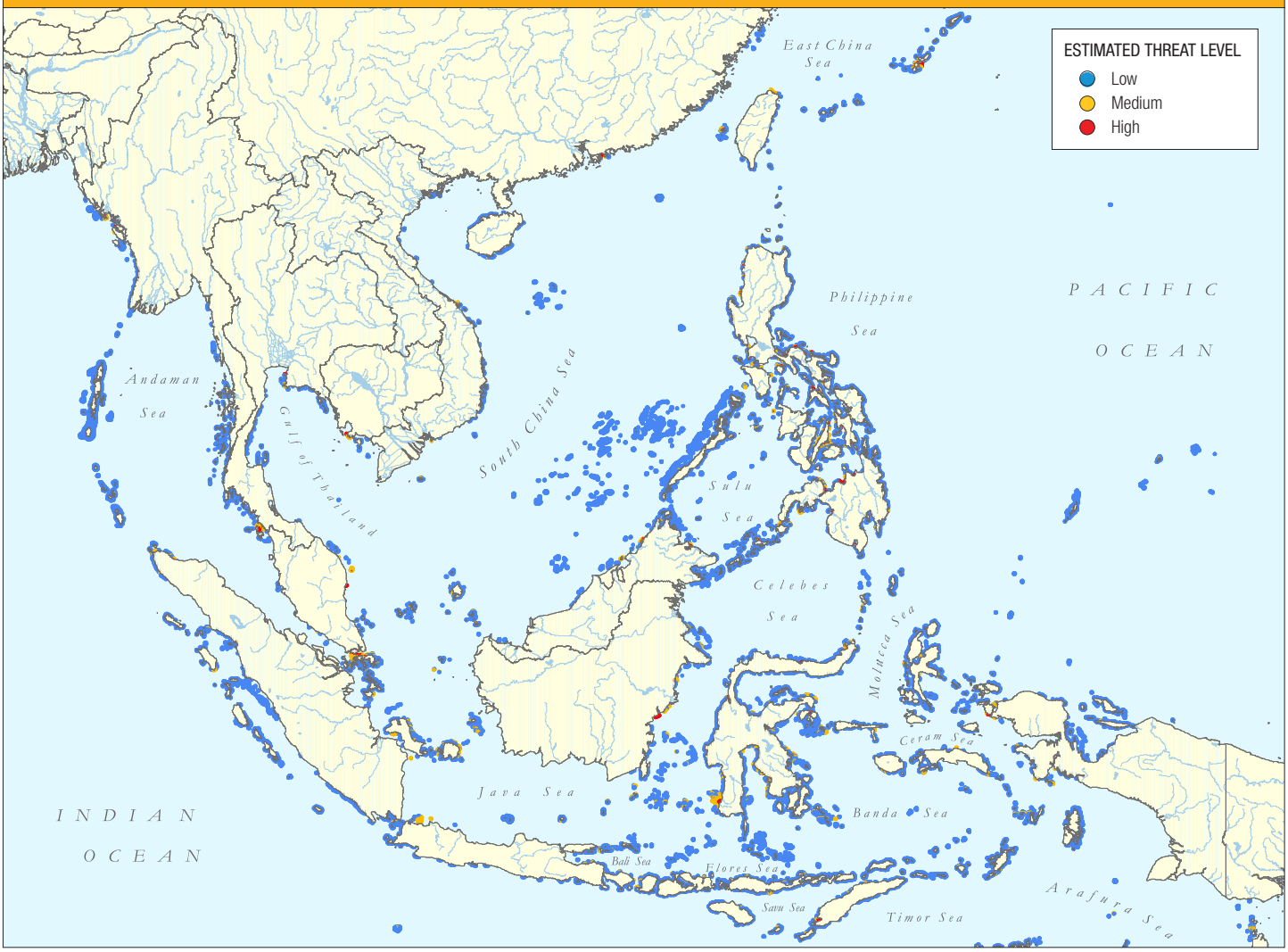
MARINE-BASED POLLUTION

Southeast Asia is a major hub for shipping traffic. The region has several megaports and an extensive network of shipping lanes. Marine-based activities that threaten coral reefs include pollution from ports, oil spills, ballast and bilge discharge, garbage and solid waste dumping from ships, and direct physical impacts from groundings and anchor damage.

Oil is the most common marine-based pollutant. When oil bioaccumulates, it can damage coral reproductive tissues, harm zooxanthellae, and inhibit juvenile recruitment. Sublethal exposure to oil can cause deterioration of the physical reef structure and may seriously reduce resilience of coral reefs to other stresses.[21] Although major oil spills make the headlines, oil generally enters the marine environment through more frequent minor oil spills, routine maintenance of oil infrastructure (drilling rigs and pipelines), maritime transport, and the intentional discharge of oil. When ships discharge bilge and ballast water, they can release a toxic mix of oil, nutrients, exotic marine species, and other pollutants into the marine environment. Many of these pollutants dissipate over time. However, the amount of traffic in some shipping areas and the level of enclosure in many ports allows the toxins to accumulate. In major port areas such as Jakarta Bay, Singapore, and Manila Bay, the threat from marine pollutants is significant.

Some impacts from marine traffic can be reduced through environmental control measures. The use of mooring buoys instead of anchors can reduce physical damage to coral, and pollution levels can be watched in high-risk areas by monitoring hydrocarbon levels. Oil spill contingency plans and a system to police illegal dumpers are essential to reducing the threats from marine pollution.

MAP 3. REEFS THREATENED BY MARINE-BASED POLLUTION



MODELING THE THREAT FROM MARINE-BASED POLLUTION

The RRSEA analysis of threat from marine-based sources of pollution is based on the location of ports, major shipping lanes, and oil infrastructure. These components were buffered based on distance rules developed with project partners and aggregated into a map layer reflecting the threat from marine-based pollution. This estimate was adjusted for the natural vulnerability of the area to pollution. The assessment does not address the fine-scale impact of anchor damage, but it is an indicator of the broad-scale impact of pollutants.

MARINE-BASED POLLUTION RESULTS FOR SOUTHEAST ASIA

Marine-based pollution is the least pervasive of the threat categories evaluated. It threatens an estimated seven percent of the coral reefs within the region, with only about one percent estimated to be under high threat. Japan and Taiwan have high levels of threat relative to the region, each at about 15 percent. Cambodia and Singapore have relatively small areas of coral reefs, but high percentages of those reefs are estimated to be threatened (medium or higher) from marine pollution — 30 and 100 percent, respectively.

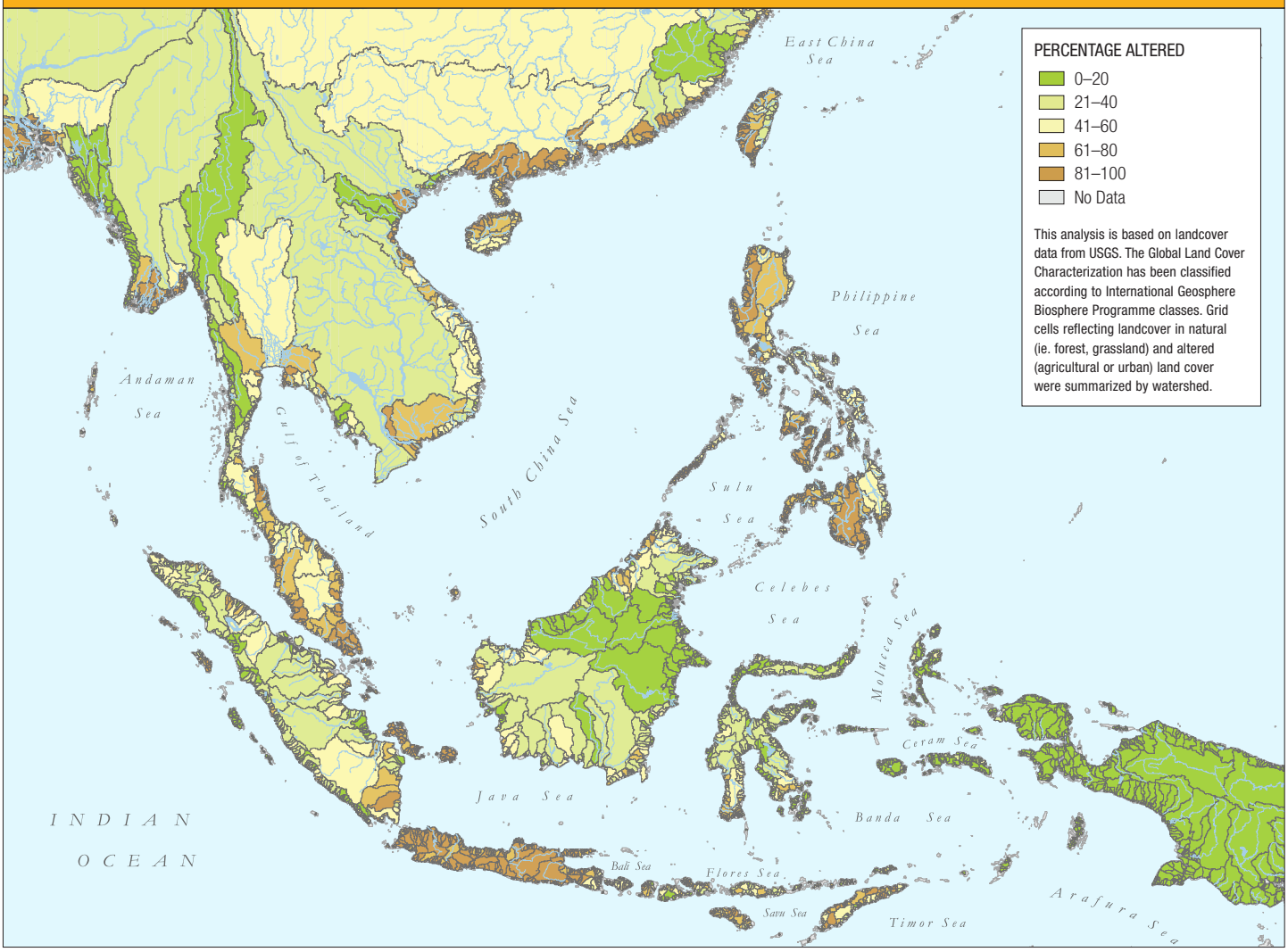
SEDIMENTATION AND POLLUTION FROM INLAND SOURCES

Coral reefs typically thrive in clear tropical waters that have low nutrient levels. Because the zooxanthellae that corals depend on need high levels of light, sediment in the water column can significantly affect coral growth or even instigate coral die-off. Even in the most pristine ecosystems, wind and water erode soil that then enters rivers, but poor agricultural practices and land-use changes throughout Southeast Asia are rapidly accelerating sedimentation in the region. Map 4 reflects the extent of land cover change across Southeast Asia. Despite more integrated coastal planning, many upland activities detrimental to the health of ecosystems downstream continue unabated.

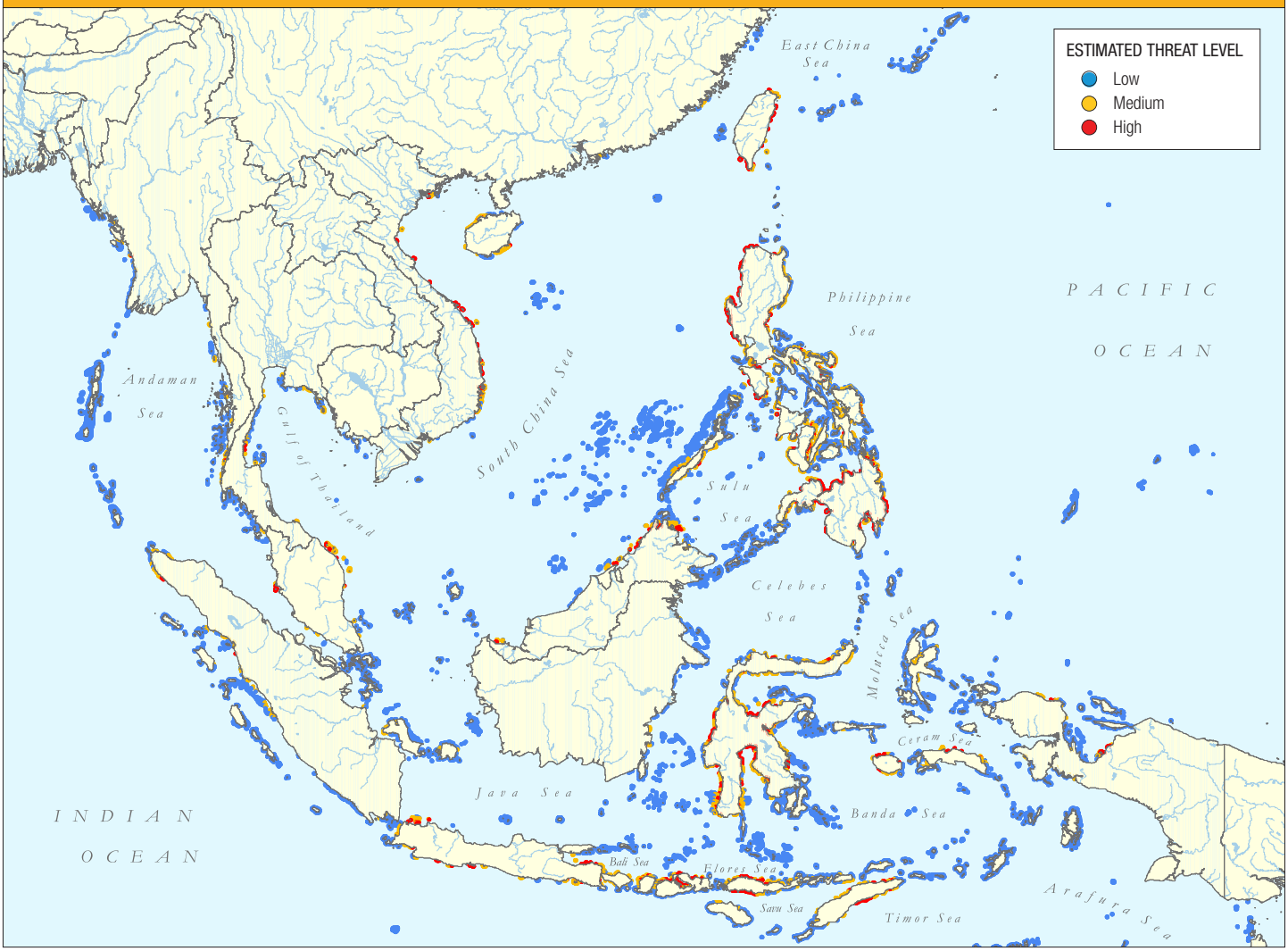
Logging, as well as agricultural conversion, tillage practices, river modifications, and road construction are triggering unprecedented erosion rates throughout the region. Partial clearing of virgin forest can generate two to three times as much sediment as forested areas, and clearcut logging may increase sediment loads 10-fold.[22] Road construction for logging is particularly detrimental, often accounting for the majority of the erosion in a logging concession. Despite the short-term financial gains from logging and agriculture ventures, losses often outweigh the benefits. A study comparing potential gains from various economic activities on Palawan in the Philippines found that revenues from logging would be only one half of what could be gained from healthy reef fisheries and tourism.[23]

In addition to sediment, nutrients and fertilizers that have not been absorbed by the soil can enter rivers and flow to the sea. High nutrient effluent levels can initiate toxic algal blooms and facilitate growth of algae that not only use up valuable solar energy but also inhibit colonization by larval recruits. Studies at

MAP 4. PERCENTAGE OF ALTERED LANDCOVER BY WATERSHED



MAP 5. REEFS THREATENED BY SEDIMENTATION AND POLLUTION FROM INLAND SOURCES



MODELING SEDIMENTATION AND POLLUTION FROM INLAND SOURCES

To estimate sediment risk at coral reef locations, the RRSEA project first estimated relative erosion rates across the landscape based on slope, land cover type, precipitation, and soil type. These relative erosion rates were then summarized by watershed to estimate the resulting sediment delivery at river mouths. Sediment plume dispersion was modeled with a function in which sediment diminishes with distance from source. The estimated sediment plumes were calibrated against both observed sediment plumes and observed sediment impact on coral reefs.[24] The threat estimate was adjusted to account for natural vulnerability.

SEDIMENTATION AND POLLUTION RESULTS FOR SOUTHEAST ASIA

The RRSEA model suggests that over 21 percent of the coral reefs of Southeast Asia are at risk from sediment from inland sources. Vietnam, Taiwan, and the Philippines have relatively large percentages of reefs threatened by sedimentation, with nearly 50 percent threatened in Vietnam and Taiwan and about 35 percent in the Philippines. Because small islands often have watersheds below the minimum threshold size required for inclusion in the RRSEA analysis, the model underestimates threat in these areas. For example, many islands in Japan have been significantly impacted by sediment resulting from deforestation and poor agricultural practises, but the model cannot capture these threats because of the size of the watersheds on these islands.

various sites in Indonesia show a 30–60 percent decrease in coral diversity as a result of pollution and sedimentation.[25]

Numerous factors determine erosion rates, including the slope of the land, type of vegetation cover, texture of the soil, patterns of rainfall, and the distance water flows before reaching a stream. In addition, land management, such as tillage method and orientation of row crops to hillsides, affects erosion rates. Downstream, sediment plumes can significantly impact coral reef distribution. The location of the plume can vary seasonally, but it is strongly influenced by precipitation, river flow, erosion rate, and currents. Mangroves and seagrasses near the river mouth can help to mitigate impacts by filtering sediment and nutrients from the water column before they reach coral reefs.

OVERFISHING

More than 80 percent of the populations of Indonesia, Malaysia, the Philippines, Taiwan, and Singapore reside within 50 km of the coast.[26] Many of these people have come to rely on the coastal zone not only for their food, but also for their livelihoods. *(See Table 1.)* However, coastal resources have increasingly been exploited beyond their sustainable limits as populations in the region have skyrocketed. Much of this growth is occurring among people living at subsistence levels. For example, small-scale operations contribute about 95 percent of total marine fisheries production in Indonesia.[27] Although the population explosion has put unprecedented pressures on coastal resources and jeopardized food security throughout the region, regional population increase is not solely responsible for the increasing pressure on coastal fish resources. The demand in wealthy Southeast Asian countries and other nations around the world for marine aquarium fish, live reef food fish, pelagics, and bottomfish has further fueled regionwide exploitation of certain species.

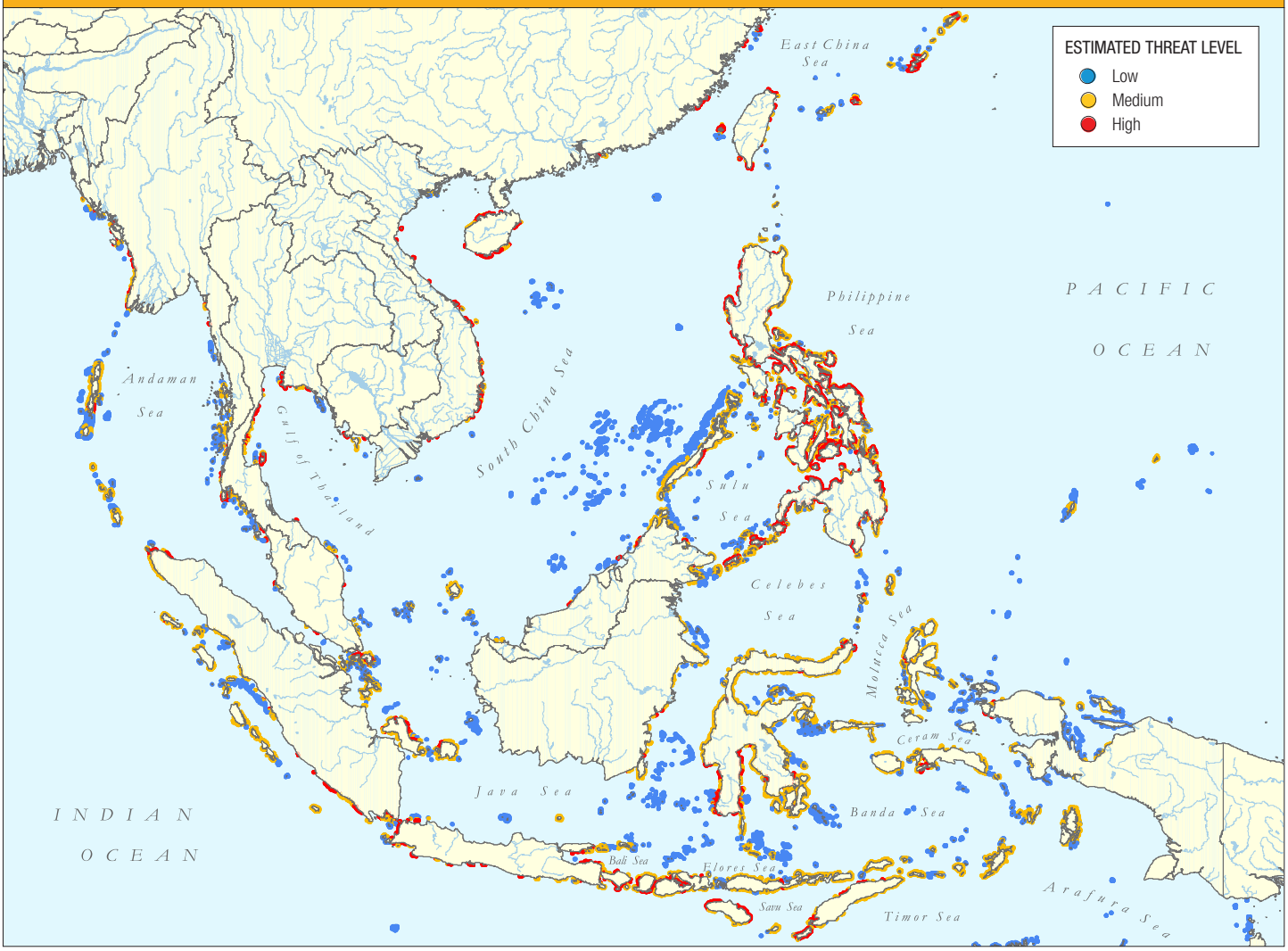
Overfishing is a complex problem with varied impacts on coastal communities, the economy, and coastal ecosystems. If effectively managed, fisheries can provide a renewable source of food and livelihoods, but in Southeast Asia, many fish species are currently overexploited. Coral reefs are capable of supporting low levels of fishing sustainably, especially when the fishing is done with nondestructive gear and effort is spread among several species of carnivorous fishes. Fishing effort on any given species should not cause it to decline to the point where it is vulnerable to natural fluctuations in survival rate. However, widespread poverty and the generally open-access nature of coral reef fisheries in the region can cause people to enter or remain in reef fisheries until the average fisher makes no net profit because of high effort and low catch. If stock levels are low enough, fishers may shift from high-valued fish to less valuable species.[28] Overfishing can also cause the mix of fish species to change radically and total fish abundance to drop by an order of magnitude. Moreover, because fish play an integral role in the balance of the coral reef ecosystem, their removal makes reefs less resilient to natural and anthropogenic disturbances. Without the normal suite of fish and invertebrates, corals are more likely to be replaced by algae that prevent coral settlement and growth.

