CHAPTER 4. THREATS TO CORAL REEFS IN SOUTHEAST ASIA

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

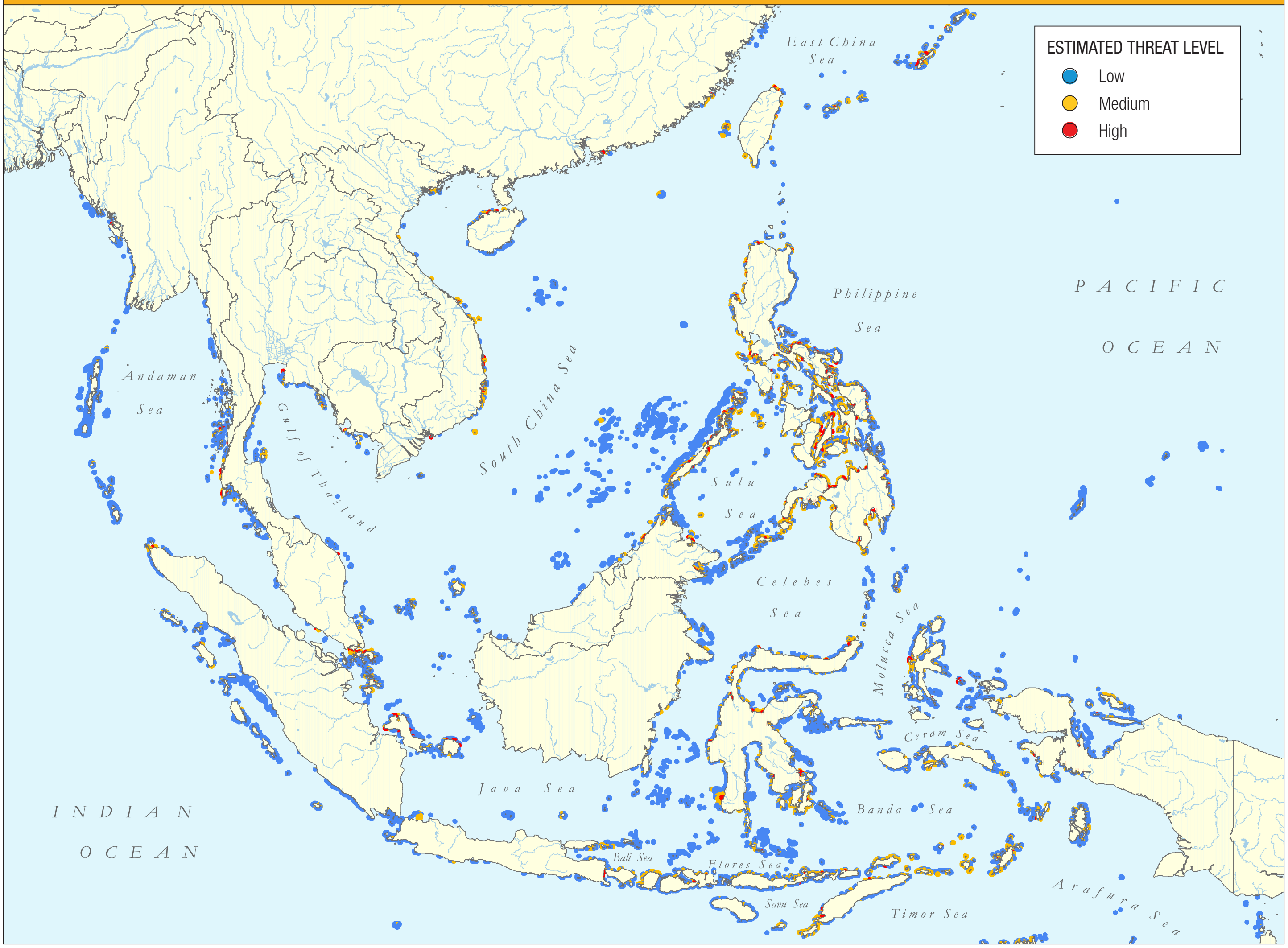
The growing populations, expanding industrial economies, and emerging tourism markets in Southeast Asia drive the demand for the construction of new infrastructure in the coastal zone. Coastal development can result in direct or indirect pressures on coral reefs — both of which can be devastating to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

