II. Pacific Ocean Analysis: Threats, Impacts, and Solutions

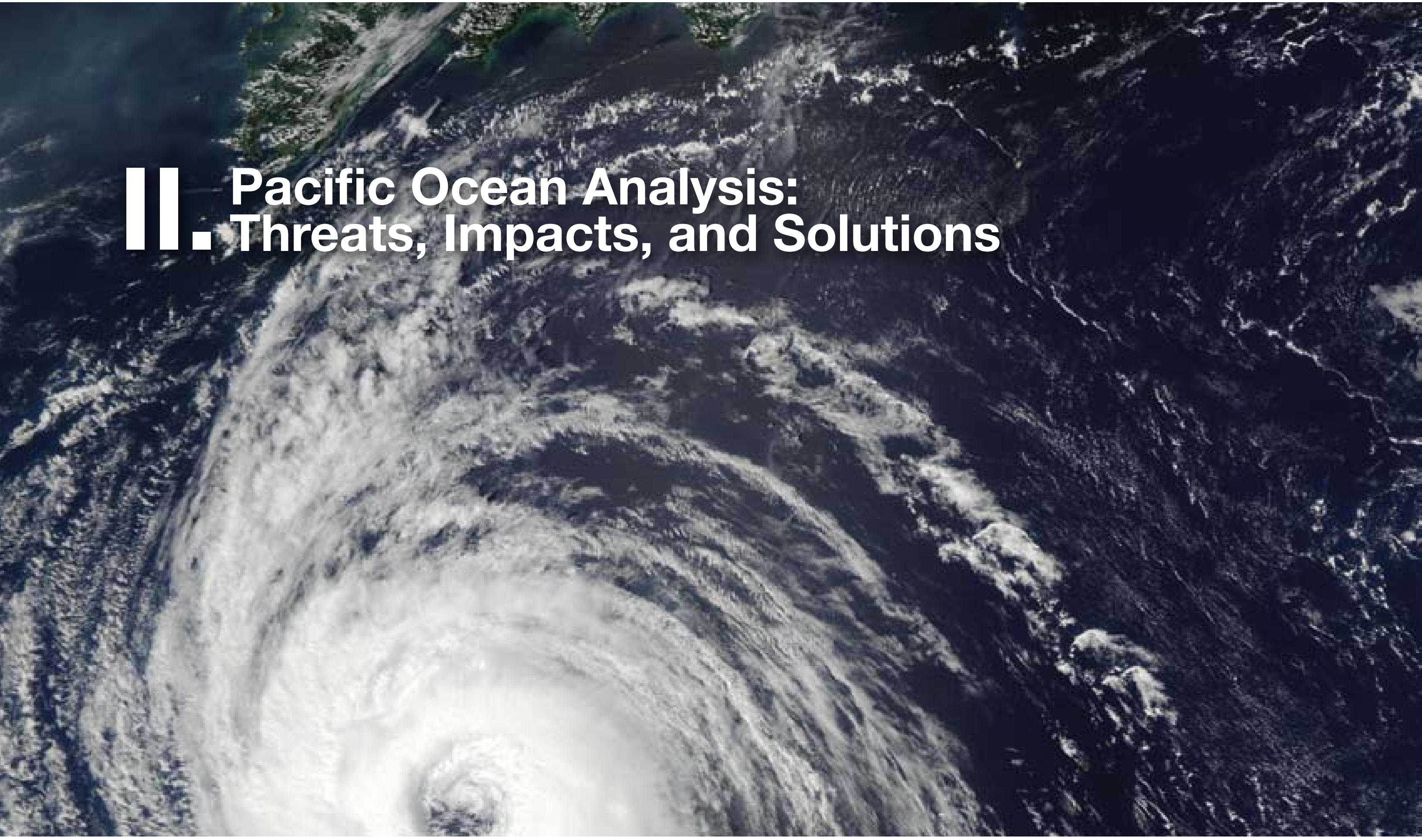

Photo: Typhoon Sinlaku moving through the North West Pacific, south of Japan. Among the impacts of climate change are increased tropical storm frequency and intensity. (Jacques Descloitres, MODIS Land Rapid Response Team, NASA/GSFC)