When overfishing is caused by large-scale commercial operations, government regulations and enforcement may be the key to reducing the problem. However, where coral reefs are adjacent to crowded coastlines, effective fisheries management is crucial. Key elements in improving compliance with fishing regulations include the development of alternative livelihoods, the implementation of small fishing reserves, and the involvement of fishers in resource decisionmaking. *(See Chapter 7.)*

BOX 4. SUBSURFACE REEFS AND TRAWLING

The Reefs at Risk analysis focuses on threats to shallow coral reefs. Unlike shallow reefs, which have distinct physical shapes that are easily mapped, little information exists about the extent of subsurface reefs and coral communities. However, subsurface reefs are believed to cover considerable areas, particularly in the South China Sea. Subsurface reefs have many of the same pressures and threats as shallow reefs, but are also impacted by commercial trawling. Trawlers typically operate in deeper waters, over areas where subsurface reefs and coral communities are likely to be found. Because large corals damage trawl nets, boats avoid them when possible, but may use old gear or chains to remove the corals and make it easier to trawl. Trawling for fish and shrimp is widespread in Southeast Asia, notably in the Gulf of Thailand and the South China Sea, but has been banned in some areas.

MAP 6. REEFS THREATENED BY OVERFISHING



MODELING THE THREAT FROM OVERFISHING

Overfishing of coral reefs is widespread in Southeast Asia. Overfishing typically results in shifts in fish size, abundance, and species composition. RRSEA developed an indicator that evaluates the pressure on coral reefs fisheries from local populations within 10 km of the coast and evaluates overfishing pressure out to 20 km offshore. This indicator does not address remote offshore fishing. It was adjusted to include an estimate of management effectiveness.

OVERFISHING RESULTS

Overfishing is the most pervasive of the threats evaluated. The RRSEA project estimates that across the region, 64 percent of coral reefs are at risk (medium threat or higher) from overfishing, with about 20 percent at high risk. Most countries have 50 percent or more of their reefs classified as threatened by overfishing. Cambodia, China, Japan, and the Philippines have even higher pressure from overfishing, with over 70 percent of their reefs threatened and over 35 percent classified as high risk.

DESTRUCTIVE FISHING

Fishers in Southeast Asia have adapted to market demands by using specialized, often destructive, fishing techniques such as poison fishing and blast fishing. Each of these methods contributes to overfishing of economically important fish and may cause the unintended exploitation of countless other species, fundamentally changing the marine ecology of the region.

Poison Fishing

Traditional communities throughout the region have long used natural poisons to capture fish. However, these practices were typically small-scale and had only incidental consequences. Today, poison fishing is far more damaging. The commercial use of poisons to capture live reef fish began in the Philippines in the 1960s and soon spread to Indonesia, Vietnam, and parts of Malaysia. Poison fishing typically employs sodium cyanide, a deadly broad-spectrum poison. Crushed into plastic squirt bottles and applied to reefs by divers, the poison acts as an anesthetic, stunning fish and making them easier to capture. Unfortunately, other fish are damaged, killed, or left exposed to predation as the poison stuns them. Corals are also affected. Initial exposure can cause effects ranging from slight to full coral bleaching, and repeated applications of cyanide may cause coral death. Poisons are the predominant method used to obtain high-value live reef fish in Southeast Asia. The full extent of poison fishing is unknown because it targets some of the most pristine and isolated coral reefs, where observations are limited. *(See Box 5.)*

Governments and nongovernmental organizations in the region are working to combat poison fishing, which is illegal in most countries in Southeast Asia. However, poison fishing remains a widespread problem in Indonesia and Vietnam, where laws have been difficult to enforce.

Blast Fishing

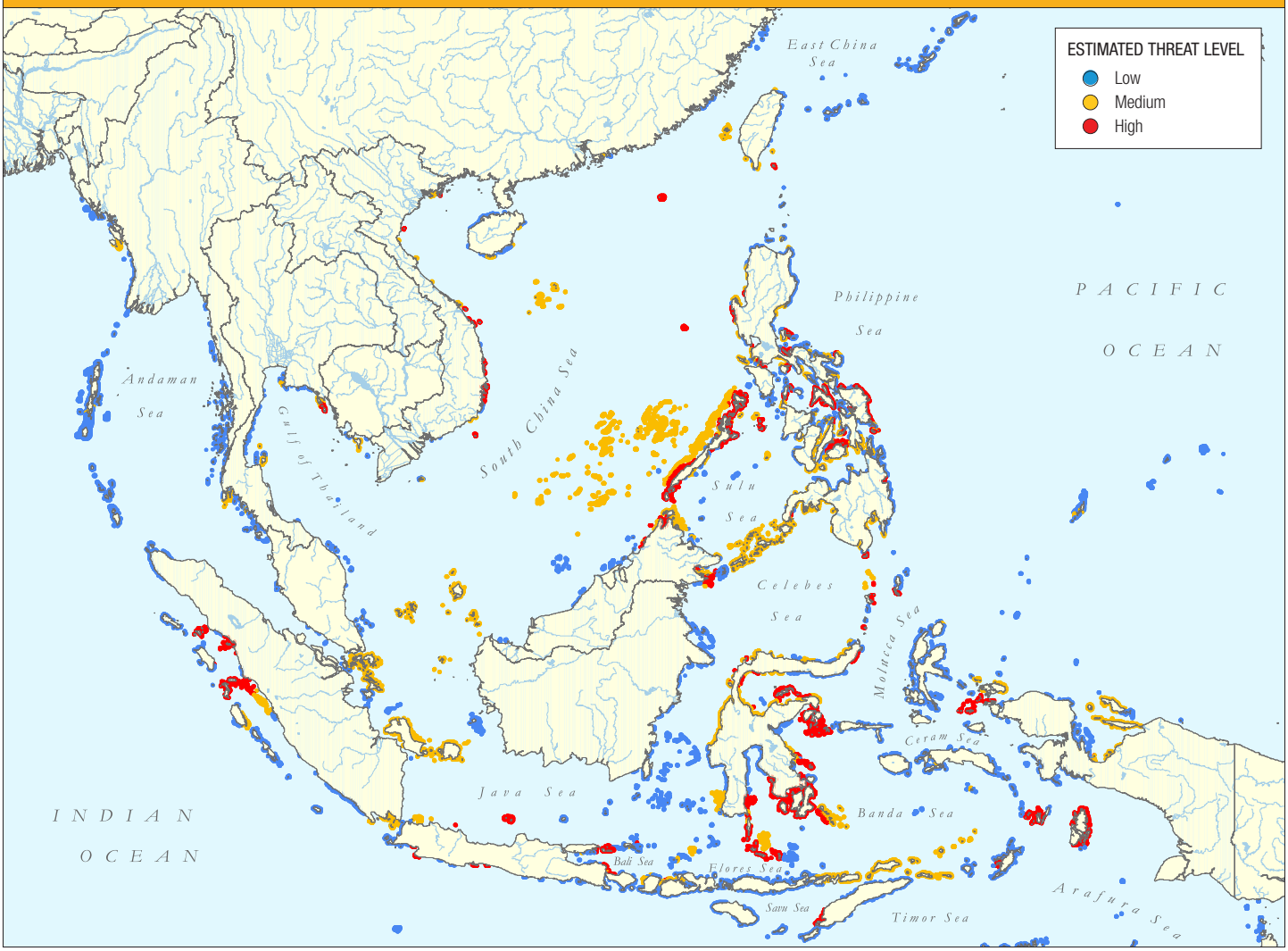
Although outlawed throughout Southeast Asia, blast fishing is practiced regularly in most countries in the region. During World War II, Japan and the Allied powers left behind thousands of unexploded shells, littering the waters of Southeast Asia and the Western Pacific. In the past, these shells were repacked with explosives to make bombs for fishing. Today, fishers no longer employ World War II era shells but instead use dynamite or grenades. They also fill empty beer or soda bottles with potassium nitrate, an artifical fertilizer, and pebbles, topping them with a commercial fuse or blasting cap. The bombs kill most fish nearby by bursting their gas-filled swim bladders. Although some fish float to the surface, many sink and are not retrieved. Bombs can cost US$1–$2 to construct but may bring in a catch with a market value of US$15–$40.[29]

The effects of blast fishing can be devastating to both reefs and people. Prematurely exploding bombs have led to lost limbs and lives. Depending upon the distance from the substrate at the time of explosion, a typical 1-kg beer bottle bomb can leave a crater of rubble 1–2 m in diameter.[30] The extent and severity of damage to reefs often depends on the amount and type of explosive, the depth of the water, and the distance to stands of corals. Regularly bombed reefs frequently exhibit 50–80 percent coral mortality.[31] In a few areas, community-based education programs and active community management are helping to change fishing practices at local levels.[32]

PHOTO: HELEN FOX

Use of explosives on a coral reef destroys the reef structure, and can leave a crater of rubble several meters wide. Local conditions, including nutrient and sediment levels, presence of herbivores, and the availability of coral larvae, affect whether the reef will recover.

MAP 7. REEFS THREATENED BY DESTRUCTIVE FISHING



MODELING THE THREAT FROM DESTRUCTIVE FISHING

The RRSEA project evaluted the threat from destructive fishing by combining separate maps of areas where fishing with poisons and blast fishing are reported to be occurring or have been recorded recently. These maps were based on observations of destructive fishing from existing databases[33] and the opinion of project experts on where these harmful practices occur. The maps were aggregated into a single estimate of pressure from destructive fishing, which was then adjusted for management effectiveness. The resulting indicator portrays the broad pattern of threat, but it may underestimate many areas at risk because of inconsistent standards of definition and lack of information about where destructive practices are occurring.

DESTRUCTIVE FISHING RESULTS

RRSEA estimates that 56 percent of the coral reefs of Southeast Asia are at risk from destructive fishing practices. The estimated threat from destructive fishing is particularly high in the Spratly and Paracel Islands and in Vietnam. For many reefs in the South China Sea, this threat is the only significant one caused by human activities. Over two thirds of reefs in the Philippines, Malaysia, and Taiwan as well as over 50 percent of the reefs in Indonesia are threatened by destructive fishing.

BOX 5. THE LIVE REEF FISH TRADE

The live reef fish trade has two main components — live food fish and ornamental aquarium fish. Accurate figures are not available on the total value of these trades, but extrapolation from partial estimates indicates that the total value of the trade exceeds US$1 billion per year. Southeast Asia is the hub of this trade, supplying up to 85 percent of the aquarium trade and nearly all of the live food fish trade.[a]

Live Reef Food Fish Trade

In upscale restaurants across Southeast Asia, diners can feast on live reef fish for up to US$100 per kg. In 2000, Hong Kong alone imported an estimated 17,000 tonnes of live food fish. Typical wholesale prices for these species range from US$11 to US$63 per kilogram, bringing the value of the industry to approximately US$400 million for Hong Kong. Many live reef food fish on the Hong Kong market are cultured, and poisons are not used to capture live fish in Australia and most of the Pacific. However, in other parts of Southeast Asia, particularly Indonesia and Vietnam, cyanide is widely used to capture both live reef food and aquarium fish.[b] A 1998 global assessment of the status of some 200 fisheries around the world concluded that the live reef fishery of Southeast Asia is one of the most threatened fisheries on the planet.[c]

Ornamental and Aquarium Trade

The trade in marine ornamentals began modestly in the Philippines in 1957, but it has since grown into an international multimillion dollar business. In 1998 and 1999, Southeast Asia contributed some 36 percent of the global trade in hard corals, with Vietnam alone contributing 25 percent.[d] The global wholesale value of the ornamental fish market was US$963 million in 1996, making this industry a key source of commerce for fishers in Southeast Asia.[e] Between 1996 and 1999, the share of the U.S. ornamental fish market coming from Southeast Asia increased from 67 to 78 percent.[f] The United States is by far the largest consumer, importing about 60 percent of all marine ornamental fish and 70–90 percent of all live coral worldwide.[g]

Although the aquarium trade is high-value in some areas, it is unsustainable as currently practiced. Cyanide fishing remains the predominant technique for fish capture in most Southeast Asian countries. The economic benefits for fishers are minimal. In the Philippines, for example, fishers who supply the aquarium trade typically earn only about US$50 per month.[h] Less destructive techniques such as net capture are on the rise as a result of retraining efforts, but they have not yet overtaken cyanide fishing as the practice of choice. The Marine Aquarium Council (MAC), a nonprofit organization, is working to unite industry, hobbyists, environmentalists, and governments to create a set of core standards that can be used to certify businesses that uphold best practices.[i]

a. C.V. Barber and V.R. Pratt, *Sullied Seas: Strategies for Combating Cyanide Fishing in Southeast Asia and Beyond* (Washington, DC: World Resources Institute and International Marinelife Alliance, 1997), pp. 2, 15.
b. International Marinelife Alliance-Hong Kong, unpublished data.
c. M.L. Weber, "A Global Assessment of Major Fisheries at Risk, Relevant Management Regimes, and Non-governmental Organizations," unpublished draft report (Philadelphia: Pew Charitable Trusts, 1998).
d. Data derived from the CITES database managed at the UNEP World Conservation Monitoring Centre.
e. W.A. Tomey, "Review of Developments in the World Ornamental Fish Trade: Update, Trends and Future Prospects," in K.P.P. Namibar and T. Singh, eds., *Sustainable Aquaculture: Proceedings of the INFOFISH-AQUATECH '96 International Conference on Aquaculture* (Kuala Lumpur, Malaysia: INFOFISH, 1997).
f. Data derived from the United States Fish and Wildlife Customs Declarations, unpublished data.
g. J. Baquero, "Marine Ornamentals Trade: Quality and Sustainability for the Pacific Region," Suva, Fiji, South Pacific Forum Secretariat and the Marine Aquarium Council (1999), p. 50.
h. M.D. Spalding, C. Ravilious, and E.P. Green, eds., *World Atlas of Coral Reefs* (Berkeley: University of California Press, 2001).
i. Marine Aquarium Council, "Background of Marine Aquarium Council (MAC)," http://www.aquariumcouncil.org/aboutb.html (September 17, 2001).

CLIMATE CHANGE AND CORAL BLEACHING

Many corals and other reef organisms have become highly adapted to local conditions and are extremely sensitive to change. When corals are stressed, they eject their zooxanthellae or cause them to lose their chlorophyll. Without zooxanthellae, corals become pale or turn completely white — a response known as coral bleaching. A variety of factors can trigger bleaching, including temperature extremes, sedimentation, pollution, air exposure, or changes in salinity.[34] However, temperature-correlated bleaching is the most widely reported.

The range of temperatures tolerated by reef-building corals worldwide is relatively narrow, usually between 16°C and 36°C.[35] On any particular coral reef, the range is even narrower. Studies have shown that even temperatures of only 1–2°C above the normal threshold temperature for a few weeks are sufficient to drive a bleaching event.[36] Corals often recover from bleaching, but extreme or prolonged temperature anomalies can cause significant mortality.

Climate Change and Mass Bleaching Events in Southeast Asia

Scientific studies now confirm that the earth's surface has warmed 0.6°C during the past hundred years, a rate unprecedented in the past thousand years.[37] Evidence suggests that increases in both air and sea temperatures are mostly a direct result of anthropogenic activities such as burning fossil fuels and forest clearing, which release greenhouse gases into the atmosphere.[38] In some places, changes may be even more dramatic, as in Phuket, Thailand, where the temperature increased between 1981 and 1999 at a rate of more than 2°C per hundred years. Sea-surface temperatures have now moved so close to coral thermal limits that the fluctuations of temperatures within natural climatic events such as the El Niño Southern Oscillation (ENSO) can cause massive coral bleaching.[39] In fact, reports of mass coral bleaching have increased greatly since 1979.[40]

Most episodes of mass coral bleaching can be attributed to ENSO events. The most severe ENSO event since statistics have been recorded occurred in 1997–98.[41] Although effects from the 1997–98 event were most severe in the central Indian Ocean, major bleaching was also reported across Southeast Asia, where an estimated 18 percent of reefs were damaged.[42] These patterns of bleaching and coral mortality can be linked to high sea-surface temperature anomalies that were caused by the ENSO event. *(See Map 8.)*

Despite the severity of bleaching in the region, recovery is occurring. New coral growth has been observed, but patterns of recovery are site specific. Local turbulence, temperature, salinity, and levels of ultraviolet radiation affect how severely specific sites are impacted and how well they recover.[43] The rate of recovery may also be influenced by other factors including existing levels of human disturbance.

Owing to the lack of data and intense and unpredictable local variations, the RRSEA project was not able to incorporate coral bleaching into the Reefs at Risk threat model. However, observations of bleaching reports from throughout the region are presented on Map 8 and are summarized by country in Chapter 5.

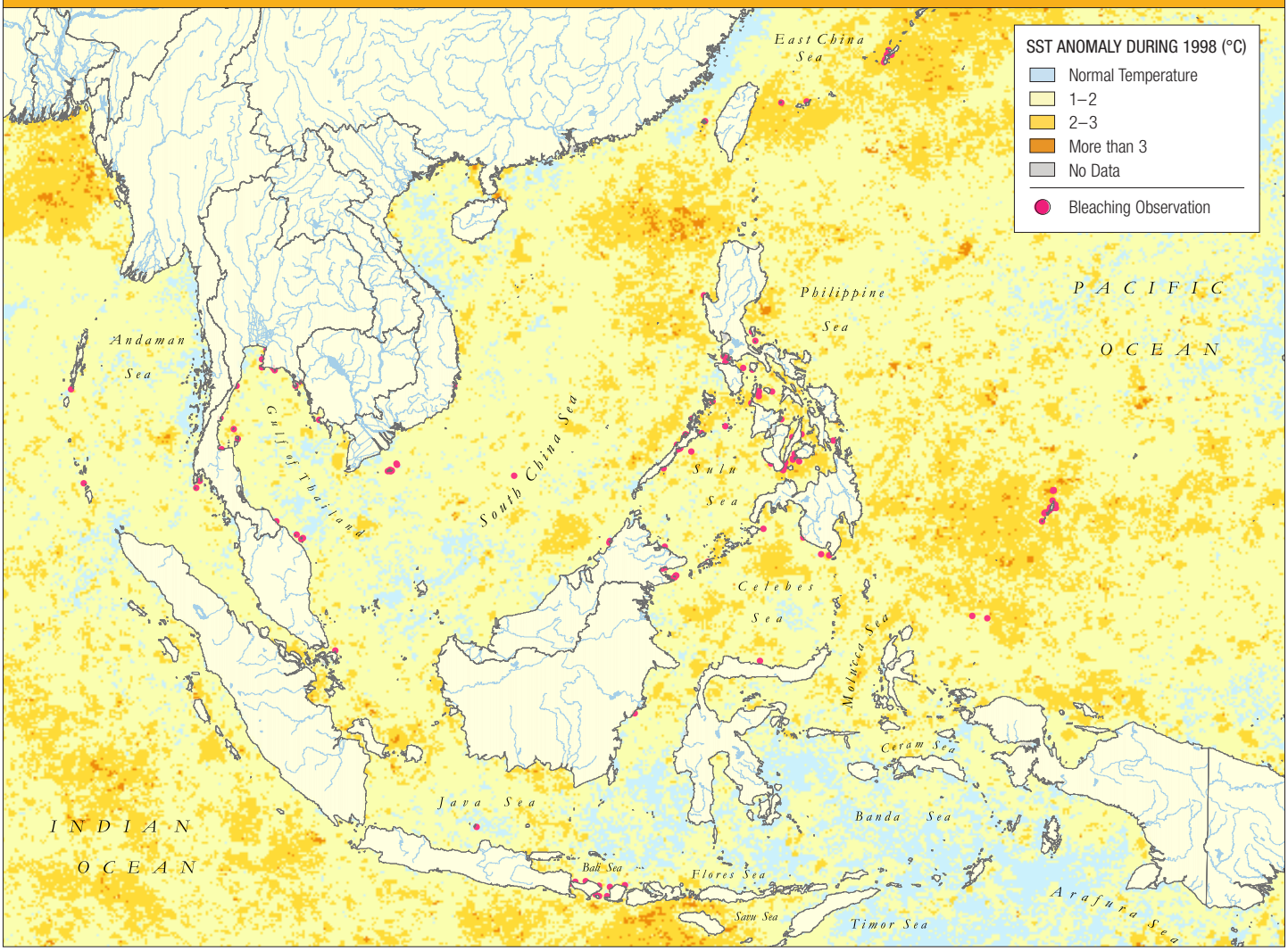
Outlook

The wide global extent of coral bleaching observed during the 1997–98 ENSO foreshadows the likely serious consequences of rising sea-surface temperatures associated with global climate change. The extent and productivity of coral reefs in coming decades may depend on how fast corals can adapt to increased

PHOTO: MARK SPALDING

The most widespread coral bleaching event on record occurred during the 1997–98 ENSO.