MARINE-BASED POLLUTION

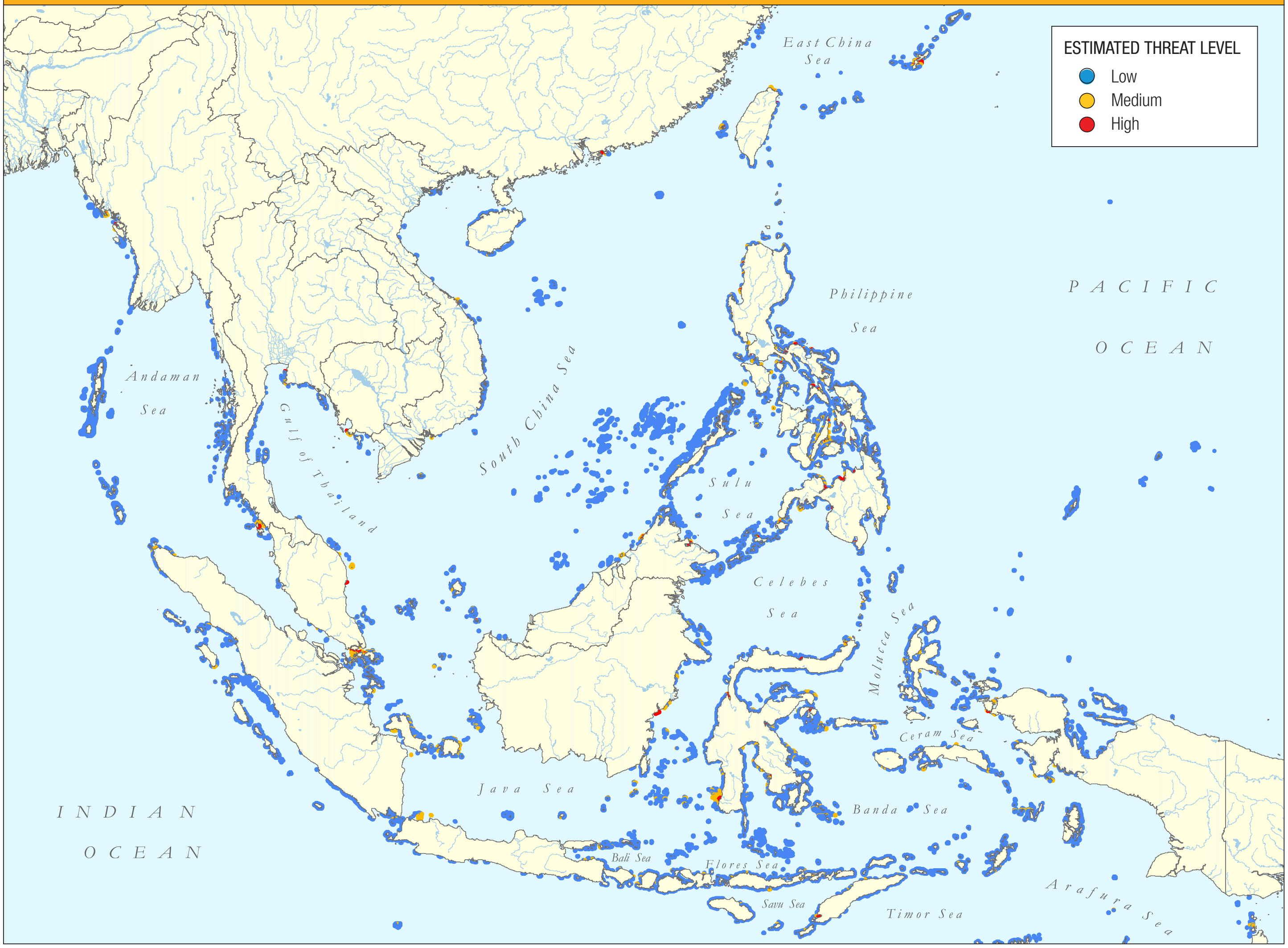
Southeast Asia is a major hub for shipping traffic. The region has several megaports and an extensive network of shipping lanes. Marine-based activities that threaten coral reefs include pollution from ports, oil spills, ballast and bilge discharge, garbage and solid waste dumping from ships, and direct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