This analysis of the Pacific Ocean region distills key findings from the seven regional studies that follow, and highlights threats that are common to all of the individual regions, such as climate change, land-based pollution, and commercial fishing. Taken together, the Pacific is an extremely diverse region, with great variation in ecological, social, economic, cultural, and infrastructural make-up. China, for example, is one of the fastest growing countries in the world and faces enormous population pressures that, in turn, further threaten valuable marine resources. By contrast, some of the more remote South Pacific islands have smaller populations and fewer resources. Both regions, however, face threats to their marine and human systems. Certain coastal and nearshore ecosystems, such as the coral reefs, seagrass, and mangroves in Central America and Southeast Asia, are extremely vulnerable to anthropogenic or climate-induced threats; other areas, like the coasts of Fiji, the Hawaiian Islands, and Australia, are heavily trafficked by tourists. Though the exact threats to and socioeconomic impacts in each region may differ in severity, the Pacific Ocean as a whole faces grave threats to its viability.

As the first to comprehensively analyze the threats and impacts to the waters surrounding Pacific countries and territories, this synthesis takes a regional and country-by-country/territory-by-territory approach, where relevant peer-reviewed research is available. Other reports have also methodically prioritized marine threats and impacts. The 2008 Science article by Ben Halpern et al., “A Global Map of Human Impact on Marine Ecosystems,” offers a world map of human impacts on the oceans. It analyzes 17 anthropogenic stressors, including coastal runoff and pollution, warming water temperature due to human-induced climate change, oil rigs that damage the sea floor, and five different kinds of fishing, among others, for 20 marine ecosystems. Unlike the Halpern report, which developed ecosystem-specific, multiscale spatial models based on interviews with experts to assess anthropogenic impacts on marine ecosystems around the world, our report draws on existing scientific literature to synthesize the major threats and their impacts in 50 countries or territories exclusively around the Pacific. In addition to the Halpern report, the 30+ Global International Waters Assessment reports developed by United Nations Environment Programme (UNEP) present comprehensive and integrated global assessments of waters in different regions, including marine areas. Each report uses available data and expert knowledge to present the ecological status and causes of environmental problems, examine the socioeconomic causes of such issues, and analyze policy options. While we draw on the reports mentioned above, our synthesis primarily utilizes the existing scientific literature. As an extensive literature review documenting threats and impacts, it is the first of its kind.

The sections in this report offer regional analyses of the threats facing each of the seven regions within the Pacific Ocean. The four primary broad threats identified in this report and the consensus statement include:

- **Pollution:** The literature identifies nutrients (36 locations) as a severe impact threat. Chemical pollution is also a Pacific-wide moderate impact threat, but the research does not document the extent of such pollution, nor all of the chemical inputs that could affect our systems. This category includes nutrient pollution from fertilizer runoff and organic pollutants from sewage, solid waste including plastic marine debris, toxic dumping, and oil spills, and chemical pollution including urban runoff. Such forms of pollution can create dead zones, algal blooms, and acidic areas, and alter the basic ecosystem structure, pose human health risks, and stress economies.
- **Habitat Destruction:** Productive marine habitats are lost to destructive fishing practices, poor agricultural land use, and inappropriate coastal development. Such practices can reduce fishery productivity, create erosion, reduce coastal ecosystem health, and limit livelihoods. Sedimentation is a severe impact threat in 36 countries or territories. Coastal development and land reclamation are widespread moderate impact threats throughout the Pacific, which lead to the destruction of critical ecosystems that produce invaluable services and products for society in 35 countries or territories.
- **Overfishing and Exploitation:** Commercial fishing is identified in 40 countries or territories as a severe impact threat. Across the Pacific, commercial fishing has some of the greatest impacts on both the environment and society. Unsustainable resource use reduces fish stocks throughout the Pacific, limiting fish catches and often causing ecological shifts that further reduce biodiversity and productivity. By-catch further reduces fish stocks. Artisanal and recreational fishing suffer when local needs outstrip local supply, causing displacement of fishing activity, reduced income, and insecure food supply. Habitat destruction exacerbates overfishing by reducing fishable area and productivity.
- **Climate Change:** Sea surface temperature increase (an overall moderate impact threat, identified in 36 countries or territories), sea level rise (an overall moderate impact threat, identified in 30 countries or territories), and ocean acidification (an overall low impact threat, identified in seven countries or territories), all resulting from climate change, threaten the Pacific. Although it has become an increasingly important issue, many countries lack research documenting place-based, present and expected future impacts of climate change. Pacific countries and territories have already identified strong effects of ocean warming, changes in ocean circulation, and abrupt shifts in precipitation patterns. The bleaching and subsequent death of reef-building corals caused by warm water pulses has destroyed reef ecosystems. Some ocean areas have already acidified to levels known in laboratory studies to cause harm to ocean life. The rates of current environmental change far outpace anything seen in human history, and are likely to accelerate in the near future. Many areas of the Pacific Ocean may become uninhabitable due to sea level rise. These changes will increase the number of impoverished people and reduce the stability of many countries and territories.

In addition to the primary threats listed above, the following have been identified as priority concerns:

- **Invasive Species:** While few countries and territories have documented research on invasive (non-indigenous) species, evidence suggests that marine invasives, identified in 18 locations, can adversely affect the habitats they invade both ecologically and economically. Invasives compete with other species for habitat and food and can induce disease; already disturbed habitats are prone to invasions. Invasive species can, in fact, alter the functions of entire ecosystems.
- **Multiple Stressors:** When marine life is subjected to multiple stressors, such as pollution, habitat destruction, overfishing, and climate change, populations of ecologically and economically important species can collapse, from coral reefs to kelp forests to cold water deep seas. In this sense, global climate change is coming at the worst possible time, when many communities around the Pacific—both human and ecological—are threatened by other major problems.

Major Threats Facing the Pacific Ocean

Pollution

Organic pollutants from sewage, nutrient pollution from fertilizer run-off, plastic marine debris, toxic dumping and oil spills, urban run-off and other pollutants combine to create one of the most critical classes of ocean threats.

Habitat Destruction

Productive marine and coastal habitats are lost to destructive fishing practices, poor agricultural land use, inappropriate coastal development, and industrial wastewater.

Overfishing & Exploitation

Unsustainable resource use reduces fish stocks throughout the Pacific, limiting fish catches and often causing ecological shifts that further reduce biodiversity and productivity.

Climate Change

Carbon dioxide (CO^2) discharged to the atmosphere both alters seawater chemistry, resulting in ocean acidification, and causes the ocean to warm, leading to sea level rise, habitat shifts, increased storm intensity, altered precipitation patterns, and coral bleaching.

This document does not explore in depth two areas/issues prevalent throughout the Pacific due to limited knowledge and scientific data: first, the Pacific Ocean High Seas, and second, climate-change and some of its associated threats, such as ocean acidification and UV-B radiation.

The Pacific Ocean High Seas

The main threats to the Pacific Ocean High Seas, the open ocean beyond the exclusive economic zones (EEZs), include overfishing, destructive fishing (such as high seas bottom trawling), and other extractive activities that have resulted in serious declines in global fish stocks and marine biodiversity. The lack of effective regional and international governance and enforcement contributes to these problems and presents further challenges for sustainable management of marine resources. Recent proposals to mitigate climate change through ocean iron fertilization and other “geo-engineering” solutions, for example, highlight a number of gaps in the legal framework and governance regime for the high seas. The potential for future harmful activities, such as sea floor mining, is great unless an ongoing and concerted regional and/or international body successfully governs and monitors such activities.