MAP 8. SEA-SURFACE TEMPERATURE ANOMALIES AND OBSERVATIONS OF CORAL BLEACHING, 1998



temperature extremes, in terms of both physiological adaptation and evolutionary change. Because corals have generation times that range from decades to centuries, some scientists believe they could take centuries to millennia to adapt — too slow to respond to the current pace of global climate change. Other researchers have pointed to the wider range of temperature tolerances shown by the same species in different areas. They hypothesize that individual corals may be able to adapt but also that the right conditions of currents could allow heat-resistant larvae and zooxanthellae from corals occurring in naturally warmer waters to recolonize newly warming areas.

In addition to the problems associated with rising sea-surface temperatures, corals may also be placed under stress by projected increases in atmospheric CO_2. Some scientists believe that elevated atmospheric CO_2 levels will reduce the alkalinity of surface waters, thereby reducing the calcification rate and skeletal strength of corals. Increases in atmospheric CO_2 thus could cause the rates of reef growth to fall behind rates of natural erosion. The balance of many reefs may shift from that of gradually accreting structures to that of gradually eroding structures. This change might eventually compromise the effectiveness of some coral reefs in providing shoreline protection and other benefits.[44]

Although scientists and others continue to monitor coral reef growth and recovery following bleaching events, it remains unclear whether coral reefs will be able to adapt with sufficient speed to adjust to the dramatic changes predicted under climate change scenarios. Where direct human impacts already threaten coral reefs, resilience may be lower and recovery rates may be slower.

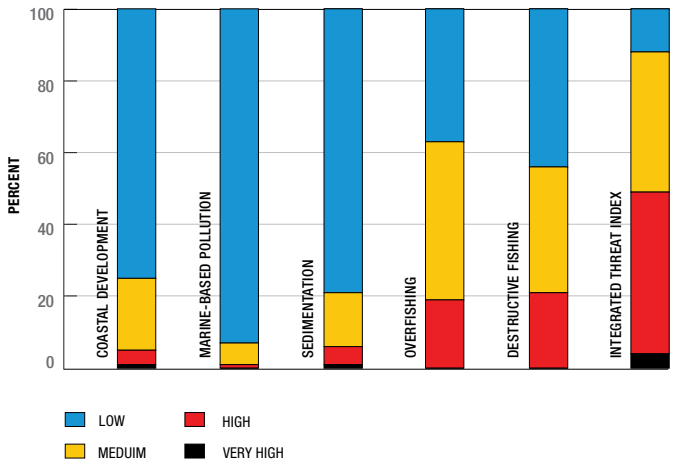
CHAPTER 5. STATUS OF CORAL REEFS IN SOUTHEAST ASIA

PHOTO: WOLCOTT HENRY

Although highly diverse and extraordinarily valuable, the coral reefs of Southeast Asia are also severely threatened. The heavy reliance on marine resources across the region has resulted in the overexploitation and degradation of many coral reefs, particularly those near major population centers.[45] The RRSEA analysis examined five broad categories of threat and then integrated them into the Reefs at Risk Threat Index, based upon the highest level of threat scored in any single category and with regard to cumulative threat. For example, a reef ranked as being under high threat for three different threats, ranks very high for integrated threat. Threats facing reefs in Southeast Asia are extremely pervasive. Coastal development, local overfishing, and sedimentation all damage corals near the shore. At the same time, remote and offshore reefs are buffeted by destructive fishing practices and commercial overfishing.

Overfishing is the most pervasive threat to reef health, putting 64 percent of reefs at risk. Although some remote reefs remain in pristine condition, destructive fishing practices are now threatening many of them. Poison and blast fishing techniques employed to collect fish for the live reef fish trade endanger 56 percent of the region's reefs. Coastal development and land-use changes also put significant pressure on coral reefs in the region, affecting 25 percent and 21 percent of reefs, respectively. The combined sedimentation and pollution from these two activities place 37 percent of the region's reefs at risk. Compared to the other threats evaluated, marine-based pollution is the least pervasive threat, affecting only 7 percent of reefs. When all of these threats are aggregated, human activities threaten the vast majority of coral reefs in the region — 88 percent. Nearly 50 percent of those threatened coral reefs are under high or very high threat. *(See Figure 2.)*

FIGURE 2. THREAT ESTIMATES FOR SOUTHEAST ASIA BY TYPE OF THREAT



The reefs of the Philippines, Vietnam, Singapore, Cambodia, and Taiwan are some of the most threatened in the region, each with over 95 percent threatened. The reefs off the Nusa Tenggara chain in Indonesia; Okinawa, Japan; and Sabah, East Malaysia are also highly threatened. Malaysia and Indonesia each have over 85 percent of their coral reefs threatened. *(See Table 3 and Map 9.)* Because of the extent of their reef area and the high proportion of their reefs that are threatened, Indonesia and the Philippines alone account for much of the region's threatened reefs. Indonesia and the Philippines together possess 77 percent of the region's coral reefs and 79 percent of all threatened reefs in the region. *(See Table 3.)*

A small number of islands face low levels of threat. Reefs under relatively little pressure include some of those in the Makassar Straits, Flores Sea, and Banda Sea. Isolated areas off the Andaman Islands, West Papua, Myanmar, and Thailand are also under low stress. *(See Map 9.)* Even though they face little threat from development and local overfishing, the reefs are not necessarily safe. If destructive fishing techniques were applied in these areas, the level of risk would quickly change from low to high.

This chapter contains country-specific discussions of coral reef status. It includes the limited data available through monitoring of current coral reef conditions and the RRSEA model's analysis of human pressure to provide the most complete picture of the likely status, threats, and future condition of the coral reefs of Southeast Asia. Country summaries are presented from south to north across the region.

For detailed summaries about the threat and status of specific coral reefs see www.wri.org/wri/reefsatrisk.

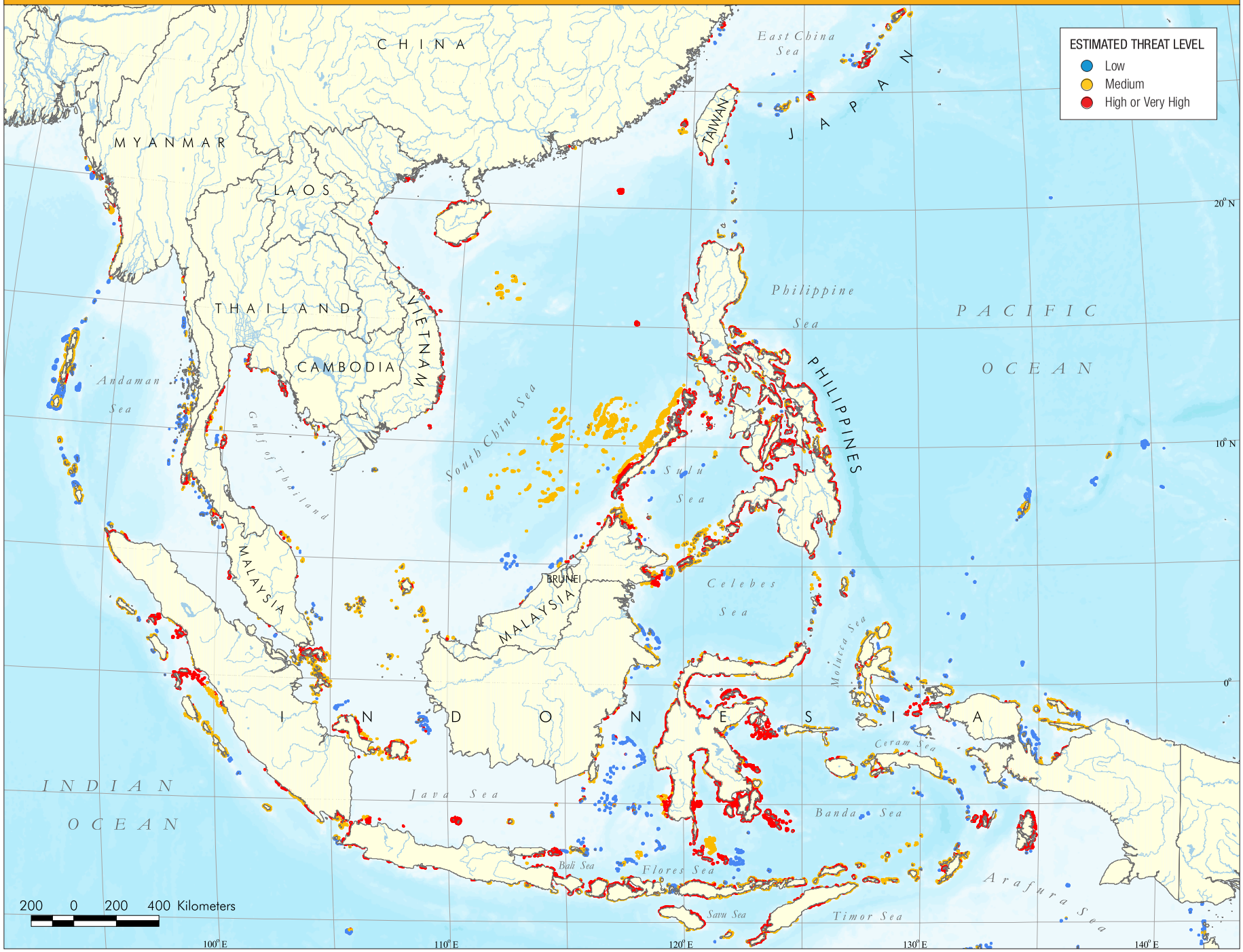
TABLE 3. REEFS AT RISK SUMMARY BY COUNTRY (OR AREA)

	REEF AREA[a] (KM²)	REEF AREA AS PCT. OF TOTAL IN REGION	REEFS AT RISK THREAT INDEX								PERCENTAGE AT MEDIUM OR HIGHER THREAT
			LOW		MEDIUM		HIGH		VERY HIGH		
			KM²	PCT.	KM²	PCT.	KM²	PCT.	KM²	PCT.	
Indonesia	50,875	51%	6,930	14%	19,809	39%	23,403	46%	733	1%	86%
Philippines	25,819	26%	559	2%	7,099	27%	16,311	63%	1,850	7%	98%
Spratly and Paracel Islands	5,752	6%	0	0%	5,752	100%	0	0%	0	0%	100%
Malaysia	4,006	4%	533	13%	1,771	44%	1,541	38%	161	4%	87%
India (Andaman & Nicobar Islands)	3,995	4%	1,790	45%	2,119	53%	86	2%	0	0%	55%
Japan	2,602	3%	581	22%	983	38%	951	37%	87	3%	78%
Thailand	1,787	1.8%	419	23%	427	24%	917	51%	24	1%	77%
Myanmar	1,686	1.7%	742	44%	604	36%	336	20%	4	0%	56%
Vietnam	1,122	1.1%	43	4%	252	22%	551	49%	276	25%	96%
China	932	0.9%	71	8%	130	14%	706	76%	25	3%	92%
Taiwan	654	0.7%	0	0%	189	29%	367	56%	98	15%	100%
Brunei Darussalam	187	0.2%	147	79%	30	16%	10	5%	0	0%	21%
Singapore	54	0.1%	0	0%	0	0%	54	100%	0	0%	100%
Cambodia	42	0.0%	0	0%	0	0%	38	90%	4	10%	100%
Regional Total	**99,513**	**100%**	**11,815**	**12%**	**39,165**	**39%**	**45,271**	**45%**	**3,262**	**3%**	**88%**

SOURCE:
Reefs at Risk in Southeast Asia, WRI, 2002.

NOTES:
a. The RRSEA analysis was performed on grid cells that are 1 km resolution, so the grid cell counts presented on this table equate to reef area (km²). However, given the resolution and variation in the source data, reef area statistics are usually rounded to two significant digits (or the nearest 100 km²), as in Table 2.

MAP 9. REEFS THREATENED BY HUMAN ACTIVITIES – THE REEFS AT RISK INDEX

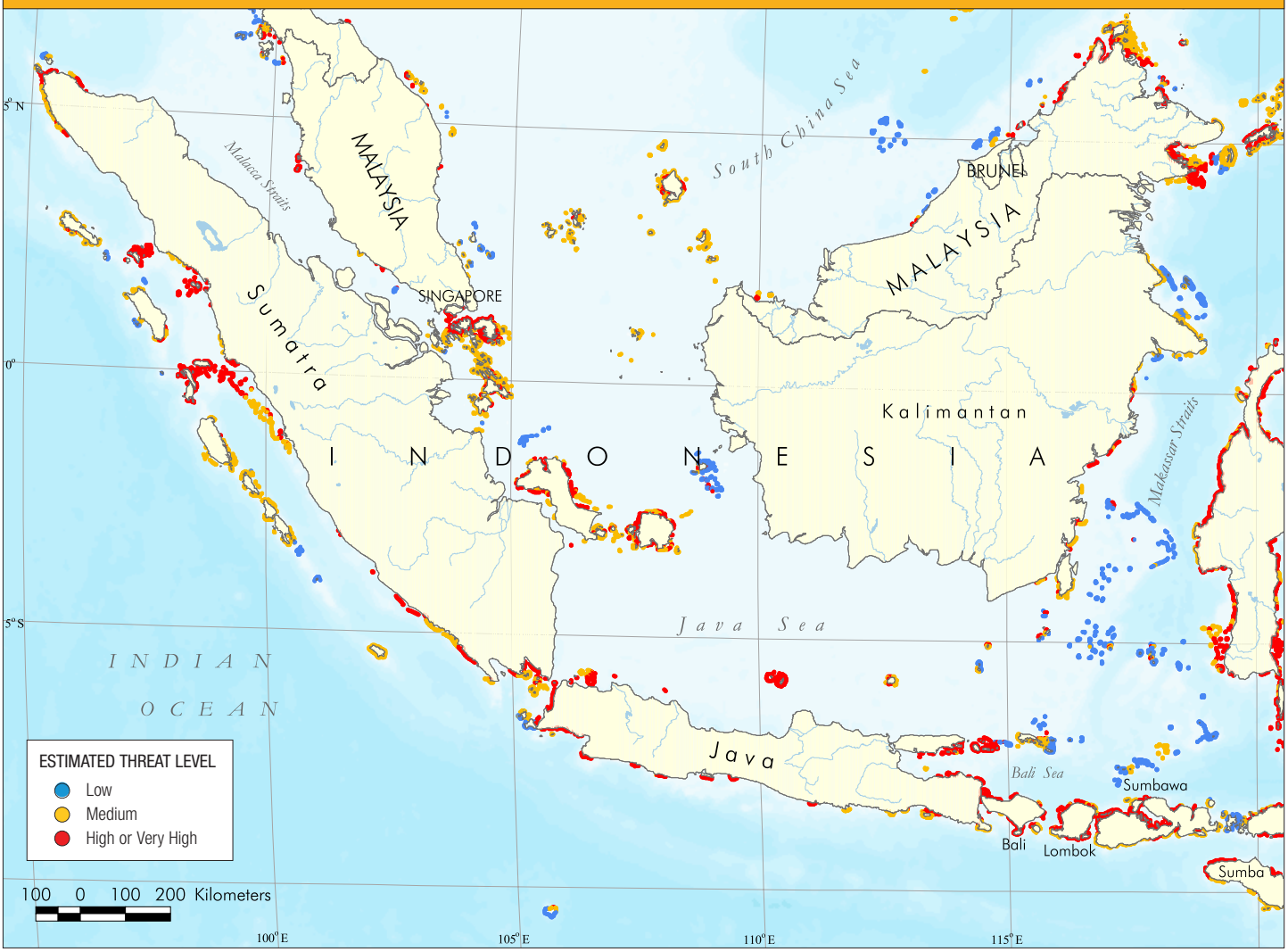


INDONESIA

Indonesia is the largest archipelagic nation in the world, with a coastline stretching over 95,000 km around more than 17,000 islands.[46] An extensive group of coral reefs protect these islands. RRSEA estimates that Indonesia has approximately 51,000 km^2 of coral reefs; this number does not include reefs in remote areas that have not been mapped or subsurface reefs. If this conservative estimate is accurate, 51 percent of the region's coral reefs and 18 percent of the world's coral reefs are found in Indonesian waters.[47] Most of these reefs are fringing reefs, adjacent to the coastline and easily accessible to coastal communities. Coastal and marine industries such as oil and gas production, transportation, fisheries, and tourism represent 25 percent of the nation's GDP and employ more than 15 percent of the workforce.[48] Although coastal communities have long extracted marine resources sustainably, population growth has put additional pressure on Indonesia's coral reefs.

Aside from their sheer magnitude, Indonesia's coral reefs are also among the most biologically rich in the world, containing an extraordinary array of plant and animal diversity. Today, more than 480 species of hard coral have been recorded in eastern Indonesia, approximately 60 percent of the world's described hard coral species.[49] The greatest diversity of coral reef fish in the world are found in Indonesia, with more than 1,650 species in eastern Indonesia alone. In fact, Indonesia's coral reefs help to support one of the largest marine fisheries in the world, generating 3.6 million tonnes of total marine fish production in 1997.[50] Because many reefs in eastern Indonesia have yet to be

MAP 10. REEFS AT RISK IN WESTERN INDONESIA

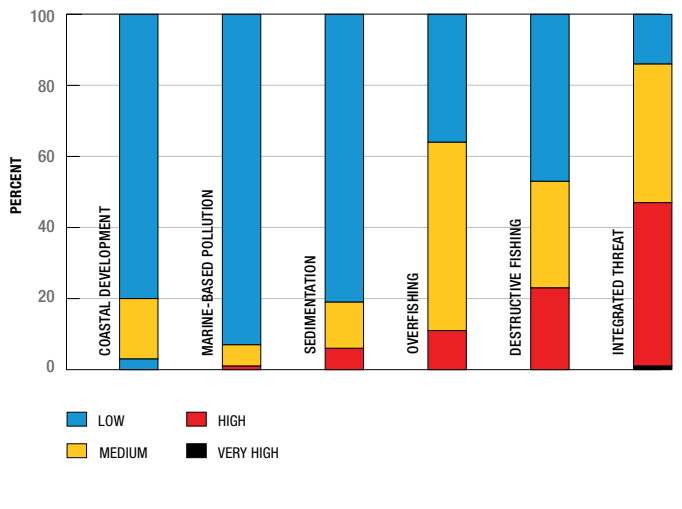


surveyed, the actual extent of Indonesia's biological endowment is still unknown.[51]

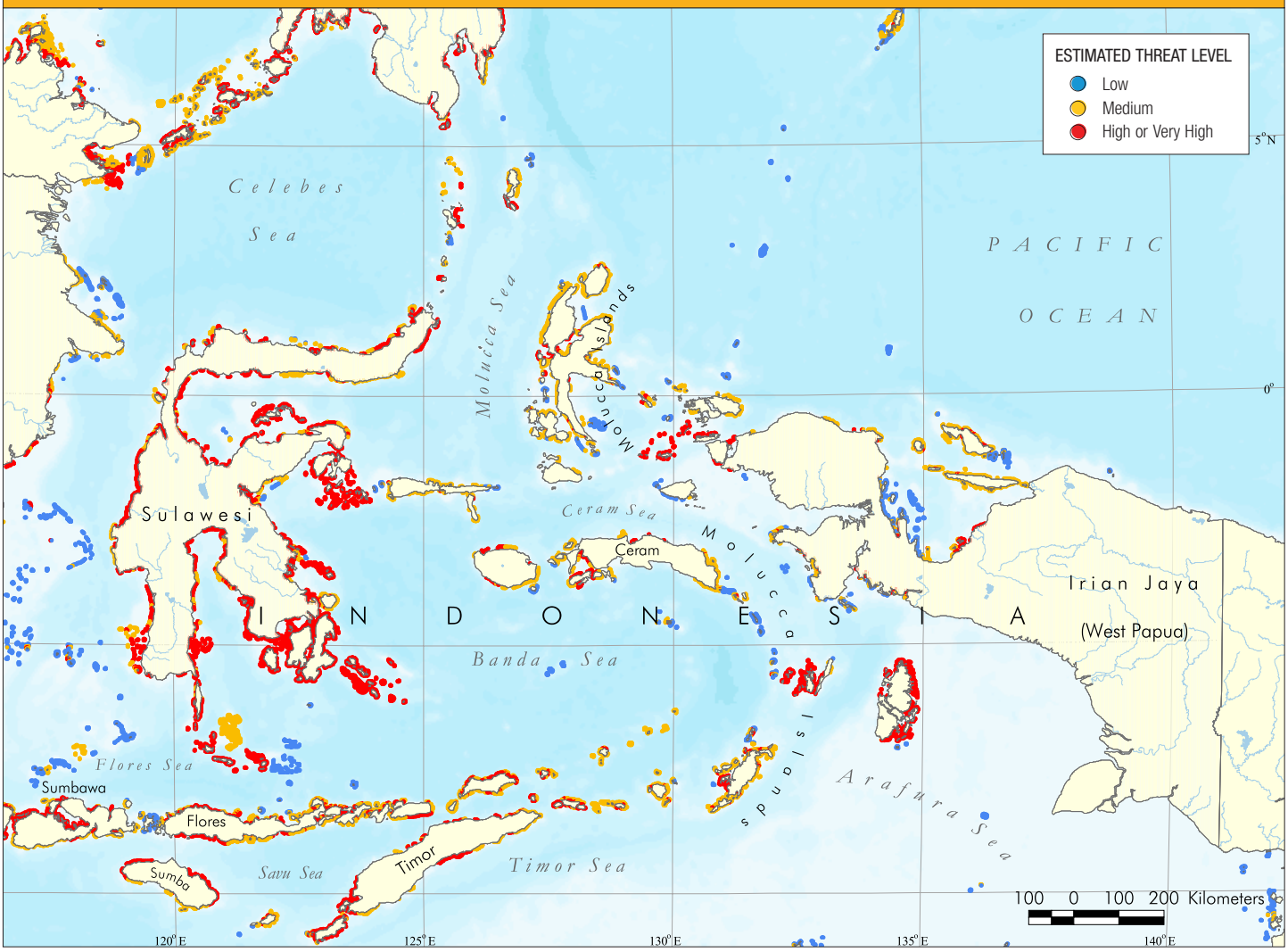
Indonesia's rich supplies of corals and reef fish are endangered by destructive fishing practices. Cyanide and blast fishing are widespread throughout the archipelago even in protected areas. In the early 1990's, around 65 percent of surveys in the Maluku islands had evidence of bomb damage.[52] Despite the short-term profits, studies have shown that the economic costs of blast and poison fishing are prodigious.[53] RRSEA estimates that the net economic loss in Indonesia from blast fishing over the next 20 years will be at least US$570 million. The economic loss from cyanide fishing is estimated to be US$46 million annually.[54]

Indonesian reefs are also subject to various pressures from inland activities. The average annual deforestation rate in

REEFS AT RISK IN INDONESIA



MAP 11. REEFS AT RISK IN EASTERN INDONESIA



Indonesia between 1985 and 1997 was 1.7 million hectares.[55] Deforestation and other land-use changes have increased sediment discharge onto reefs, and pollution from industrial effluents, sewage, and fertilizer compounds the problem. Reefs affected by land-based pollution have shown 30–50 percent less diversity at depths of 3 m, and 40–60 percent less diversity at 10 m, in comparison to pristine reefs.[56]

The 1997–98 ENSO event triggered widespread bleaching in Indonesia, with western and west-central Indonesia most affected. Bleaching was recorded in East Sumatra, Java, Bali, and Lombok. In the Seribu Islands northwest of Jakarta, 90 to 95 percent of the coral reef from the reef flat down to 25 m died. Two years later, the Seribu Islands had significant recovery, with live coral cover of 20–30 percent in 2000.[57]

Cumulatively, these pressures appear to have significantly degraded Indonesia's reefs over time. Unfortunately, Indonesia has only limited monitoring. Few reefs are regularly studied, making the assessment of condition and change for the country quite difficult. Currently, most monitoring clearly indicates that reef condition is declining. In the past fifty years, the proportion of degraded reefs in Indonesia increased from 10 to 50 percent.[58] Between 1989 and 2000, reefs with over 50 percent live coral cover declined from 36 to 29 percent.[59] Western Indonesia, which is more developed and holds the majority of Indonesia's population, faces the greatest threats to its coral reefs. Surveys conducted between 1990 and 1998 show that reef condition improves from west to east. The percentage of reefs in good or excellent condition (live coral cover of more than 50 percent) is 23 percent in western Indonesia compared to 45 percent in eastern Indonesia.[60]

RRSEA modeling suggests that human activities threaten over 85 percent of Indonesia's coral reefs, with nearly one half at high threat. The principal threats to Indonesian reefs are overfishing and destructive fishing, which threaten 64 and 53 percent of Indonesia's reefs, respectively. However, the areas at risk from destructive fishing are probably underestimated because information is not available for many areas. Both coastal development and sedimentation from inland sources threaten about 20 percent of the country's reefs.