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

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

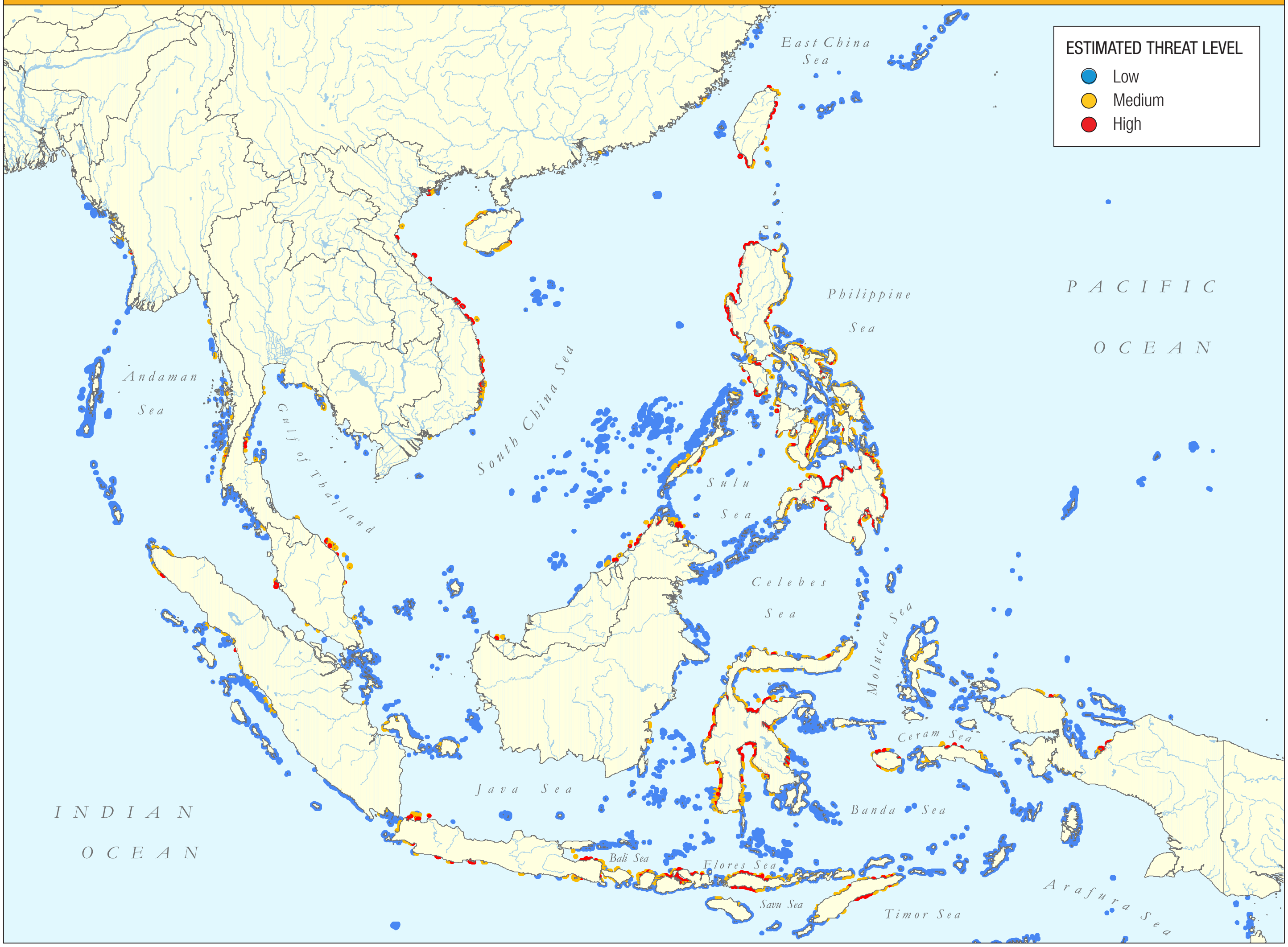
Coral reefs typically thrive in clear tropical waters that have low nutrient levels. Because the zooxanthellae that corals depend on need high levels of light, sediment in the water column can significantly affect coral growth or even instigate coral die-off. Even in the most pristine ecosystems, wind 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.