Few specific management measures exist to protect coral reefs in Indonesia. Until 1999, no identifiable institution had oversight for the management of coastal resources.[61] Owing to a lack of coordination and political upheavals, Indonesia is not achieving government management targets set in 1984. Originally, Indonesia had planned to have 85 marine protected areas covering 10 million ha by 1990 and 50 million ha by 2000.[62] However, in 2000, Indonesia had just 51 marine protected areas (MPAs) that include coral reefs, covering an area of 6.2 million ha.[63]

Governance responsibility for Indonesian coastal resources was given to the Ministry of Marine Affairs and Fisheries in 1999. The government has also sponsored the Coral Reef Rehabilitation and Management Program (COREMAP), a 15-year initiative aimed at strengthening the management of the country's coastal resources while considering the needs of coastal communities. However, to date, COREMAP has had only limited success. On a local scale, several NGOs have had success instituting collaborative and community management frameworks.[64] This bottom-up approach may become increasingly important as the Indonesian government continues to undergo decentralization.

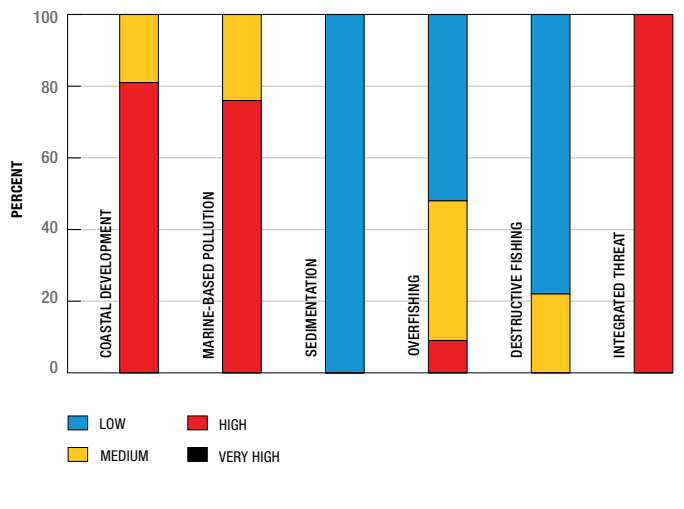
SINGAPORE

The Republic of Singapore, despite its small size, is a focal point for trade and economic development in the region, with one of the world's busiest ports and largest oil refineries.[65] The income generated from industry and shipping traffic has helped it become one of the wealthiest nations in the region, with a per capita GDP second only to Japan. *(See Table 1.)*

Relative to its small land area, Singapore is endowed with considerable biological wealth. Fringing and patch reefs grow around both the main island and more than 60 small offshore islands. These reefs contain more than 197 hard coral species in 55 genera and 111 species of reef fish from 30 coral families.[66] Singapore's coral reef area is estimated to be about 54 km^2.

Singapore's coral reefs are not subject to the unsustainable fishing practices that are so pervasive throughout the rest of the region. Fisheries and the trade in aquarium fish are well controlled. Sewage and industrial waste treatment are relatively good, and marine pollution from ships is mitigated by effective regulatory measures.[67] However, the development required to

REEFS AT RISK IN SINGAPORE



build and maintain its globally important port has taken a substantial toll on corals reefs.

During the past four decades, Singapore has engaged in extensive land reclamation and coastal development projects. Reclamation has been particularly devastating. Around 60 percent of total coral reef area has been lost owing to nearshore reclamation, and the accompanying sediment loads have triggered declines in coral cover in almost all sites monitored since 1987. Average visibility has been reduced from 10 m in the 1960s to about 2 m today.[68] Most reefs have lost up to 65 percent of their live coral cover since 1986. Experts estimate that about 70 percent of Singapore's reefs are degraded compared to conditions 50 years ago. Singapore's reefs were further damaged by the 1997–98 bleaching associated with ENSO. Nearly 90 percent of hard corals bleached, and 25 percent of these have failed to recover.[69]

The RRSEA model indicates that all of Singapore's reefs are threatened by human activities. The dominant threat is coastal development, with its associated sedimentation and pollution. *(See Map 10.)*

Currently, no national policy or specified agency exists to manage coral reefs. Nevertheless, strong measures and consistent monitoring of effluents throughout the nation help to curtail risks from marine pollution. Nongovernmental organizations are taking a strong role in raising awareness and protecting coral reefs through a wide range of activities.

MALAYSIA

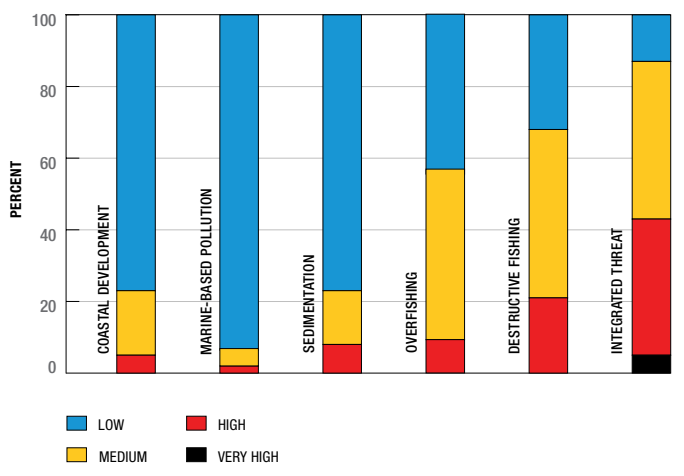
Malaysia encompasses 11 states and 2 federal territories on the Malay Peninsula and 2 states on the island of Borneo, 600 km to the east. *(See Map 10.)* The wide geographic range that Malaysia covers means that coral reefs can be found in varied conditions across the country. Little reef development occurs along the west coast of Peninsular (or West) Malaysia, but the east coast of West Malaysia has some fringing reefs along the coast and many reefs around the offshore islands. East Malaysia, which is comprised of the states of Sarawak and Sabah, makes up the northern one third of the island of Borneo. Because of high sedimentation, reef development around Sarawak is limited. However, Sabah contains more than 75 percent of all Malaysian reefs and has high levels of coral diversity. Overall, more than 350 coral species have been recorded in Malaysia.[70]

Threats facing Malaysian reefs differ by location. Peninsular Malaysian reefs are most affected by development. High-traffic shipping lanes run along the western coast of Peninsular Malaysia through the Straits of Malacca. Reefs in this area can be subject to oil spills and anchor damage. Agriculture and development on the peninsula have caused increased sediment and nutrient runoff. Some west coast reefs are now damaged by seasonal macroalgae blooms.[71] Destructive fishing practices are not widespread in Peninsular Malaysia due to higher enforcement and less dependence on coastal fisheries.[72]

East Malaysian reefs are subject to different threats. Both blast and cyanide fishing methods are widespread around Sabah, particularly around Labuan. Blast and cyanide fishing have ruined formerly pristine reefs like those surrounding the islands off Semporna. In damaged sites like Boheydulang and Bodgaya Island, abundance and size of fish are markedly decreased. In Sarawak, river sedimentation is also an important threat. Reefs near the Miri River have 20–30 percent live coral cover and large amounts of algal growth.[73]

Information about coral cover in Peninsular Malaysia is somewhat limited. Surveys of coral reefs along the east coast of Peninsular Malaysia suggest relatively high coral cover, 55–70 percent on most fringing reefs. On the west coast of the peninsula, the percentage of live coral cover is generally lower, from 25 to 45 percent.[74]

REEFS AT RISK IN MALAYSIA



Coral surveys are more extensive in East Malaysia. From 1996 to 1999, 49 coral reefs throughout Sabah were surveyed. Live coral cover ranged from 15 to 75 percent. Dead coral cover, which is indicative of recent damage, accounted for 10–20 percent of benthos cover at nearly 70 percent of surveyed sites.[75] Only 10 percent of reefs had dead coral cover under 10 percent.[76] Coral reefs on Sipadan Island are thought to be in the best condition among reefs off the coast of Sabah.[77] Bleaching surveys in East Malaysia during the 1997–98 ENSO event indicate moderate bleaching. At Pulau Gaya and Lahad Datu, approximately 30 pecent of the coral cover was bleached.[78]

The RRSEA project found that over 85 percent of Malaysian reefs are threatened by human activities. Destructive fishing and overfishing are the primary threats, impacting 68 percent and 56 percent of reefs, respectively. Coastal development and sedimentation from upland sources each affect approximately 23 percent of coral reefs in Malaysia.

Malaysia has several marine protected areas, including the Turtle Islands Heritage Park, a historic transboundary park jointly administered with the Philippines. These MPAs vary in their management effectiveness; most marine parks in Malaysia suffer from issues such as inadequate personnel, logistical problems, and scarce financing. Enforcing regulations and monitoring reef status are particularly challenging.

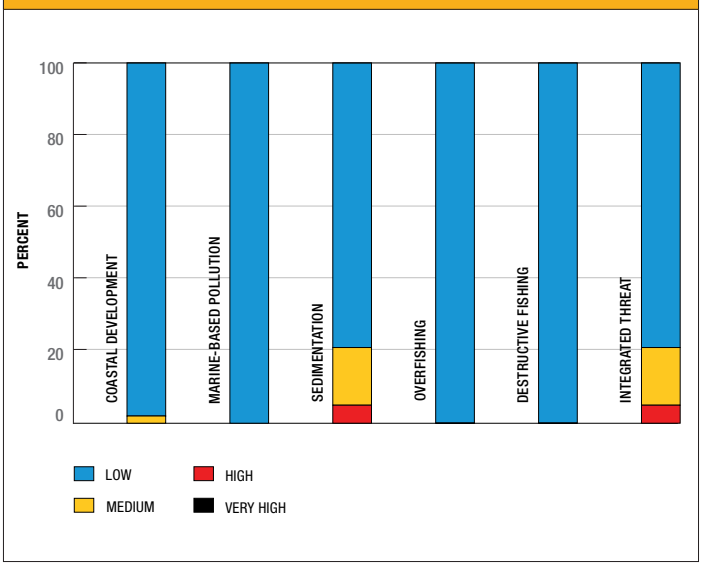
BRUNEI DARUSSALAM

Brunei Darussalam is one of the smallest nations in Southeast Asia. Unlike other nations in the region, the people of Brunei are not as reliant on the biological resources in their coastal zone for their livelihoods because the country has lucrative offshore oil and gas industries. Brunei, however, has a trawling fleet to exploit offshore fisheries. Coral reefs cover roughly 200 km^2 and include fringing reefs, patch reefs, and one atoll.[79]

Although Brunei's reefs cover only a small area, they are fairly diverse. Surveys completed in 1987 and 1992 found 185 species from 72 genera in Brunei's waters.[80] Coral cover, however, is relatively low—40 percent at Pelong Rocks and 27 percent at Two Fathom Rock.[81] Because they are not commercially exploited, Brunei's coral reefs remain in relatively good condition. Despite extensive oil drilling and coastal development, they are among the least threatened in the region. According to the RRSEA model, only about 21 percent of Brunei's coral reefs are at risk from human activities, particularly from sedimentation as a result of upland activities. *(See Map 10.)*

The Department of Fisheries in the Ministry of Industry and Primary Resources is responsible for the management of coral reefs in Brunei. Although it developed an integrated coastal management plan, Brunei has yet to implement it proactively. The country is currently courting more tourism development, but new regulations will require projects to con-

REEFS AT RISK IN BRUNEI DARUSSALAM



MAP 12. REEFS AT RISK IN THE MALAY PENINSULA

duct an environmental impact assessment. However, technical capacity and scientific knowledge in the country are limited, and Brunei is seeking help from international organizations in executing comprehensive monitoring programs.

THAILAND

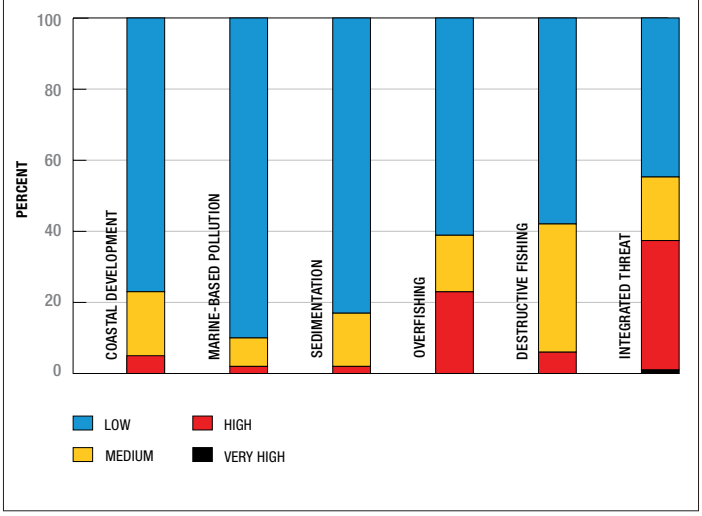
An estimated 1,800 km^2 of coral reefs grow along Thailand's coastline in the Gulf of Thailand and the Andaman Sea. The structure and distribution of coral reefs vary significantly between the two. Because of climatic and oceanographic variations in their water bodies, threats and reef condition can also be substantially different. *(See Map 12.)*

Fishing has long been an important economic activity in Thailand, but widespread destructive fishing techniques and trawling have had impacts on coral reefs since the early 1960s.[82] Destructive fishing practices on both coasts have damaged countless reefs, but these activities are believed to have declined as the tourism industry has grown.[83] The rise in tourism and other population pressures, however, have caused sedimentation and wastewater pollution to increase, and damage from boat anchors, divers, garbage, erosion, and sewage and wastewater discharge is evident.[84]

Significant coral bleaching episodes have also plagued Thai reefs. Coral reefs in the Andaman Sea suffered extensive coral bleaching and subsequent mortality in 1991 and 1995, and some bleaching was observed in 1998.[85] Coral bleaching during the 1997–98 ENSO event was widespread in the Gulf of Thailand, where it had not previously been recorded; as many as 60 percent of corals may have bleached in some locations.[86] Unfortunately, the frequency and intensity of bleaching in Thai waters appear to be increasing.

From 1995 to 1998, Thailand began a comprehensive reef survey program that included coral reef mapping and field surveying. Scientists surveyed 251 reef sites in the Gulf of Thailand and 169 sites in the Andaman Sea. Reef condition was evaluated based on a ratio of live to dead coral cover. Using this indicator, 16 percent of reefs in the Gulf of Thailand were rated as excellent, 29 percent good, 31 percent fair, and 24 percent poor. In the Andaman Sea, 5 percent of reefs were rated as excellent, 12 percent good, 34 percent fair, and 50 percent poor. Monitoring

REEFS AT RISK IN THAILAND



suggests that the condition of coral reefs in the Gulf of Thailand has worsened since the late 1980s, while the condition of reefs in the Andaman Sea has remained stable or improved slightly.[87]

The RRSEA model shows that about 77 percent of Thailand's reefs are threatened by human activities, with over 60 percent of corals in the Andaman Sea and nearly 90 percent in the Gulf of Thailand at risk. Overfishing is the most pervasive threat, affecting about one half of all reefs. Sedimentation and pollution associated with coastal development and inland activities threaten over 40 percent of the country's reefs. Destructive fishing activities have damaged many reefs in the past and may continue to be a problem in some areas.

The Department of Fisheries and the Royal Thai Forestry Department are responsible for enforcing coral reef protection regulations. Nonetheless, interpretation of the laws is complex and regulations are sometimes unclear. Designated marine protected areas cover nearly 40 percent of coral reefs, although sites in the Gulf of Thailand are underrepresented. Unfortunately, the effectiveness of Thai MPAs has been compromised by local conflicts, unclear boundaries, jurisdictional issues, and controversial priority setting that places more emphasis on tourism than conservation.[88] An active NGO network in Thailand is currently taking action to foster better community-based management of coral reefs and restoration of forests and mangroves.[89]

INDIA (ANDAMAN AND NICOBAR ISLANDS)

The Andaman and Nicobar Islands are two chains of islands belonging to India. Located north of Sumatra, these 530 islands divide the Bay of Bengal from the Andaman Sea. Only 38 of the islands are inhabited, but the population is growing rapidly, from 279,000 in 1991 to a projected 405,000 in 2001. Most of the islands are forested, mountainous, and have extensive fringing reefs.[90] *(See Map12.)*

The biological importance of the islands is still being researched. Recent surveys have identified 219 coral species, 120 species of algae, 70 species of sponges, 571 species of reef fish, and 8 species of shark. The islands also contain dugong, dolphin, and turtle habitats. The Nicobars contain some of the best nesting sites for leatherback turtles in the Indian Ocean.[91]

Both chains of islands have remained relatively pristine, although development is encroaching on some areas with negative effects. On some islands, deforestation has significantly increased sediment outflows on nearshore reefs and turbid freshwater discharge has spurred algal growth. Industrial pollutants are affecting the area around Port Blair.[92] The islands also support active fisheries. Nevertheless, the lack of comprehensive surveys of the islands makes assessment of threats and conditions difficult.

The 1997–98 ENSO event had less impact on the Andaman and Nicobar Islands than had been originally thought. Initially, 80 percent of corals were believed to be dead. However, recent surveys in five sites indicate an average of 56 percent live coral cover, 20 percent dead coral cover, and 11 percent coral rubble.[93]

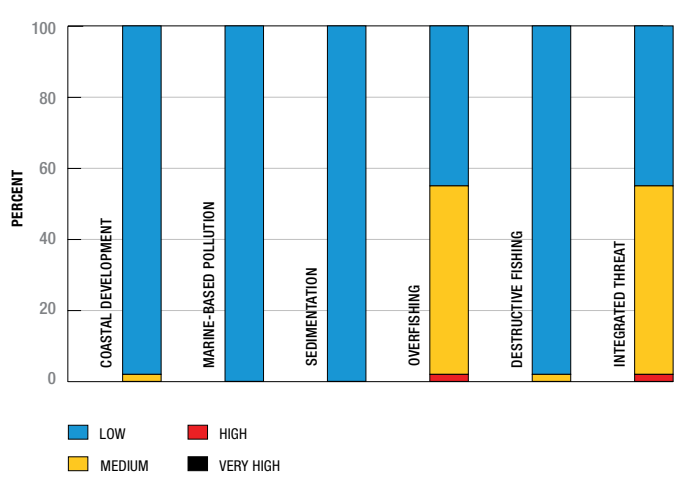
The RRSEA analysis identifies overfishing, which may affect 55 percent of reefs, to be the only major threat to the Andaman and Nicobar Islands. The threats from sedimentation and inland pollution are underestimated in the analysis because of the islands' small watershed size and limited landcover data.

The islands are covered by a network of more than 100 marine protected areas. Many of these MPAs include entire islands and extend into intertidal waters, but most do not include coral reef areas. In addition, management of the protected areas is weak and monitoring of condition is inconsistent.[94]

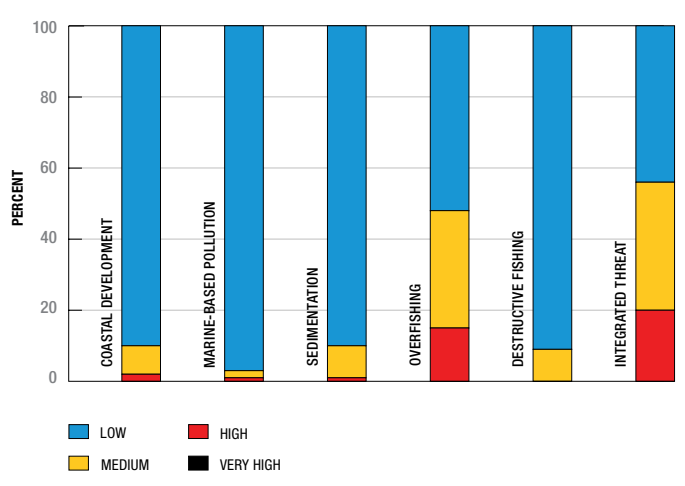
MYANMAR (BURMA)

The coastline of Myanmar extends for approximately 15,000 km along the Bay of Bengal and the Andaman Sea.[95] The north-central part of the country is dominated by the vast delta of the Ayeyarwady (Irrawaddy) River, one of the largest rivers in Southeast Asia. The chain of islands between the Ayeyarwady Delta and the Andaman Islands contains coral reefs, but they have been only minimally surveyed. Along the southern coast is a complex of forested offshore islands known as the Mergui Archipelago, where the majority of Myanmar's coral reefs are found. The Mergui reefs are thought to be similar in structure and diversity to the reefs around the offshore

REEFS AT RISK IN THE ANDAMAN AND NICOBAR ISLANDS



REEFS AT RISK IN MYANMAR



islands of Thailand.[96] Currently, 65 coral species in 31 genera have been cataloged in Myanmar's reefs, but these figures are probably an underestimate.[97] Lack of surveys and scientific information impedes a true evaluation of the wealth of Myanmar's reefs. The RRSEA project estimates that Myanmar has 1,700 km^2 of coral reefs.

The current government, which is led by a military junta, has been in power since 1988. Because movement within the country is restricted, scientific surveys and conservation projects have been limited in scope. Most development occurs around the capital of Yangon (Rangoon), but it is beginning to spread to more rural areas. Tourist operators from Thailand are now being allowed to take groups to the Mergui Archipelago. However, the paucity of information about development, biology, and ecosystem change has made assessing the threats to Myanmar's reefs difficult.

According to the Reefs at Risk analysis, 56 percent of Myanmar's reefs are threatened. The RRSEA model suggests that overfishing is the primary threat to nearly one half of Myanmar's reefs. Destructive fishing, coastal development, and sedimentation each threaten an estimated 10 percent of Myanmar's reefs. Marine-based pollution impacts only 3 percent of reefs. *(See Map 12.)*

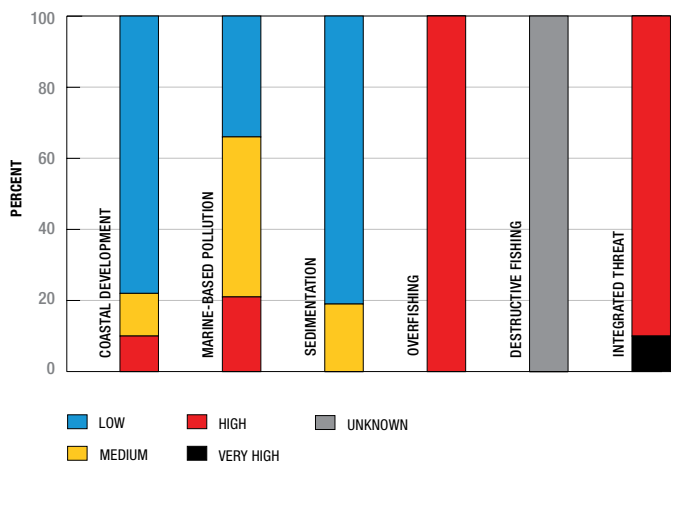
CAMBODIA

Information on the distribution and condition of Cambodia's coral reefs is still very limited. Most corals are found on rocky bases and a few are organized into fringing reef formations. Surveys on Koh Tang, one of the 52 islands offshore of Cambodia, indicate 70 species of coral from 33 genera.[98] Islands farther inshore generally support lower diversity because of turbid waters unfavorable for coral growth. Cambodia has relatively limited coral reef areas, estimated by the RRSEA study to be under 50 km^2.

Cambodia's coral reefs have been subject to a variety of human pressures, particularly those related to unsustainable fishing practices and poor land management. Blast fishing has been reported, and fishers have depleted lucrative commercial fish.[99] Overfishing and illegal fishing from foreign vessels are thought to be a problem, but statistics are incomplete.

Bleaching from the 1997–98 ENSO event affected

REEFS AT RISK IN CAMBODIA



Cambodian reefs, with one survey indicating that 80 percent of corals in Sihanoukville bleached during 1998.[100] However, national bleaching and coral mortality statistics are not available.

Surveys of coral condition are limited to a few sites within Cambodia. Studies in four locations in Koh Kong province in 2001 found live coral cover ranging from 23 to 42 percent.[101]

The RRSEA model suggests that all of Cambodia's coral reefs are at high risk from human activities. Overfishing is believed to affect all reefs in Cambodia's waters. Limited data suggests that many reefs are threatened by destructive fishing. Coastal development, sedimentation, and marine-based pollution are also significant threats. *(See Map 12.)*

Management for conservation of coral reefs in Cambodia is still rudimentary. Most laws relate to the protection of fisheries rather than coral reefs. However, the government is making strides in some areas. Coral collection, an important threat from 1995 to 1997, is declining because the Fisheries Department has tightened controls and confiscated coral from vendors.[102]

VIETNAM

Vietnam has an extensive coastline that stretches from north to south across more than 15° of latitudinal variation. Scientists have described more than 300 species of scleractinian corals in Vietnamese waters. The southern reefs are the most diverse, with 277 species of coral that form both fringing and platform reefs. Fringing reefs in the north are typically less diverse, with only

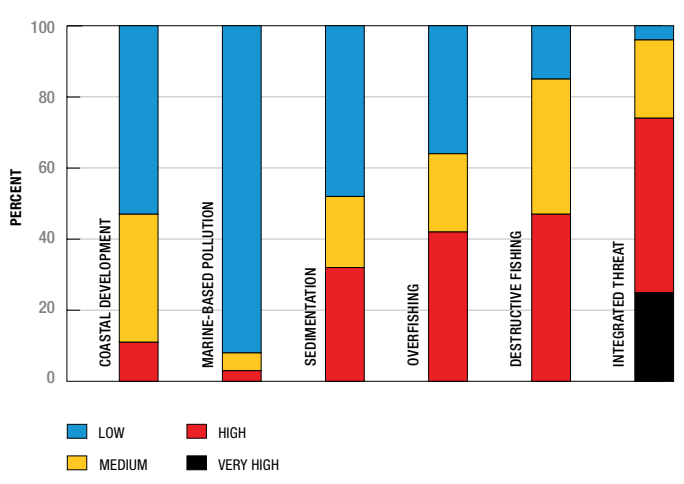
165 species.[103] Vietnam's estimated 1,100 km² of coral reefs face a variety of threats, particularly in areas of high population density.

Vietnam has a long history of traditional marine fisheries, with many local communities relying on coastal resources for their livelihoods. However, increases in population, the poverty of small-scale fishers, and the arrival of nonresident harvesters from nearby China and Hong Kong have taken a huge toll on marine fisheries. During interviews conducted in early 1999, overfishing, the decline in marine resources, and destructive fishing were cited as problems in the vast majority of provinces.[104]

Vietnam's reefs are affected by sedimentation from many rivers throughout the country, especially the Mekong and the Red rivers. Coastal development only compounds this pressure. Scientists have observed frequent algal blooms around Binh Thuan province, Khanh Hoa province, and Ho Chi Minh City as well as marine pollution around the northern areas of Quang Ninh and Hai Phong.[105]

Recovery from damage associated with the 1997–98 ENSO event has been slow. Because of stresses from human activities and bleaching, coral cover in most areas has been declining since the ENSO event, and sedimentation has caused coral loss in Ha Long Bay and the Cat Ba Islands. Reefs around Binh Thuan, which are near an upwelling, are a notable exception. Bleaching has also caused decreased fish diversity, especially among butterfly fishes.[106]

REEFS AT RISK IN VIETNAM



Coral reef condition in Vietnam is declining. Surveys conducted from 1994 to 1997 from over 142 sites portrayed a grim picture. Only 1 percent of reefs were found to be in excellent condition (i.e., with over 75 percent live coral cover). Reef classified as good (with 50–75 percent coral cover) accounted for 26 percent of reefs. Of the remaining areas, 41 percent were found to be in fair condition (with 25–50 percent coral cover) and 31 percent were found to be in poor condition (with under 25 percent coral cover).[107]

The RRSEA model found 96 percent of the coral reefs in Vietnam to be threatened by human activities, with nearly 75 percent at high or very high threat. Destructive fishing is the most pervasive and significant threat, with 85 percent of the reefs at medium or higher threat from this activity. Overfishing was estimated to threaten more than 60 percent of Vietnam's reefs, and sediment from upland sources was estimated to threaten 50 percent of the country's reefs. Coastal development is a threat to over 40 percent of the reefs. *(See Map 12.)*

Vietnam is addressing coral reef issues with two national strategic plans focusing on fisheries and tourism. Tourism, which accounted for approximately 6 percent of GNP in 2000, is expected to grow to 12 percent by 2010. Through zoning and the creation of natural reserves and classified sites, Vietnam hopes to have models for sustainable tourism in Con Dao, Cat Ba, and Ha Long Bay National Parks. Out of Vietnam's 20 MPAs, only these 3 parks contain reefs. An additional proposal recommends a national system of 30 coastal and marine reserves, which would increase the areas protected from 1,528 ha to 3,118 ha.[108]

PHILIPPINES

Philippine coral reef area, the second largest in Southeast Asia, is estimated at 26,000 km² and holds an extraordinary diversity of species. Scientists have identified 915 reef fish species and more than 400 scleractinian coral species, 12 of which are endemic.[109]

A large coastal population, rapid population growth of about 2.3 percent per year, high poverty rates, and fisher over-capacity have resulted in major overexploitation of Philippine reef fisheries.[110] Demersal fish stocks are biologically and economically overfished in almost all areas other than eastern Luzon, Palawan, and the southern Sulu Sea.[111]

Destructive fishing techniques are thought to be the largest contributor to reef degradation in the Philippines.[112] *Muro-ami*, a technique that involved sending a line of divers to depths of 10–30 m with metal weights to knock on corals in order to drive fish out and into waiting nets was extremely damaging to reefs, leading to its ban in 1986. Rampant blast fishing and sedimentation from land-based sources have destroyed 70 percent of fisheries within 15 km of the shore in the Philippines, which were some of the most productive habitats in the world.[113] Although increased enforcement, larger penalties, and educational campaigns slowed the damage in the 1990s, many fishers have brought destructive practices to new areas. Reports indicate that many operations have shifted to more remote, pristine areas such as the Palawan group of islands, the Sulu Archipelago, parts of the Visayas, and western Mindanao.[114]

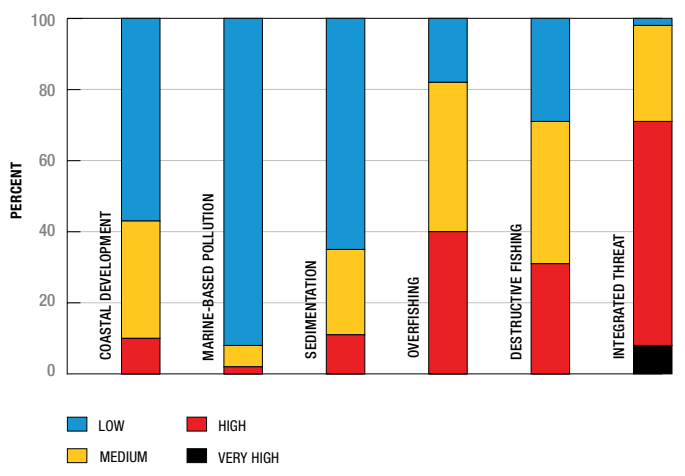
Coastal development, agriculture, aquaculture, and land-cover change threaten many Philippine coral reefs. Over 80 percent of original tropical forests and mangroves in the Philippines have been cleared, increasing sediment outflow onto reefs.[115] Mangroves continue to be cut and converted to fish ponds, allowing more nutrients and sediment to reach reefs.[116] Domestic and industrial wastes are rarely treated in the Philippines and are often discharged directly into the sea.

The first ever mass-bleaching event in the Philippines was reported in 1998–99. It began at Batangas, off Luzon, in June 1998 and then proceeded nearly clockwise around the Philippines, correlating with anomalous sea-surface temperatures.[117] Reefs off northern Luzon, west Palawan, the Visayas, and parts of Mindanao were affected. Subsequent mortalities were highly variable, but Bolinao was among the worst areas with 80 percent coral bleaching.[118]

In the late 1970s, the most extensive survey of coral reefs conducted in the Philippines showed widespread human impact on the reefs. The Inventory of the Coral Resources of the Philippines (ICRP) found only about 5 percent of reefs to be in excellent condition, with over 75 percent coral cover (both hard and soft).[119]

More recent surveys in 1997 found a slightly lower percentage of reefs to be in excellent condition. They found only 4 percent of Philippine reefs in excellent condition (i.e., over 75 percent hard or soft coral cover), 28 percent in good condition

REEFS AT RISK IN THE PHILIPPINES

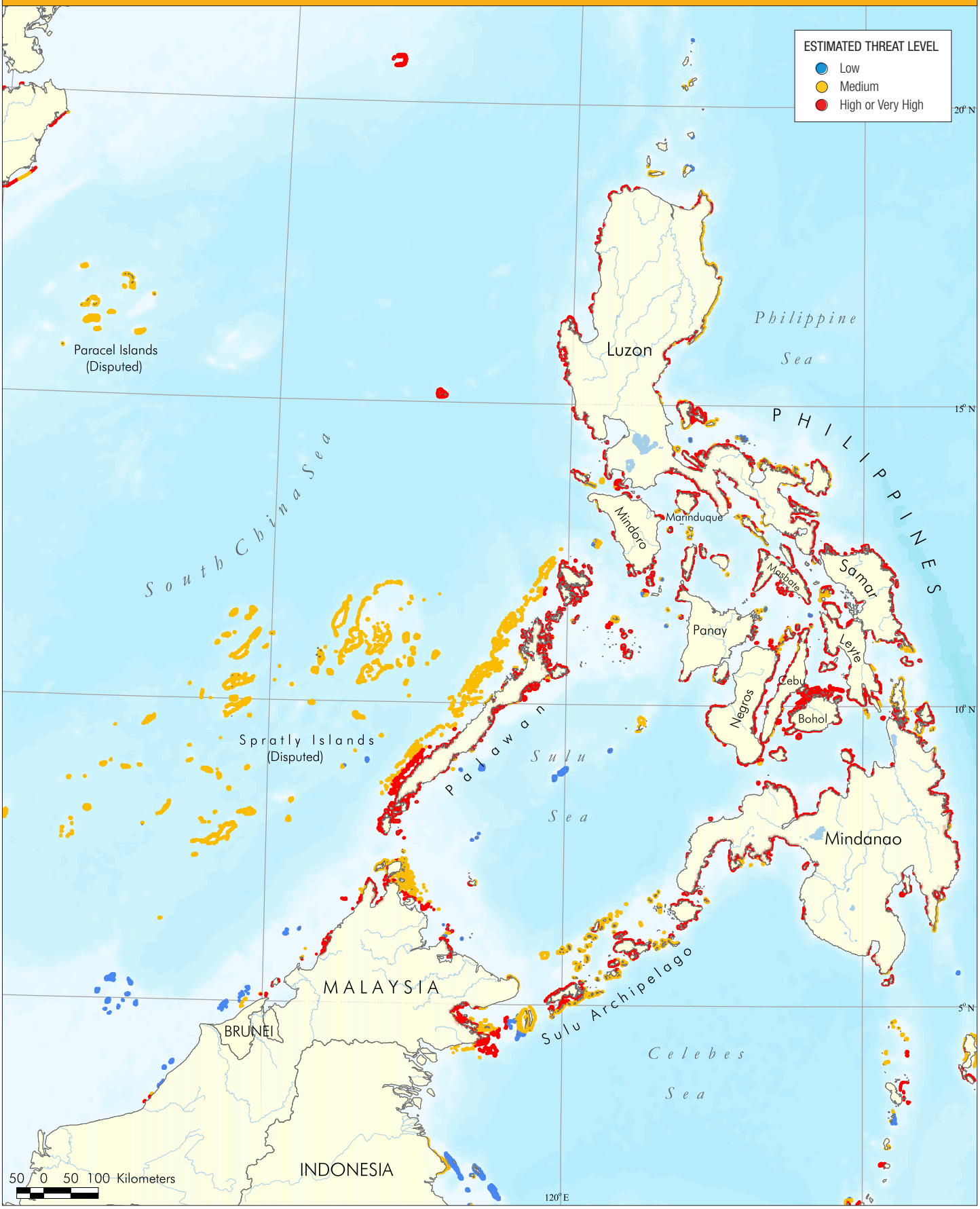


(50–75 percent coral cover), 42 percent in fair condition (25–50 percent coral cover), and 27 percent in poor condition (less than 25 percent coral cover). The Visayas have experienced the most significant decline in coral cover, exhibiting an average of only 11 percent hard coral cover. Coral status information for Mindanao and the Sulu Archipelago is limited.[120]

The RRSEA model suggests that overfishing and destructive fishing are the most severe threats to coral reef health. Over 80 percent of Philippine reefs are threatened by overfishing, although this figure is likely to be an underestimate because it only accounts for nearshore fishing pressures. The model's mapping of areas at risk from blast fishing and fishing with poisons suggests that over 70 percent of Philippine reefs continue to be at risk from these practices. In addition, coastal development pressures threaten over 40 percent of Philippine reefs, and about 35 percent of reefs are under pressure from sedimentation and pollution associated with land-use changes. When the various threats from human activities are combined, the model estimates that 98 percent of Philippine reefs are at risk from human activities, with 70 percent at high or very high risk.

Government agencies managing coral reefs in the Philippines are generally understaffed and insufficiently funded for effective management and monitoring of coral reefs. Many laws and regulations concerning coral reefs already exist, including bans on cyanide fishing, blast fishing, and the collection or export of hard (Scleractinia) corals. For the most part, though, these laws

MAP 13. REEFS AT RISK IN THE PHILIPPINES AND THE SOUTH CHINA SEA



are not adequately enforced.[121] About 500 MPAs are currently listed in Philippine records, but many were never actually established and even fewer are effectively managed.[122] The Philippine government has actively encouraged local management of reefs, and there have been some outstanding success stories.[123]

SPRATLY AND PARACEL ISLANDS (SOUTH CHINA SEA)

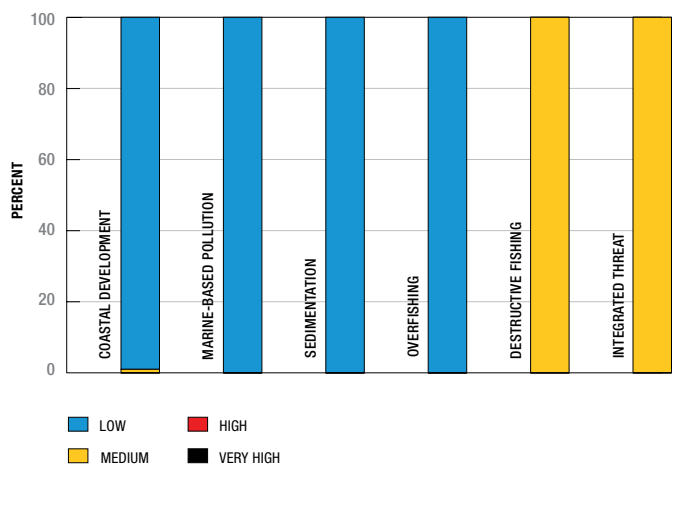
The biologically and geologically rich resources of the South China Sea (SCS) have been the source of intense territorial disputes. The People's Republic of China, the Philippines, Vietnam, Malaysia, and Brunei Darussalam all claim some of the islands and reefs of the area, particularly in the area known as the Spratly Islands. Many of these claims are overlapping.

The strategic and economic importance of the SCS is clear. Total fisheries production is estimated at 30 million tons annually, only 13 percent of which is currently harvested.[124] Fishing provides both a substantial portion of animal protein intake for the countries surrounding the SCS, and work for approximately 2 million people in the region.[125] In addition, the SCS is rich in petroleum. Oil and natural gas rigs dot the periphery of the basin. In 1982, the offshore petroleum in the SCS was valued at US$76 billion.[126] Because it lies in the heart of Southeast Asia, the SCS is also a major navigational shipping highway, with more than 300 ships passing through each day.[127]

The SCS also has vast ecological wealth.[128] The nearshore areas of the SCS contain more than 70 coral genera.[129] The biodiversity of the SCS has potentially important benefits for the entire region; research indicates that currents carry fish and coral larvae from reefs in the south-central portion of the SCS to surrounding damaged reefs.[130] Thus destruction of coral reefs in the SCS affects biodiversity and reef health on a regional scale.