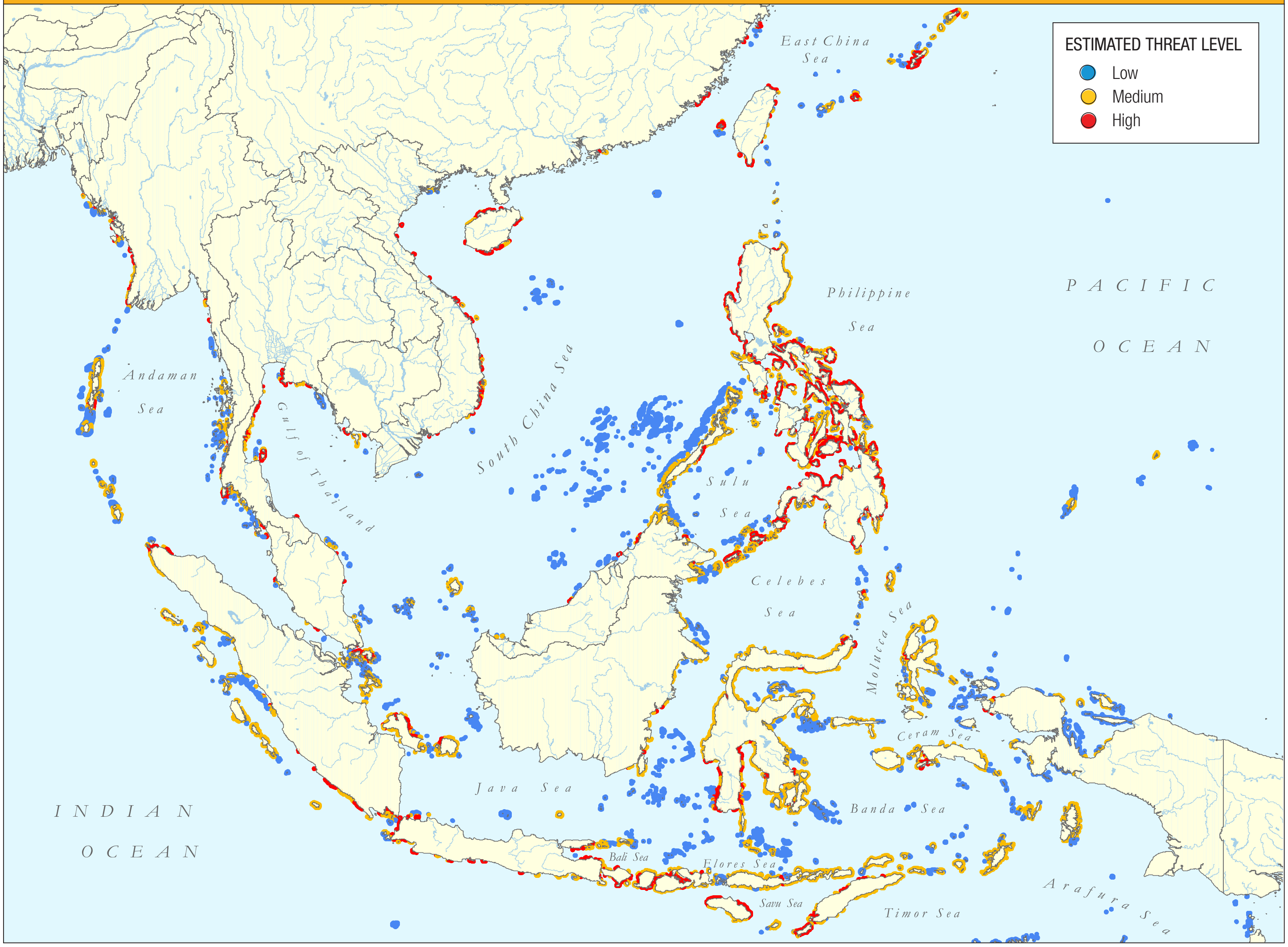
Overfishing is a complex problem with varied impacts on coastal communities, the economy, and coastal ecosystems. If effectively managed, fisheries can provide a renewable source of food and livelihoods, but in Southeast Asia, many fish species are currently overexploited. Coral reefs are capable of 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