The controversial issues of ownership have prevented long-term monitoring of reef condition. A proposal to create a marine park has been examined by claimant nations in a series of workshops.[131] In the meantime, however, uncoordinated enforcement throughout the area makes the SCS susceptible to unsustainable commercial fishing and destructive fishing practices. The RRSEA analysis concludes that the only significant threat facing the coral reefs of the SCS is destructive fishing. However, the project was not able to assess the impact of commercial

REEFS AT RISK IN THE SPRATLY AND PARACEL ISLANDS

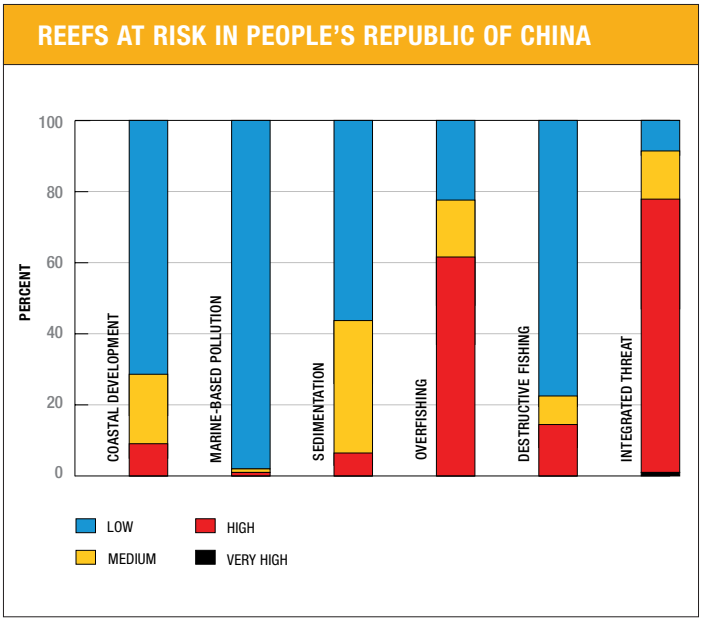


fishing or marine-based pollution from shipping due to lack of data. Minor pressures from military bases may also be present. *(See Map 13.)*

Until an agreement can be reached on creating a marine park, claimant countries have proceeded with joint research expeditions. The advancement and success of these joint oceanographic and marine scientific research expeditions (JOMSRE) are important milestones in the confidence-building efforts among nations with overlapping claims in this disputed area. Through bilateral arrangements, the Philippines and Vietnam successfully conducted two JOMSREs in the SCS during the summers of 1996 and 2000, in which they undertook studies on the physical, chemical, and biological oceanography of the area as well as its coral reef ecology.

PEOPLE'S REPUBLIC OF CHINA

China has an extensive coastline that stretches from its border with Vietnam along the northern South China Sea to the Korean peninsula. However, unlike Taiwan and Japan, China does not benefit from warm-water currents. The lack of warm water along much of China's coast has inhibited coral reef growth. Reefs do not grow north of Guangdong Province.[132] The most extensive reefs grow around Hainan Island and the surrounding 300 small islands. Initial surveys reveal 150 hard coral species,[133] 30 soft coral species, 569 fish species, and 700 species of molluscs.[134]



China's reefs have been particularly targeted for valuable edible fish and mollusc species. Overfishing and destructive fishing practices have badly damaged coral communities around Hong Kong, causing most high-value fish species to become locally extinct.[135] Around Hainan Island, illegal fishing activities and the sale of living corals for the aquarium trade are also problems.[136]

Sedimentation, freshwater incursion, and sewage outflows have adversely impacted China's reefs, particularly near the mainland. Reefs around Hong Kong had up to 80 percent coral mortality in 1994, when the swollen Pearl River caused freshwater upwellings and algal blooms.[137]

Few coral reef surveys have been carried out in China, with more information available about the reefs in the Sanya Reserve than anywhere else. Reefs in the Ya Long Bay area of the reserve have high live coral cover at 80–90 percent, and they are in good condition.[138] Coral cover in the Qionghai Coral Reserve on the eastern Hainan Islands averages between 60 and 70 percent.[139] Reefs outside of reserves are probably not faring as well.

The RRSEA analysis finds that 92 percent of China's reefs are under significant threat. Overfishing is the most pervasive, threatening over three-quarters of China's reefs. Sedimentation from upland sources is estimated to impact 40 percent of all reefs, and coastal development endangers over 28 percent. *(See Map 14.)*

Monitoring capacity in China is generally low, and coral reefs have not been a key issue in policy negotiations. Localized efforts to protect reefs, however, have had some success. On Hainan, marine authorities have strictly enforced a law banning coral mining, closing some 90 kilns throughout the island.[140] Cooperation between hotel operators and the Hainan Marine Department have helped to reduce illegal fishing activities that damage reefs.[141]

TAIWAN

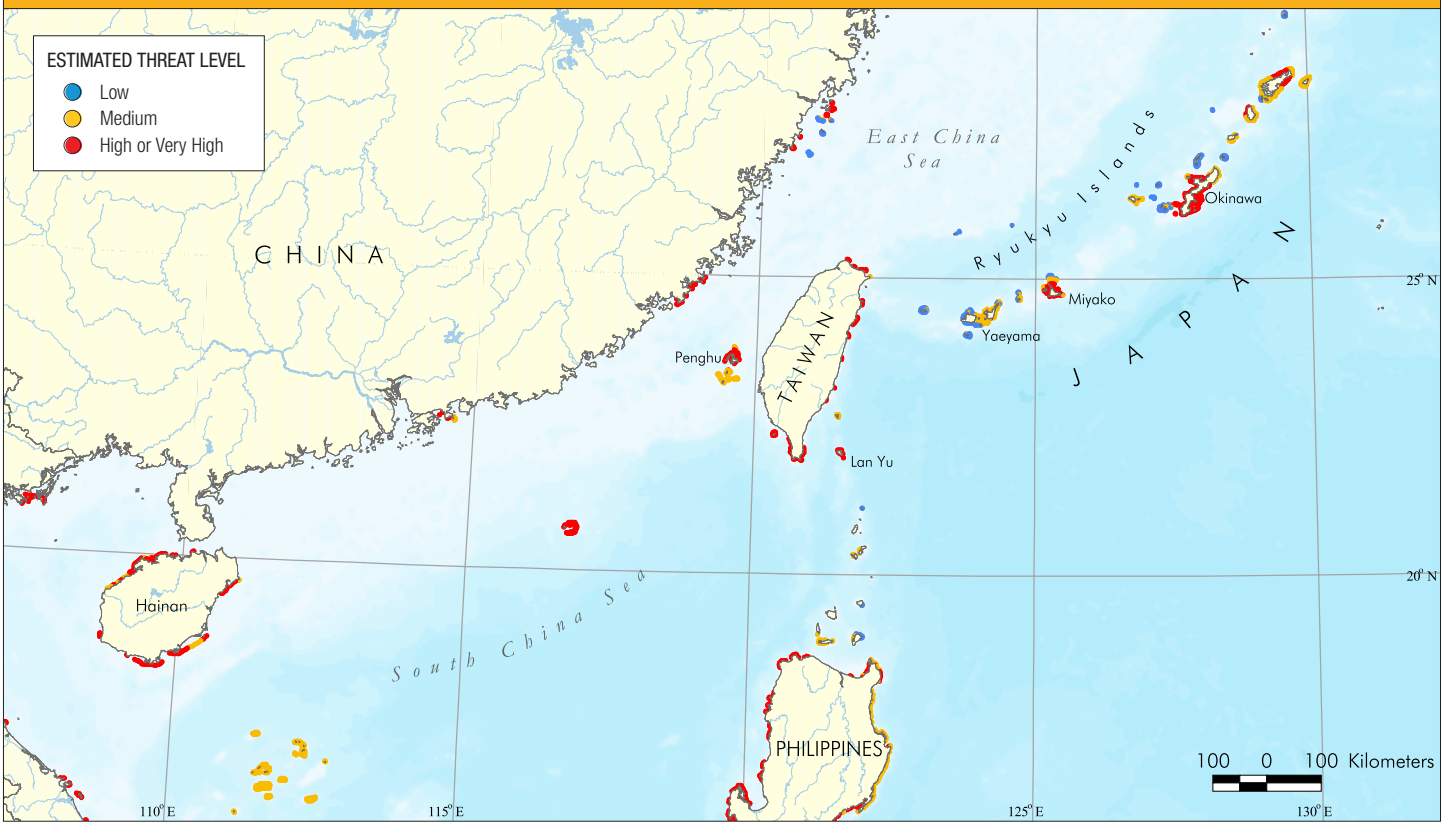
Taiwan is near the thermal boundary where coral reefs can no longer grow. The southern tip of the island and many offshore islands have numerous well-developed fringing reefs. However, along the northeast and east coasts, corals form patchy communities rather than reefs. Fish and coral larvae carried by the Kuroshio, a warm-water current originating in the North Equatorial Current, help to give Taiwan's reefs relatively high biodiversity despite their proximity to the boundary where reef can no longer grow.[142] Taiwan's reefs hold approximately 300 species of scleractinian corals and 1,200 species of reef fish.[143]

Taiwan's biodiversity has traditionally been important for tourism and fishing. Approximately 150,000 people are dependent on coral reefs for some aspect of their livelihoods.[144] The Taiwanese rely on fish for a sizable amount of their protein intake; in 1997, per capita fish consumption was 39 kg per year. *(See Table 1.)* Coral reefs also attract tourists for recreational fishing, diving, swimming, and snorkeling.

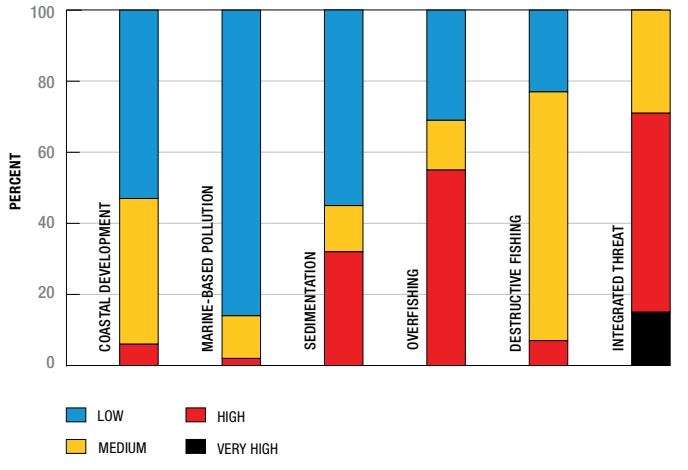
Aside from natural disturbances like typhoons, the largest threats to Taiwan's nearshore coral reefs are dynamite fishing, sedimentation, and wastewater pollution from expanding urban development. Dynamite fishing has become a threat, particularly since 1987, when enforcement was transferred to local authorities. Evidence of dynamite fishing has been reported in Keelung, Kenting, and Penghu.[145] Thermal effluents from a power plant in Nanwan Bay are so high that they have caused coral bleaching every summer since 1987.[146] In some locations, live coral cover has dropped from 50 percent to 30 percent in the last 10 years.[147]

The 1997–98 ENSO event caused extensive coral bleaching on southern Taiwan reefs. In the Penghu Islands, Lutao, and Lanyu, approximately 30–50 percent of coral colonies

MAP 14. REEFS AT RISK IN THE FAR NORTH



REEFS AT RISK IN TAIWAN



bleached. According to surveys in 1999 and 2000, 20 percent of coral colonies died.[148]

The RRSEA analysis of human pressures finds that all of Taiwan's reefs are threatened, with destructive fishing threatening 75 percent of reefs, overfishing 70 percent, and sedimentation and coastal development each threatening about 45 percent of the reefs.

The management effectiveness of marine protected areas in Taiwan has been rated as poor. Most MPAs lack adequate laws to protect the environment, and enforcement of laws that do exist is lax. However, members of the scientific community, government, and local communities formed the Taiwanese Coral Reef Society (TCRS) in 1996, which is helping to raise awareness about the threats to coral reefs and their value to Taiwan.

JAPAN

Japan is on the edge of a delicate mix of biology, climate, and chemistry that coral reefs need to form. The Kuroshio current allows reefs to grow at some of the highest latitudes in the world and carries reef larvae from the Philippines.[149] In fact, the Kuroshio is so efficient at larval transport that Japanese waters support coral biodiversity nearly equal to that of the Philippines.[150]

Although Japan's reefs are often endangered by tropical typhoons and Crown-of-Thorns starfish *(Acanthaster planci)* infestations, sedimentation, pollution, overfishing, dredging, trawling, poorly managed tourism, port and seawall construction, and other threats caused by human activities are more pervasive and damaging.

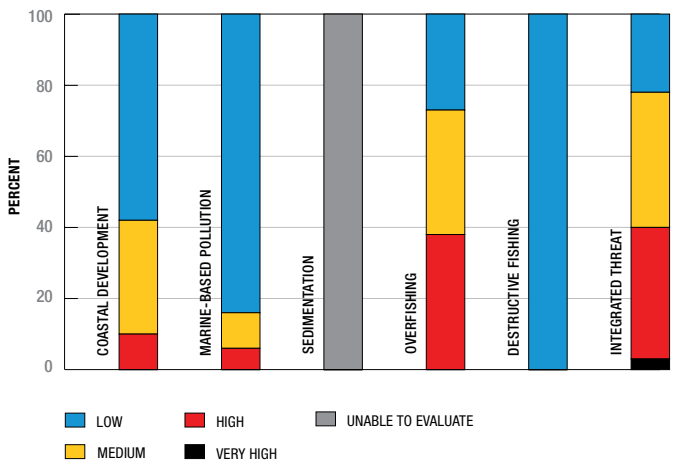
Sedimentation from terrestrial runoff of red clay soils remains one of the most serious threats to Japanese reefs. Poor land-use practices, road building, coastal development, and river modification projects have all led to increased sediment loads on coral reefs. Between 1981 and 1990, 19 percent of Japanese reefs were removed to dredge harbors or build erosion barriers.[151] Airport construction and land reclamation projects planned on Ishigaki Island and Henoko, Okinawa, may release further sediment onto already vulnerable reefs.[152]

From 1990 to 1992, the Japan Environment Agency conducted extensive surveys to examine live coral cover throughout the islands. The Agency found that coral cover in the reef flats was typically quite low. The surveys indicated that 61 percent of communities in the Nansei Islands had under 5 percent coral cover, 30 percent had coral cover between 5 and 50 percent, and only 8 percent of communities had over 50 percent coral cover. On Okinawa reef edges, 67 percent of reefs had under 5 percent cover.[153] Surveys from 1972 and 1990 in the Ryukyu Islands indicate that during that time a substantial number of reefs dropped from over 50 percent coral cover to under 25 percent cover. One third of coral species in Japan are now at risk of becoming locally extinct.[154]

The 1997–98 ENSO bleaching was the most severe coral bleaching and mortality event ever observed in southern Japan. Severity and mortality varied owing to variations in local conditions, with Okinawa and the Kume islands hardest hit. Yoron Island was also particularly affected, exhibiting 70–90 percent mortality in the south and 30–60 percent in the north.[155] Bleaching in the Nansei Islands was between 40 and 60 percent. In Koshikijima Island, western Kyushu, eastern Shikoku, and Kushimoto, bleaching typically affected under 20 percent of corals. The Kerama Islands experienced the lowest degree of bleaching.[156]

The RRSEA model suggests that nearly 80 percent of Japan's reefs are at risk from human activities. *(See Map 14.)* Overfishing is the most pervasive cause, threatening over 70 percent of Japan's reefs. Coastal development pressure, including accompanying sedimentation, threatens over 40 percent of coral reefs. The project was not able to evaluate sedimentation from upland sources for these areas of Japan because the watershed size is below the minimum used in the analysis.

REEFS AT RISK IN JAPAN



In the last decade, Japan has increased its monitoring capacity and its reef protection programs and has established a center for coral reef information. Japan has six Natural Parks located in the Amami, Ryukyu, and Ogasawara Islands. However, the natural park system covers a relatively small area of coral reefs, only 1.7 percent of the country's total coral reef area.[157] A higher percentage of coral reefs is included in other parks that are more focused on tourism but whose management effectiveness in terms of conservation is not known.

BOX 6. THREAT ANALYSIS AT LOCAL SCALES

The RRSEA analysis contains a standardized, consistent analysis of human pressure on coral reefs across the region. It is primarily based upon 1:1 million scale data sets. *(See Appendix 1.)* This scale of analysis is useful for comparisons among countries and for subnational examination within most countries. However, more refined data are needed for detailed local planning. The RRSEA project is working with local partners to improve data and apply some of the threat analysis techniques to smaller areas. These studies will incorporate local information on location, status, and protection as well as observed impacts on coral reefs; they will provide a more detailed examination of human pressure on coral reefs.

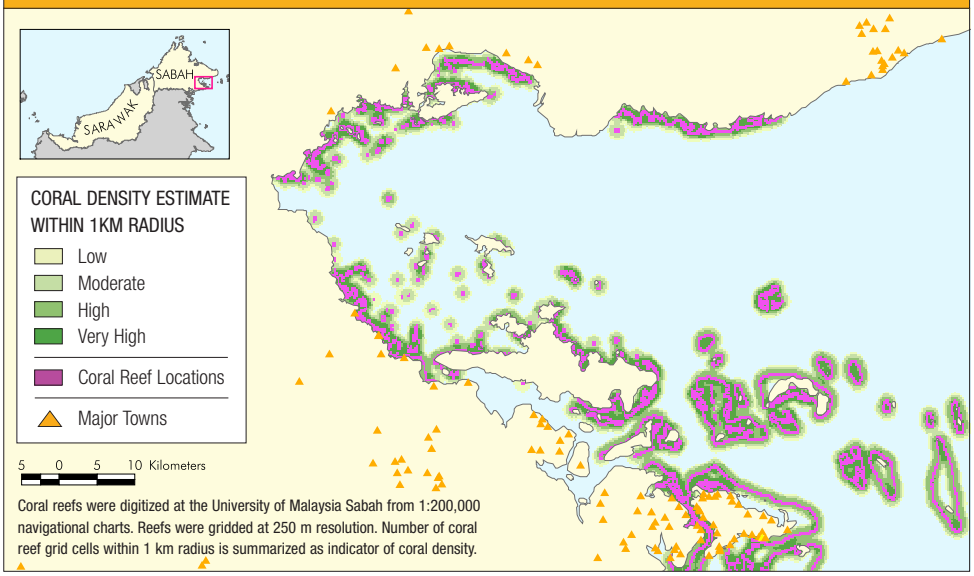
Reef Threat Analysis in Sabah, East Malaysia

Sabah has high reef diversity and contains 3,000 km^2 of reefs, 75 percent of all reefs in Malaysia. Destructive fishing and sedimentation are key pressures currently threatening reefs in Sabah. The government of Sabah is addressing these threats with two distinct activities, one focused on better enforcement of regulations on destructive fishing and one on improved coastal management *(described below)*.

In 1997, the Town and Regional Planning Department began leading an 11-agency working group to improve coastal management and mitigate sedimentation with an Integrated Coastal Zone Management (ICZM) plan. The project has developed extensive sets of maps and GIS data. (See www.iczm.sabah.gov.my.) Thus far the work has focused on the terrestrial environment, with few data developed on seagrasses or coral reefs. However, the University of Malaysia Sabah (UMS) developed a base data set on coral reef locations under the RRSEA project and provided it to the Department of Planning. This base data set on coral reef locations is being ground-truthed and updated using aerial photographs, and it will help to guide future coastal development away from sensitive coastal areas. The Department of Planning, the 11-agency working group, UMS, and WRI initiated a joint activity to examine threats to coral reefs from human activities in Sabah; the information will feed into the development of the ICZM statutory plan for Sabah.

For additional information on application of RRSEA data and model techniques, see www.wri.org/wri/reefsatrisk.

MAP 15. REEF DENSITY IN SABAH



Coral reefs were digitized at the University of Malaysia Sabah from 1:200,000 navigational charts. Reefs were gridded at 250 m resolution. Number of coral reef grid cells within 1 km radius is summarized as indicator of coral density.

This simple mapping of coral reefs and reef density is a starting point for ground-truthing and further analysis to identify sensitive areas.

CHAPTER 6. THE ECONOMIC LOSS ASSOCIATED WITH CORAL REEF DEGRADATION

PHOTO: WOLCOTT HENRY

Coral reefs have important ecosystem functions that provide crucial goods and services to hundreds of millions of people, mostly in developing countries. Within Southeast Asia, in particular, the potential sustainable economic value of coral reefs is substantial, as is the potential economic loss if these resources are degraded.

THE ECONOMIC VALUE OF HEALTHY REEFS

Coral reef fisheries are an important source of food and income for local populations. In the Philippines, for example, coral reefs supply between 11 and 29 percent of the total fisheries production.[158] In addition, the extraordinary biodiversity of coral reefs provides scientific, pharmaceutical, and educational value. Moreover, coral reefs are potent tourist attractions, and they protect countless coastal developments from shoreline erosion. Where tourism currently exists or the potential for development is good, tourism associated with reefs can be extremely valuable. Although reefs identified as having good tourism potential make up only a small percentage of the coral reefs of the region, they represent some of the highest value reefs in the region.

Over the past decade, several efforts have advanced our ability to quantify the economic value of coral reefs.[159] Table 4 provides a summary of the sustainable annual economic net benefits per square kilometer of healthy coral reef in Southeast Asia. These values are the potential monetary benefits to society after the costs of operation have been deducted. Estimates of total potential annual economic net benefit per square kilometer of healthy coral reef in areas with tourism potential range from US$23,100 to US$270,000. The range in potential benefits is large because of the variety and scale of different tourism operations. The range of total annual net benefits is lower for areas without tourism potential, US$20,000–US$151,000 per square kilometer. *(See Table 4.)*

TABLE 4. POTENTIAL SUSTAINABLE ANNUAL ECONOMIC NET BENEFITS PER KM² OF HEALTHY CORAL REEF IN SOUTHEAST ASIA

RESOURCE USE (DIRECT AND INDIRECT)	PRODUCTION RANGE	POTENTIAL ANNUAL NET BENEFITS (US$)		
Sustainable Fisheries (local consumption)	10–30 tonnes	$12,000	–	$36,000
Sustainable Fisheries (live fish export)	0.5–1 tonnes	$2,500	–	$5,000
Coastal Protection (erosion prevention)		$5,500	–	$110,000
Tourism and Recreation	100–1,000 persons	$700	–	$111,000
Aesthetic/Biodiversity Value (willingness to pay)	600–2,000 persons	$2,400	–	$8,000
Total (fisheries and coastal protection only)		**$20,000**	**–**	**$151,000**
Total (including tourism potential and aesthetic value)		**$23,100**	**–**	**$270,000**

SOURCES:
Adapted from A.T. White, H.P. Vogt, and T. Arin, "Philippine Coral Reefs under Threat: The Economic Losses Caused by Reef Destruction," *Marine Pollution Bulletin* 40, 7 (2000): 598-605; A.T. White and A.Cruz-Trinidad, *The Values of Philippine Coastal Resources: Why Protection and Management are Critical* (Cebu City: Coastal Resource Management Project, 1998) p. 28; and H.S.J. Cesar, "Economic Analysis of Indonesian Coral Reefs," Working Paper Series 'Work in Progress' (Washington, DC: World Bank, 1996).

NOTE:
Data are based on estimates for Indonesia and the Philippines only. *(See Appendix 2 for additional detail.)*

INDIVIDUAL GAIN AND SOCIETAL LOSS

This report has detailed the many human activities that damage or degrade coral reef resources. Degraded coral reefs lose value because they are less productive, providing fewer goods and services than healthy reefs. For instance, although a healthy coral reef might provide an average sustainable fisheries yield of 20 tonnes per year, the yield of a reef damaged by destructive fishing practices is likely to be much lower, under 5 tonnes per year.[160] Even if they are only partially destroyed, coral reefs do not quickly return to high levels of productivity. Blasted reefs can take up to 50 years to regain 50 percent of their original coral cover and be productive again.[161]

Activities that damage coral reefs can be lucrative to individuals in the short term. However, net benefits to those involved in the destructive activity are often small compared to the net losses to society from the decreased production of the coral reef ecosystem. Table 5 compares benefits to individuals and losses to society in terms of reduced goods and services over a 20-year period for many of the damaging activities described in this report. For example, fishers engaged in blast fishing may earn US$15,000 per square kilometer, but they generate losses to society over a 20-year period ranging from US$91,000 to US$700,000 per square kilometer. The wide range of losses reflects the wide range in the value of potential tourism benefits that could be lost. *(See Table 5.)*

VALUATION ESTIMATES FOR INDONESIA AND THE PHILIPPINES

By integrating information on potential net annual benefits per square kilomter of healthy coral reefs *(from Table 4)* with data on coral reef area from RRSEA, one can estimate the potential total sustainable annual economic net benefits from coral reefs for Indonesia and the Philippines. This analysis is based upon estimates of coral reef area, extent of areas with tourism potential, and level of coastal development. The estimate considers fisheries, tourism, coastal protection, aesthetics, and biodiversity benefits, but it does not include future value from potential pharmaceutical development. The potential sustainable economic net benefits per year from coral reefs are US$1.6 billion for Indonesia and US$1.1 billion for the Philippines. This benefit comes primarily from sustainable fisheries, followed by coastal protection and tourism. *(See Table 6.)* Assuming the same yield and prices for the rest of the region, the sustainable fisheries benefit for all of Southeast Asia is estimated to be US$2.4 billion per year.[162]

TABLE 5. TOTAL NET BENEFITS AND LOSSES ON SOUTHEAST ASIAN CORAL REEFS BY ACTIVITY (NET PRESENT VALUE[a] IN US$ 000 PER KM² OVER 20 YEAR PERIOD)

ACTIVITY	NET BENEFITS TO INDIVIDUALS	LOSSES TO SOCIETY				
		FISHERY	COASTAL PROTECTION	SUSTAINABLE TOURISM	OTHERS (E.G. BIODIVERSITY)	TOTAL LOSSES (QUANTIFIABLE)
Poison Fishing	33	37	N.Q.	3-409	N.Q.	40-446
Blast Fishing	15	80	8-170	3-450	N.Q.	91-700
Coral Mining	121	87	10-226	3-450	> 67	167-830
Sedimentation from Upland Activities	98	81	N.Q.	192	N.Q.	273
Overfishing	39	102	N.Q.	N.Q.	N.Q.	102

SOURCE:
Adapted from H. Cesar et al., "Indonesian Coral Reefs – An Economic Analysis of a Precious but Threatened Resource," *Ambio 26*, 1(1997): 345-58.

NOTES:
a. The Net Present Value (NPV) provides a summary of the value of the resource by aggregating annual benefits over a 20-year period, but it gives greater weight to the near future by using a "discount rate" of 10 percent per year. This discount means that the current benefits of a future good are reduced by 10 percent for each year into the future. Use of this high discount rate may underestimate future losses.
N.Q. = not quantified.

TABLE 6. POTENTIAL SUSTAINABLE ANNUAL ECONOMIC NET BENEFITS FOR INDONESIA AND THE PHILIPPINES (US$ MILLION)

RESOURCE USE (DIRECT AND INDIRECT)	INDONESIA (US$ MILLION)	PHILIPPINES (US$ MILLION)
Sustainable Fisheries	1,221	620
Coastal Protection (erosion prevention)	314	326
Tourism and Recreation[a]	103	108
Aesthetic/Biodiversity Value (willingness to pay)	9	10
Total Net Annual Benefits	1,647	1,064
Net Present Value (NPV)[b]	14,035	9,063

SOURCE:
Based on economic values of goods and services per km² from Table 4 and RRSEA estimates of reef area, area with tourism potential, and coastal development. *(See Appendix 2 for additional details.)*

NOTE:
a. Areas with tourism potential are defined as those within 10 km of current tourist centers.
b. For the definition of NPV, see Table 5.

ANALYSIS OF LOSS FROM DAMAGING ACTIVITIES

The majority of coral reefs across Southeast Asia are under threat from human activities. Table 7 uses economic data on potential losses from damaging activities and data from RRSEA on areas at risk from blast fishing, overfishing, sedimentation from upland sources, and areas with high tourism potential to estimate the economic costs of these human activities for Indonesia and the Philippines. *(See Table 7.)* The societal costs of these practices significantly outweigh the benefits in all categories examined.

Overfishing is the activity that is the most financially detrimental to reefs in Indonesia and the Philippines. In Indonesia, fishing sustainably can generate as much as US$63,000 per km² more over a 20-year period than overfishing on healthy reefs (the difference between a US$102,000 loss to society and a US$39,000 gain to the individual). *(See Table 5.)* The pervasiveness of overfishing in Indonesia—more than 32,000 km² of reefs are overfished—results in massive societal losses, estimated at US$1.9 billion over twenty years. Financial damage from overfishing more than 21,000 km² of reefs in the Philippines is estimated at US$1.2 billion. *(See Table 7.)*

TABLE 7. NET LOSSES TO SOCIETY OVER A 20-YEAR PERIOD FROM OVERFISHING, BLAST FISHING, AND UPLAND ACTIVITIES IN INDONESIA AND THE PHILIPPINES (US$ MILLION)

	BENEFITS TO INDIVIDUALS	LOSSES TO SOCIETY				NET LOSSES
	A	B	C	D	E=B+C+D	F=E-A
ACTIVITY	NET PRIVATE BENEFITS FROM ACTIVITY	FOREGONE SUSTAINABLE FISHERY INCOME	LOSS OF COASTAL PROTECTION	LOSS OF TOURISM REVENUES[a]	SUMMARY OF ECONOMIC LOSSES OF REEF SERVICES	NET LOSS TO SOCIETY FROM ACTIVITY
Indonesia						
Blast Fishing	370	570	160	210	940	570
Overfishing	1,160	3,030	0	N.Q.	3,030	1,870
Sedimentation from Upland Activities	20	20	0	100	120	100
Philippines						
Blast Fishing	360	640	520	370	1,530	1,170
Overfishing	740	1,950	0	N.Q.	1,950	1,210
Sedimentation from Upland Activities	60	50	0	124	174	114

SOURCE:
H. Cesar, "Economic Analysis of Indonesian Coral Reefs"; H. Cesar et al., "Indonesian Coral Reefs : An Economic Analysis of a Precious but Threatened Resource"; and H. Cesar, *Collected Essays on the Economics of Coral Reefs*, and RRSEA reef area estimates.

NOTES:
The values are presented in net present value (NPV) over 20 years using a 10% discount rate. They are based on cross-tabulations of Reefs at Risk results by threat category and benefit or loss estimates based on Table 5 and numbers from H. Cesar. For the definition of NPV, see Table 5. *(For technical details see Appendix 2.)*
a. Areas with tourism potential are defined as those within 10 km of current tourist centers.
N.Q.= not quantified

Blast fishing also results in substantial financial losses for both Indonesia and the Philippines. The total net losses from blast fishing are US$1.2 billion in the Philippines and US$570 million in Indonesia. Despite the greater area of Indonesian reefs, loss is higher in the Philippines because of the prevalence of blast fishing.

Although there are short-term gains, the rapid pace of inland development in Indonesia and the Philippines causes long-term societal losses. For this analysis, the project looked only at the impact of sedimentation caused by logging in tourism areas. Outside tourism areas, direct economic losses from sedimentation are much lower.[163] Because areas of high sediment do not always overlap with tourism centers, the estimated losses from sedimentation are relatively low (US$100 million in Indonesia and US$114 million in Philippines).

Total losses from unsustainable activities in Indonesia and the Philippines are significant. Not shown on Table 7 are potential losses from fishing with poisons, coastal development, marine-based sources of pollution, and sedimentation from upland sources in areas without significant tourism potential. Effective planning and management of coastal areas would have substantial economic benefits not only in the Philippines and Indonesia but also across Southeast Asia. These benefits could be particularly high in areas with good tourism potential.

For more information on the economic value of good stewardship, see www.wri.org/wri/reefsatrisk.

CHAPTER 7. MANAGEMENT OF COASTAL RESOURCES

PHOTO: UWE DEICHMANN

Without effective management of coastal resources, the considerable social and economic value of Southeast Asian coral reefs will be significantly reduced. Balancing the immediate needs of coastal communities, the desire for long-term sustainable resource use, and the maintenance of natural ecosystem processes are significant issues in most coastal areas. Together, these goals form the guiding principles for coastal management.

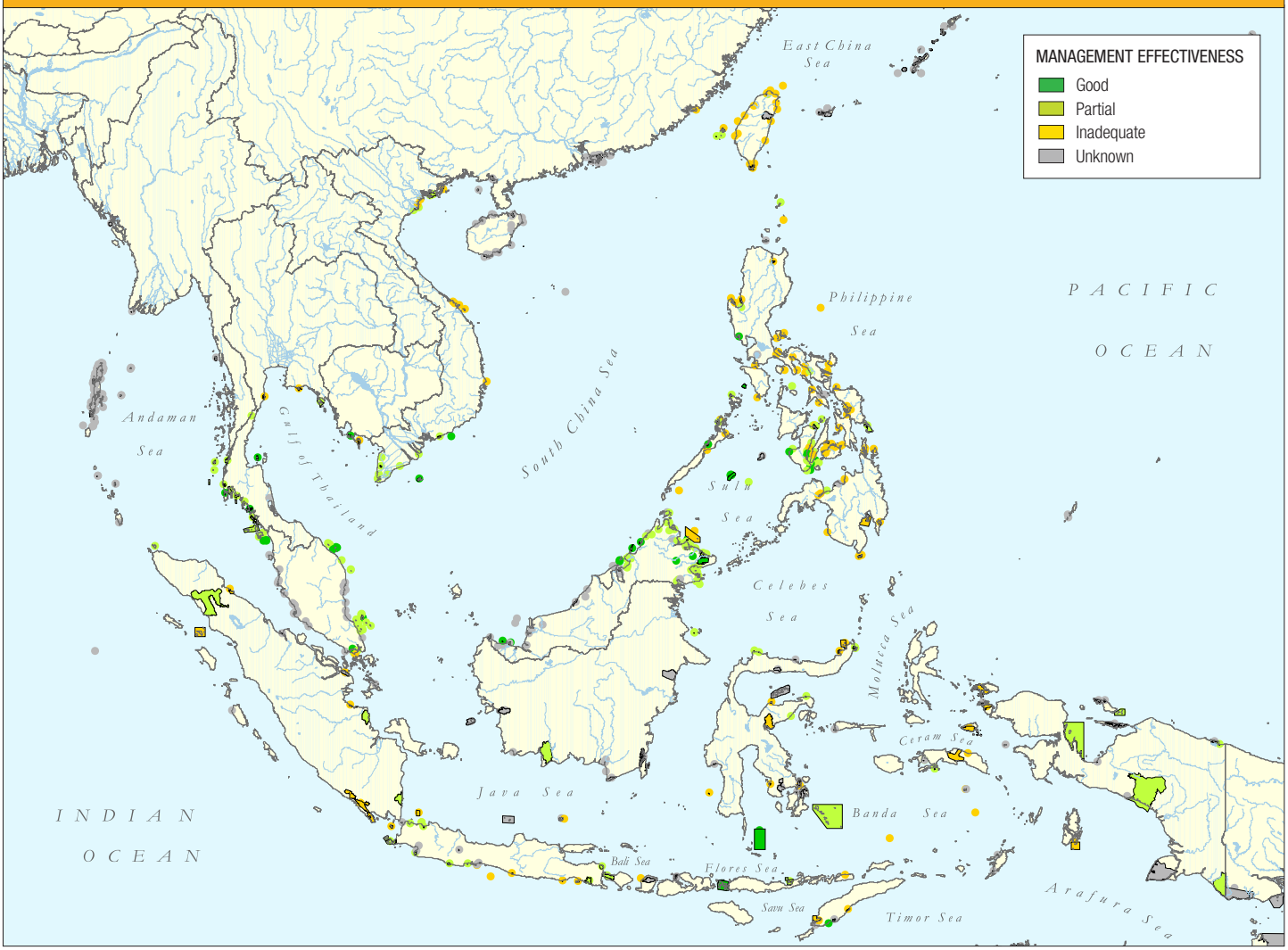
APPROACHES AND STRATEGIES

Declining resources and increasing demand have necessitated the development of active management plans. The challenge is to identify and implement the right mix of management strategies for a given location so that long-term resource needs are met for a diverse group of users. The implementation of management actions can follow several different approaches. The three primary approaches in Southeast Asia are centralized, community-based, and collaborative management. In a *centralized management* scheme, power typically rests with one authority, usually the national government. *Community-based management* has a bottom-up framework in which decisions are made at the local level. *Collaborative management* shares authority among several stakeholders, typically the community, various government agencies, universities, and nongovernmental organizations. Increasingly, management practitioners recognize that no one management approach is appropriate for all places or conditions.[164]

Four strategies are widely used in coastal resources management: (1) direct protection of specific areas, (2) legal regulation and policy, (3) economic incentives, and (4) education and awareness. *Direct protection* is perhaps the most widely applied and well-known modern management strategy used to control human access and restrict activities that negatively impact natural resources. In general, direct protection is accomplished using marine protected areas, which range from multiple use management areas to fully protected marine reserves that prohibit many activities. *Legal regulations* typically include licensing, bans on certain activities or gear, seasonal harvests, and other restrictions to control activities or access to the resources so that overall fishing effort is reduced. *Economic incentives* are designed to discourage unsustainable practices. Incentives can facilitate transition to more sustainable fishing practices, help fishers exit the industry, provide alternative income sources, and assist in paying for the costs of management. *Educational strategies* are aimed at building awareness about the biology of coral reefs, their potential value, and how people impact coral reef health.

For more information on management strategies and approaches, see www.wri.org/wri/reefsatrisk.

MAP 16. MARINE PROTECTED AREAS RATED BY MANAGEMENT EFFECTIVENESS



MANAGEMENT EFFECTIVENESS IN SOUTHEAST ASIA

Good management can minimize most threats facing coral reefs. An evaluation of management in the region is central to any threat assessment or picture of coral reef health. RRSEA focused its management assessment on MPAs because they are one of the most widely used tools and because the lack of data on the use of legal regulations, economic incentives, and educational programs prevented similar assessments of other strategies.

Marine protected areas are designated for a number of reasons, including fisheries management, tourism promotion, and the maintenance of biodiversity. Local, provincial, national, and international decrees have established hundreds of MPAs in the Southeast Asia region. Most MPAs are managed through central government programs. However, local conflicts and low enforcement capacity have made it difficult to manage MPAs in some places, creating a situation in which hundreds of MPAs exist but only a fraction operate in ways that meet their objectives. In some countries such as the Philippines and Indonesia, governments have been moving toward community-managed MPAs to enhance local support, reduce resource conflicts, and bolster enforcement.[165]

In considering the effectiveness of MPAs, it is important to remember that they typically control only direct human activities, such as unsustainable fishing practices. In many MPAs, even strict enforcement of regulations cannot control the impacts of sedimentation and pollution unless the park includes areas of adjacent watersheds. Factoring other threats into the design of both protected area boundaries and wider land-use planning initiatives is essential to good management of coastal resources.

TABLE 8. MARINE PROTECTED AREAS IN SOUTHEAST ASIA

COUNTRY	NUMBER OF MPAs	MANAGEMENT EFFECTIVENESS RATINGS				PERCENTAGE OF A COUNTRY'S REEF AREA INSIDE MPAs
		GOOD	PARTIAL	INADEQUATE	UNKNOWN	
INDONESIA	131	3	36	35	57	9%
PHILIPPINES	110	14	31	58	7	7%
MALAYSIA	136	22	63	1	50	7%
INDIA	97	0	0	0	97	3%
JAPAN	46	0	0	0	46	20%
THAILAND	17	3	11	2	1	38%
MYANMAR	3	0	0	0	3	2%
VIETNAM	25	2	13	9	1	11%
CHINA	45	0	0	0	45	2%
TAIWAN	25	0	4	20	1	14%
BRUNEI DARUSSALAM	6	0	0	0	6	0%
SINGAPORE	4	1	2	1	0	0%
CAMBODIA	1	1	0	0	0	0%
REGION	**646**	**46**	**160**	**126**	**314**	**8%**

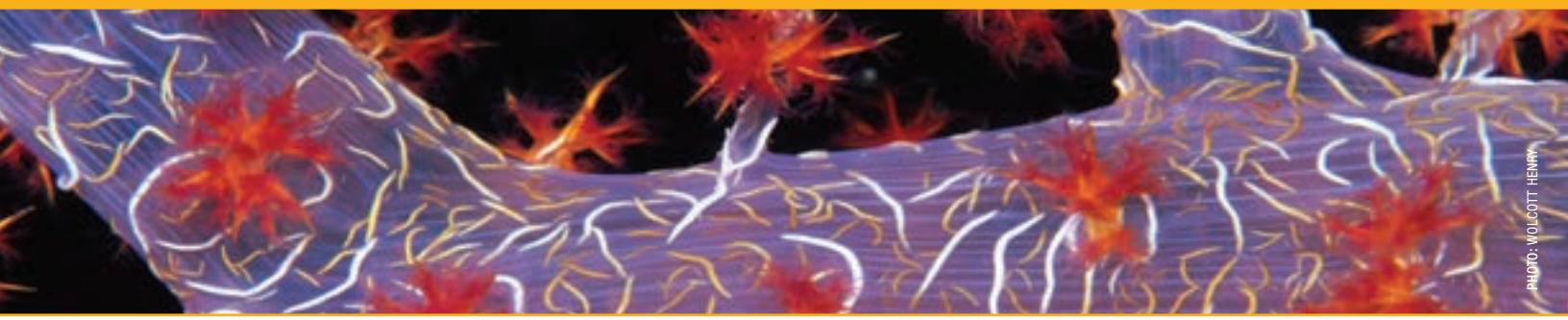
SOURCE:
Reefs at Risk in Southeast Asia, WRI, 2002.

NOTES:
This table reflects summary statistics on the MPA database compiled under the Reefs at Risk in Southeast Asia project.
Data were assembled by UNEP-WCMC, WRI, and many other project partners. The data may be incomplete for some countries.
Project partners were asked to rate management effectiveness based upon MPA resources, staff size, and existence of a management plan. Those ratings are summarized by country in this table, and are available by MPA within the full database, which can be found at www.wri.org/wri/reefsatrisk.
Estimated location and boundaries of MPAs were overlaid with a data set on coral reef locations to determine the percentage of a country's coral reefs under MPA protection. These percentages should be regarded as rough estimates based upon available data.
In addition, definitions of MPAs vary. The estimated percentage of coral reefs inside MPAs in Japan is higher than previously published estimates, which only considered reefs in the Natural Park System. The RRSEA estimate includes a broader set of MPAs, many of which do not offer comprehensive protection.

As part of the RRSEA project, local experts evaluated the effectiveness of hundreds of MPAs throughout the region. MPAs were rated based on several criteria, including staff size, management facilities, community outreach programs, and the existence of a management plan. Many "paper parks" were dropped from the full list of declared MPAs because they did not even have basic implementation. Of the remaining 646 MPAs within the RRSEA study region, the management effectiveness was unknown for nearly one half (314) of them. In reality, this lack of information probably indicates a deficiency of human and financial resources for these areas. Of the 342 MPAs that could be assessed, only 46 (14 percent) were rated as effectively managed. An additional 160 (48 percent) have partially effective management, and 126 (38 percent) have inadequate management. *(See Table 8 and Map 16.)*

The RRSEA project also estimated the percentage of coral reef area within MPAs across the region. The scale of the data and the degree of completeness of the MPA data set limit this analysis. Many MPAs are represented only by points, not their actual spatial boundaries, so their extent had to be approximated. Thus this analysis provides only a rough estimate based upon the best available data. Approximately 8 percent of the coral reefs in the Southeast Asia region lie within MPAs. However, just 1 percent of the region's reefs are in MPAs considered to be effectively managed, 4 percent of reefs are in MPAs with partially effective management, 2 percent are in MPAs with poor management, and 1 percent are in MPAs of unknown management effectiveness.

CHAPTER 8. MONITORING AND IMPROVING THE KNOWLEDGE BASE



Although the RRSEA analysis is the best available approximation of likely threats to coral reefs from human activities, it is only an estimate. The project results confirm that more extensive assessment of reef habitats and monitoring across Southeast Asia is essential. In order to understand what measures need to be taken to safeguard reefs, good documentation of where and how coral reefs are threatened is needed.

Knowledge is an important tool for empowering communities and governments to manage resources. At the local level, effective management is contingent on accurate information about biological components, threats to coastal habitats, current condition, change in condition, and the socioeconomic factors of the surrounding communities. Such information includes an initial quantitative description to provide a baseline and then an ongoing program of data gathering to track and understand change. This information is essential for informed decision making by resource management agencies, fishers, the tourism industry, and other sectors economically dependent on reef resources. In addition, the general public, nongovernmental organizations, and scientists need such data to understand better the threats to reefs and to campaign for their protection and stewardship. However, local information is not enough; for example, observations on localized bleaching events would not reveal larger-scale patterns. Similar information is needed at national and regional scales so that broader trends can be identified and priorities can be set across large areas.