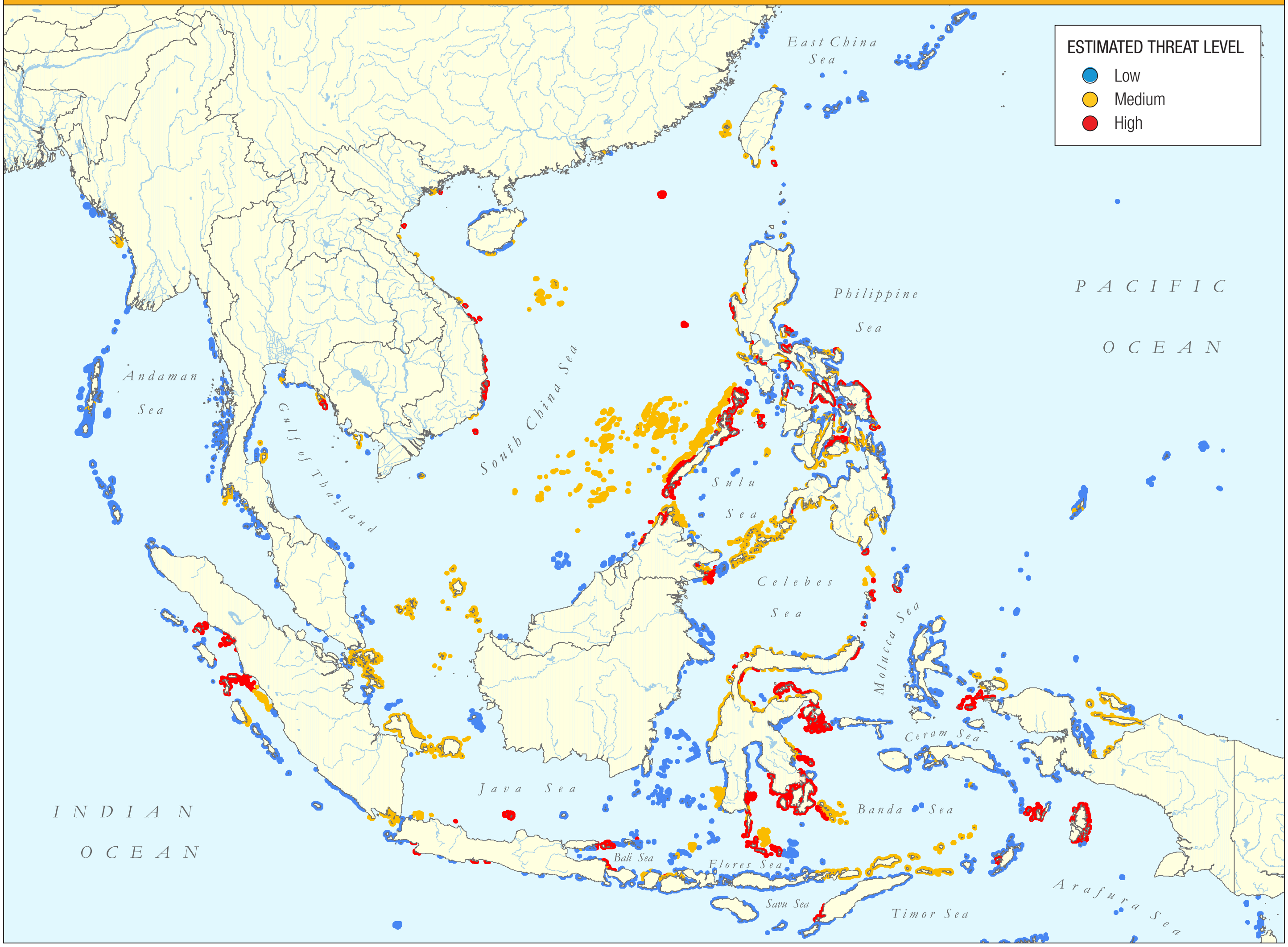
Although outlawed throughout Southeast Asia, blast fishing is practiced regularly in most countries in the region. During World War II, Japan and the Allied powers left behind thousands of unexploded shells, littering the waters of Southeast Asia and the Western Pacific. In the past, these shells were 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

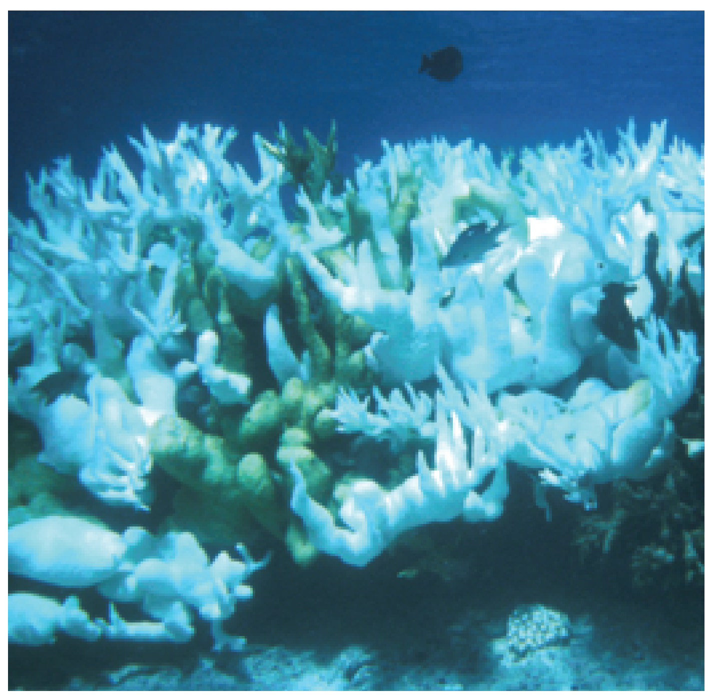
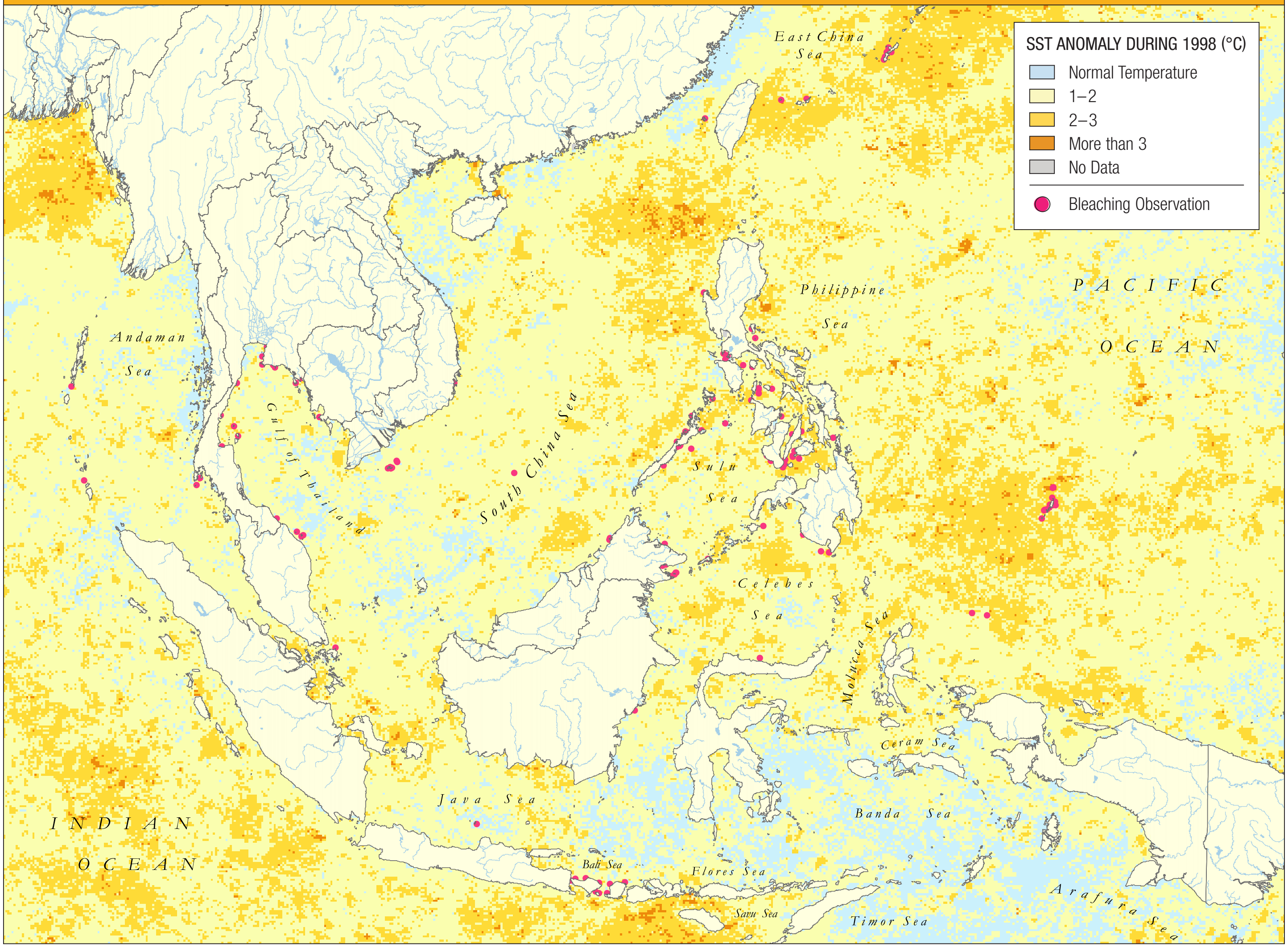


PHOTO: MARK SPALDING

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.