CURRENT STATUS OF MONITORING IN THE REGION

Although many monitoring programs are operating across Southeast Asia, existing information is insufficient to support informed decisionmaking in most locations. For many parts of Southeast Asia, even basic mapping of coral reef locations and baseline information is inadequate.

Although capacity varies widely, many countries in the region have a strong research capacity to assess reef status and perform research. One of the major recent monitoring efforts was the Association of Southeast Asian Nations (ASEAN)-Australia Living Coastal Resources project, which was active in five ASEAN countries (Philippines, Indonesia, Malaysia, Thailand, and Singapore) from 1984 to 1994. During this project, more than 40 sites were monitored and more than 950 line-intercept survey transects executed. This project improved monitoring capacity in these countries, and many of these sites are still monitored.[166]

In general, monitoring programs on coral reef status are expanding, and many countries have established national reef monitoring programs. Universities across the region play a vital role in coral reef monitoring. In the Philippines, for example, government agencies do not engage in sustained, regular monitoring of Philippine reefs, so much of the responsibility falls to universities, which have greater technical capacity.[167] In Indonesia, political factors and the sheer size of the country have made the execution of a national monitoring program difficult. Monitoring capacity in Brunei, Cambodia, Myanmar, and Vietnam is developing, but it is still lacking trained personnel and other resources.[168] In many locations around Southeast Asia, monitoring programs that use volunteers are supplementing more rigorous scientific monitoring efforts. These programs are increasing community awareness and the amount of available information on the status of coastal resources.

Although several initiatives are working to provide summary status information, coordination is limited and regional information networks are not well integrated. In fact, a centralized information node for coral reef status does not exist in Southeast Asia.

CURRENT NEEDS

Monitoring programs need to be useful to management. Baseline measurements are a required benchmark to monitor change and impacts on coral reefs accurately. In addition, the current reliance on measuring the percentage of live coral cover is insufficient for comparisons among coral reefs, although change in live coral cover is an important indicator at a single location. Biophysical monitoring needs to be linked with socioeconomic monitoring, including coastal and upland areas, so that linkages to activities and pressures causing reef degradation can be established. Information is currently inadequate for measuring impacts from land-based sources of pollution.

Although the timing and schedule for monitoring specific sites should be planned, occurences like the mass bleaching episode of 1997–98 also necessitate flexibility and quick response. Information on the extent of coral bleaching events and the degree of recovery is currently inadequate. Rapid response surveys of areas at risk and of recently bleached areas are essential to better evaluation of the extent of the coral bleaching threat associated with global climate change. Where there has been mass coral mortality, regular surveys are needed to monitor ongoing change, including corals and fish stocks. Such information would support management interventions needed to improve and accelerate recovery.

AVAILABLE TOOLS

A range of techniques is available for assessing and monitoring coral reefs. Generally, these tools entail trade-offs between cost and detail, ranging from the use of satellite imagery in order to map reef locations (with a broad spatial coverage and relatively low cost, but low detail) to running underwater transects to measure reef health (high cost, high detail). The optimal approach is through multilevel sampling, where information obtained from limited, detailed high-resolution sampling is extrapolated to large areas based on low-resolution data of wide coverage. The goal is to use all available information to improve assessments at local, national, and regional scales.

Coordination and sharing of data must be improved in the region, both to support local management and to improve knowledge of changes at national, regional, and global levels.

INTERNATIONAL INITIATIVES

Several international initiatives are focused on improving access to information on coral reefs. They were valuable sources of information for this analysis. Such international data sets are important, placing the findings of local and national monitoring programs into a wider context.

- **The Global Coral Reef Monitoring Network (GCRMN)** aims to improve the management and sustainable conservation of coral reefs through networking existing organizations and people monitoring coral reefs. GCRMN publishes a biannual summary on the status of the world's coral reefs, which is a vital consolidated source of information. (For more information, see http://coral.aoml.noaa.gov/gcrmn/.)

- **ReefBase** is a global database on coral reefs developed by The World Fish Center (ICLARM). ReefBase was initiated in 1993 to consolidate and disseminate information on the location, extent, status, threats, and management of coral reefs throughout the world. ReefBase has been a significant data source for both the global and regional Reefs at Risk analyses, and is the central information repository for the GCRMN. (For more information, see www.reefbase.org.)

- **Reef Check** is the most extensive volunteer program examining the threats to and status of coral reefs worldwide. Diving groups around the world organize annual Reef Check surveys to gather data on selected coral reefs. Across Southeast Asia, 350 reefs in 11 countries have been surveyed in the first five years of the program, providing an important source of information for the RRSEA analysis. (For more information, see www.ReefCheck.org.)

CHAPTER 9. RECOMMENDATIONS

PHOTO: TONI PARRAS

Southeast Asian coral reefs are a cornerstone of the economic and social fabric of the region, but they are severely threatened. Action is urgently needed to reverse current trends, reduce degradation, and move toward sustainable management of coastal resources. Efforts at local, national, and international levels are needed to address the problems plaguing Southeast Asian reefs. An international effort is needed to reduce emissions of greenhouse gases to slow the rate of global climate change; without such an effort, the region is vulnerable to higher sea-surface temperatures that can trigger widespread coral bleaching and sea level rise. Locally, significant threats from coastal development, pollution, sedimentation, overfishing, and destructive fishing must also be addressed. Without intervention, the compound pressures of local activities and rising global temperatures could severely jeopardize the future of the region's valuable coral reef ecosystems.

Changes in current trends will require significant political will and financial commitments. In order to move coral reefs up on government agendas, awareness about the extraordinary value of these resources must increase. Although the economic benefit from sustainable use of coral reefs usually far outweighs the economic benefits from damaging activities, the health of coastal resources is often not given sufficient consideration. In order to reverse the decline of coral reefs, government, the private sector, resource users, and the general public must be well-informed and assured of the value of well-managed reefs.

Managing reefs sustainably will require implementing management plans that incorporate the collection of baseline status information, continued monitoring, an enforcement strategy, and adaptive management. Because each site is different, a broad range of strategies may be needed to administer resources better. Effective management will require increased human resources and financial support. Because many of the pressures on coral reefs have social and economic root causes, management interventions must also look beyond biology to include major efforts focused on poverty alleviation, alternative livelihoods, governance reform, and increased public awareness of the value of and threats to coral reefs and fisheries. When well informed about the issues and appropriately funded, local governments, NGOs, village elders, and key segments of the tourism industry can be successful custodians of coastal resources.

The wealth and diversity of coral reef habitats across Southeast Asia are still considerable and will support the recovery of coral reefs if human pressures can be reduced. The following list, although not comprehensive, provides some recommendations vital to ensuring that the valuable coral reef resources of Southeast Asia are available for future generations.

MANAGEMENT AND PLANNING

- **Improve the Management of Coastal and Fisheries Resources.** Successful management of coral reefs requires a broad approach that is ecosystem-based, respecting biophysical

boundaries so that efforts to conserve coral reefs are comprehensive. No one management strategy will be right for all locations under all conditions; however, participation from a variety of stakeholders is critical to successful management. Where management is shared among government agencies, local communities, and nongovernmental organizations, it can be used to improve coordination of land and marine conservation work at national as well as local scales.

- **Improve the Management of Existing MPAs.** Although many marine protected areas have been created in Southeast Asia, most lack the staff and resources required for effective management. An absence of community involvement, low capacity for monitoring, and unsuccessful enforcement are common. Of 646 MPAs included in the RRSEA analysis, only 46 were rated as effectively managed and 160 were rated as having partially effective management. Financial and political commitments from government, NGOs, the tourism sector, and external donors are crucial to helping existing MPAs be more effective.

- **Expand the Protected Areas Network.** An estimated 8 percent of the region's coral reefs are within MPAs, and only about 1 percent are in effectively managed parks. The extent of coastal waters under protection needs to increase — whether through marine reserves or multiple-use MPAs — to protect an ecologically representative sample of the region's biodiversity, sources of larvae, and habitat essential to fisheries. If designated and properly administered, these MPAs can protect valuable goods and services and provide a regional resource that may be critical to ecosystem recovery in other areas following major impacts.

INTERVENTIONS

- **Halt the Use of Destructive Fishing Practices.** Destructive fishing practices are the human activity that is the most damaging to the coral reefs of Southeast Asia, putting an estimated 50 percent of the region's reefs at risk. Despite the fact that these practices are not ecologically sustainable or economically profitable in the long-term, fishers turn to destructive techniques out of greed, desperation, and prevailing economic interests. Increasing enforcement and awareness as well as educating fishers, training them to use alternative fishing methods, and providing them with options for alternative livelihoods are essential components in reducing the prevalence of destructive fishing practices.

- **Reduce Overfishing.** Overfishing is the most pervasive threat evaluated for Southeast Asia. To mitigate the effects of overfishing, major endeavors must focus on not only reducing fishing effort but also developing alternative livelihoods for fishers. Reducing the fishing effort would result in higher catches per fishing hour and higher incomes for those still engaged in fishing. In some cases, no-take zones need to be established around highly productive fish habitats, breeding areas, and fish migration paths. In a number of cases, local-scale involvement in reef management can be greatly enhanced by the devolution of resource ownership to these same communities.

- **Regulate the International Trade in Live Reef Organisms.** Regulating the trade in live reef organisms must be done at many levels. At the local level, fisher retraining can reduce the use of destructive fishing practices. At the national level, testing and monitoring are essential and need to be improved in both exporting and importing countries so that regulators can identify and endorse "sustainably" caught species. Throughout the region, additional cyanide detection facilities at major live fish collection and transshipment points need to be established. "Sustainably" caught, nondestructive certification should be required for export and import of all live reef organisms.

- **Develop Tourism Sustainably.** Tourism, when properly implemented, can provide important incentives for effective management and conservation of coral reefs. Many dive resorts have well protected "house reefs," and some resorts contribute to management and enforcement of the area's regulations. The siting of a resort, source of construction materials, nature of sewage and waste treatment, use of

mooring buoys, type and source of fish served, and type of souvenirs offered are many important factors determining whether tourism is environmentally sensitive and sustainable. Employing local staff, using locally produced food, providing housing for staff, and respecting the carrying capacity of the area can significantly increase the socioeconomic benefits. The development and use of certification schemes, accreditation, and awards that facilitate best practices for hotels, dive operators, and tour operators could further provide incentives for eco-friendly development.

- **Adopt Policies To Reduce Greenhouse Gas Emissions and Climate Change.** Most corals are already living in water temperatures near the upper limit of their tolerance. Climate change threatens to push water temperatures to levels at which the frequency of mass coral bleaching and mortality will increase. Although there is uncertainty associated with climate projections, taking actions to reduce greenhouse gas emissions will be critical to mitigating the effects of global climate change on Southeast Asian reefs.

INFORMATION AND AWARENESS

- **Improve Mapping, Monitoring, and Networking of Information on Coral Reefs to Support Better Management.** Managers and communities are not receiving the information and management tools they need to make sound management decisions. Data and information in accessible and understandable forms from a wide range of sources are fundamental to successful management. Resource mapping and assessment at many scales are required. Data from satellite and aerial surveys can be useful sources to map and monitor coral reef and mangrove communities and to identify both potential threats, including sediment and pollution plumes, and areas with rapidly changing land cover. Remotely sensed data are most valuable when coupled with well-designed *in situ* monitoring, including repeat monitoring of permanently marked stations. Monitoring programs on coral reefs need to be linked with monitoring of population and development, including upland activities, because this integration of information is key to understanding changes in coral reef status and to managing the resources. Better organization and collection of information, including the establishment of a centralized information node, will enable the whole region to adopt improved strategic approaches to protecting reefs.

- **Raise Public Awareness.** The economic and ecological value of coral reefs and the degree to which corals are currently being damaged by human activities are not widely understood. Education of the general public is an important aspect of policy change. A major awareness-raising campaign is needed to change behavior and create political will for appropriate action. A number of NGOs and collaborative ventures such as the International Coral Reef Inititative (ICRI) and the International Coral Reef Action Network (ICRAN) are attempting to address this challenge at many levels. However, the challenge of bridging the gap between global knowledge and local action remains considerable.

Southeast Asia harbors some of the world's most important and extensive coral reefs. These ecosystems lie at the heart of the social, cultural, and economic framework of the region. Yet they are the most threatened coral reefs in the world—a threat that imperils the social and economic well-being of millions of people. Many of the problems confronting coral reefs could be solved at no net cost. Indeed, within just a few years, changes in behavior could lead to improved economic security and long-term protection of food supplies.

Central governments to local communities throughout the Southeast Asia region need improved information about both the problems and potential solutions. Implementation of the recommendations outlined here for improved policies and management would help to create a secure future for coral reefs and allow recovery of degraded reefs. By placing coral reefs higher on the regional agenda, these beautiful and highly productive ecosystems will be in a stronger position to face growing pressures and continue to provide valuable services for the people of Southeast Asia.

APPENDIX 1. THREAT MODELING METHODOLOGY

Geographic Extent and Resolution. The Reefs at Risk in Southeast Asia (RRSEA) project includes an area in Southeast Asia approximately bounded by 90°E and 142°E longitude, and 30°N and 11°S latitude. The data integration and analysis were performed in an equal-area projection (Lambert Equal Area Azimuthal 126, 6) at a 1,000 meter (1 kilometer) resolution.

Data Development and Modeling Process. Modeling of threats to coral reefs in Southeast Asia was implemented at WRI, using an iterative approach with extensive input from project partners. *(See front cover for list of project partners.)* Input data sets, the model design, and model results have been extensively reviewed and significantly revised based on input from project partners and at two regional workshops (the RRSEA workshop, April 2000 in Quezon City, Philippines, and the International Coral Reef Symposium, October 2000 in Bali, Indonesia).

Model Overview. The modeling approach groups threats into five main categories: coastal development, marine-based pollution, overfishing, destructive fishing, and sedimentation from inland sources. Mappable component sources of potential degradation were identified for each threat category. The following provides a brief summary, but the full description of the model methodology is available from the RRSEA web site, www.wri.org/wri/reefsatrisk.

- The threat associated with coastal development was evaluated based upon a coral reef's distance from cities (stratified by size), settlements (stratified by population density and growth), airports, mines, tourist resorts, dive centers, and the coastline.
- The threat associated with marine pollution was evaluated in a similar way, based upon a reef's distance from ports (stratified by size), major shipping lanes, and oil tanks and wells.
- A watersed-based analysis was used to estimate sediment risk to coral reefs. Using a modified form of the Revised Universal Soil Loss Equation (RUSLE)[169], the analysis first calculated relative erosion rates for all land areas by 1-km grid cell based upon slope, land cover type, precipitation, and soil porosity. These relative erosion rates were summarized by watershed and then combined with an estimate of precipitation in the watershed during the peak rainfall month to estimate sediment delivery at river mouths during high flow periods. Sediment plumes (dispersion) were modeled using a distance-degrade function, and were calibrated against observed sediment plumes and observations of sediment impact to coral reefs.
- Overfishing pressure on coral reefs up to 20 km offshore was estimated based upon total population within 10 km of the coast. Excluded were coastal populations in highland areas (above 800 m) and those areas with high per capita GDP (over US$20,000 in 1997) where per capita fish consumption is less than 50 kg per year.
- The threat from destructive fishing was evaluated using an expert mapping approach instead of modeling. RRSEA worked with collaborators throughout the region to map areas where fishing with poisons and blast fishing are occurring or have occurred recently.

For three threat categories — coastal development, marine-based pollution, and pollution and sedimentation from inland sources — the "raw" threat estimates were adjusted based upon an indicator of the natural vulnerability of the area to pollution and sedimentation. In addition, three "raw" threat estimates — overfishing, destructive fishing, and coastal development — were adjusted to account for the management effectiveness of the area. The five adjusted threat estimates were then combined into an integrated estimate of threat from human activity. A 1-km resolution grid reflecting coral reef locations was overlaid with the integrated threat estimate to produce the Reefs at Risk Threat Index — coral reefs rated by estimated threat from human activities.

For full technical notes on the modeling method, including data sources, or to download model results, see www.wri.org/wri/reefsatrisk.

Table 4. Potential Sustainable Annual Economic Net Benefits per km² of Healthy Coral Reef in Southeast Asia

Coastal protection and tourism data are based on annualized figures of medium and high values from Cesar (1996). Table 4 presents annual net benefits, while White, Vogt, and Arin (2000, p. 599) focused on annual revenues. Hence estimates have been adjusted to reflect costs. This recalculation for sustainable fisheries (local consumption) assumes an average market price of US $1.5 per kg of reef fish and that fishing costs are 20 percent of revenue. Sustainable fisheries (live fish export) assumes a market price to fishers of US$10 per kg of live reef fish and costs of 50 percent of revenues. Tourism and recreation revenue estimates assume a wide range of tourism types, from huts and cottages to five-star resorts, and uses cost and revenue data from Cesar (1996, p. 21). Aesthetic / biodiversity value (willingness to pay) assumes an average expenditure of US$4 per day for entrance to a marine sanctuary for the support of conservation. Coastal protection estimates, given in Cesar (1996, p. 23), quantify loss of agricultural land in rural areas and loss of buildings, etc. in areas with considerable infrastructure and tourism presence.

Table 5. Total Net Benefits and Losses on Southeast Asian Coral Reefs by Activity (Net Present Value in US$ 000 per km² over a 20-Year Period)

The Net Present Value (NPV) presented in Table 5 is calculated over a 20-year period rather than a 25-year period, as in Cesar et al. (1997) in order to be consistent with other tables in this report.

Table 6. Potential Sustainable Annual Economic Net Benefits for Indonesia and the Philippines (US$ million)

Table 6 is based on value per unit area estimates *(See Table 4)* and reef area estimates from RRSEA.

a. Sustainable fisheries production was assumed to yield 15 mt per km² per year (McAllister 1988), annual net benefits of US$24,000 per km², and reef area estimates of 50,875 km² and 25,819 km² for Indonesia and the Philippines, respectively *(See Table 3)*.

b. Tourism and recreation were assumed to have annual net benefits of US$330 for coral reefs with low tourism potential (beyond 10 km from current identified tourism development) and US$56,000 for areas with good tourism potential (within 10 km of current tourism development). Only 3 percent of Indonesia's reefs and 7 percent of Philippine reefs were identified as having high tourism potential.

c. Aesthetic / biodiversity value was evaluated only for reefs with high tourism potential and was assumed to have annual net benefits of US$5,700 per km².

d. Coastal protection assumed annual net benefits of US$110,000 for reefs near high development areas, US$5,600 near medium development areas, and US$90 for reefs in low development areas or more than 4 km from the coastline.

e. Total net annual benefits is the sum of annual benefits from the goods and services associated with sustainable fisheries, tourism, coastal protection, and aesthetics/biodiversity. The Net Present Value (NPV) reflects these annual benefits over a 20-year period and uses a 10 percent discount rate.

Table 7. Net Losses to Society over a 20-Year Period from Overfishing, Blast Fishing, and Upland Activities in Indonesia and the Philippines (Net Present Value in US$ million)

Estimates of Net Present Value (NPV) of losses to society are based on cross-tabulations of Reefs at Risk results (area estimates) by threat category and benefit or loss estimates presented in Table 5 and Cesar (1996, 2000).

a. For blast fishing, losses of tourism, coastal protection, and sustainable fisheries were evaluated. The following per km² losses were combined with the reef area estimates for Indonesia and the Philippines.

LOSSES PER KM² PER YEAR BY LEVEL OF BLAST FISHING (US$)								
	LOSSES IN SUSTAINABLE FISHERIES			LOSSES OF COASTAL PROTECTION			LOSSES IN TOURISM REVENUE	
LEVEL OF THREAT	ESTIMATED LEVEL OF OVERFISHING			ESTIMATED LEVEL OF COASTAL DEVELOPMENT			ESTIMATED TOURISM POTENTIAL	
FROM BLAST FISHING	LOW	MEDIUM	HIGH	LOW	MEDIUM	HIGH	LOW	HIGH
Low	$0	$0	$0	$0	$0	$0	$0	$0
Medium	$17,000	$34,000	$51,100	$200	$11,300	$226,400	$650	$1,300
High	$34,100	$68,100	$102,200	$400	$22,600	$452,900	$276,500	$453,000

b. For overfishing, losses from sustainable fisheries are evaluated. Potential tourism losses are not calculated owing to lack of data. The analysis of losses to sustainable fisheries takes into account short-term benefits of overfishing and loss of sustainable fisheries. These per km² estimates are combined with reef area estimates for Indonesia and the Philippines.

LOSSES PER KM² PER YEAR BY LEVEL OF OVERFISHING (US$)		
LEVEL OF THREAT FROM OVERFISHING	BENEFIT TO INDIVIDUAL	LOSSES IN SUSTAINABLE FISHERIES
Low	$13,000	$34,000
Medium	$26,000	$68,000
High	$39,000	$102,000

c. For sedimentation from upland activities, private benefits from logging and losses to society from sustainable fisheries and tourism are evaluated.

LOSSES PER KM² PER YEAR BY LEVEL OF THREAT FROM UPLAND ACTIVITIES (US$)			
LEVEL OF THREAT FROM SEDIMENTATION FROM UPLANDS	PRIVATE BENEFITS FROM LOGGING	LOSSES IN SUSTAINABLE FISHERIES	LOSSES IN TOURISM REVENUE
Low	No logging	$0	$0
Medium	$49,000	$40,500	$96,000
High	$98,000	$81,000	$192,000

The reef area statistics by cross-tabulated threat categories are available from the Reefs at Risk web site at www.wri.org/wri/reefsatrisk.

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PHOTO: WOLCOTT HENRY

NOTES

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REEFS AT RISK IN SOUTHEAST ASIA

The Reefs at Risk in Southeast Asia project was implemented by WRI in collaboration with many partner organizations *(See inside front cover)*. This report represents a summary of a two-year collaborative effort. In addition to the report, all maps, GIS data, model results, full technical notes, and more detailed information about particular threats and specific reefs is available from the Reefs at Risk web site, www.wri.org/wri/reefsatrisk.

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