Climate Change: Predicting the Future

Global change threatens all of Earth's systems—and the Pacific Ocean is not immune to its tremendous impacts. The seven regional analyses that follow explore in depth two threats associated with climate change—sea surface temperature increase (discussed in further detail on page 19) and sea level rise (page xx). Both have vast implications for marine ecosystems and low-lying coastal regions. The environmental and socioeconomic effects of sea surface temperature increase are well documented in certain places, such as Australia, the United States, and Canada. However, they are not documented in many of the most vulnerable places. Site-specific research on ocean acidification and UV-B radiation are also less well documented in and around the Pacific. Increases in UV-B radiation will have significant effects on planktonic organisms and dissolved organic matter (Tedetti and Sempere 2006), but local studies or models predicting such impacts are limited. Many laboratory studies and studies in a few locations document the impacts of UV-B on certain organisms such as phytoplankton, coral reefs, sea urchins, and kelp (Przeslawski 2005; Villafane, Gao et al. 2005; Lesser, Barry et al. 2006; Veliz, Edding et al. 2006; Gao, Li et al. 2007; Poloczanska, Babcock et al. 2007; Torregiani and Lesser 2007; Eckes, Siebeck et al. 2008). Other effects of climate change include the possibility of increased frequency and severity of El Nino Southern Oscillation (ENSO)-like events, changes in stratification and mixing, changes in salinity, and possible effects on storms.

Ocean acidification, also associated with increasing anthropogenic carbon dioxide (CO2) emissions, joins sea warming and sea level rise as a major threat to the Pacific Ocean. Over the last two centuries, human activities have resulted in dramatic increases in atmospheric CO2 and other greenhouse gases. Not only are these gases altering Earth's climate, but they are also acidifying the ocean as CO2 gets absorbed into the ocean and lowers the pH of the waters. Under the Intergovernmental Panel on Climate Change (IPCC) emission scenarios, average surface ocean pH should decrease by 0.3-0.4 pH units from pre-industrial values (Caldeira and Wickett 2005). Growing evidence suggests that ocean acidification will strongly affect marine ecosystems, particularly those in high latitudes that are already naturally low in calcium and carbonate ion concentration, and regions that intersect with pronounced hypoxia zones. In nearshore areas, nitrogen, sulfur, and phosphorus deposition may also contribute significantly to acidification (Doney 2007).

Marine organisms are especially vulnerable to altered seawater CO2 chemistry, which influences their physiology and alters their viability through acid-based imbalance and reduced oxygen transport capacity. Acidification research to date has focused heavily on the effects on calcification and shell-forming organisms, including surface and deep-water corals, many plankton, pteropods (marine snails), mollusks, and lobsters. However, pH also negatively affects non-calcification processes such as fertilization, and non-calcifying organisms such as kelp (Fabry, Seibel et al. 2008) Ocean acidification, which compromises carbonate accretion, particularly affects reef-building corals by reducing calcification and thereby limiting their growth. On Australia's Great Barrier Reef, for example, the coral Porites has shown a 20.6% drop in growth rate over a recent 16-year period (Hoegh-Guldberg, Mumby et al. 2007). Because many of these organisms supply habitat or food sources for other organisms, acidification thus affects food web dynamics and other ecosystem processes as well. Changes in ocean circulation due to ocean acidification have also contributed to such changes. In the California Current Large Marine Ecosystem, trends in coastal upwelling from 1960s to today reveal shorter and later upwelling seasons (Bograd, Schroeder et al. 2009). In Australian waters, sea surface temperature comparisons show increases in temperatures and a delay of the peak in the annual temperature cycle, which have implications for the growth, recruitment, and spawning of fish and marine ecosystems (Caputi, de Lestang et al. 2009). Overall, ocean acidification and the synergistic impacts of other anthropogenic stressors provide great potential for widespread changes to marine ecosystems, including decreased biodiversity (Fabry, Seibel et al. 2008). Acidification will also put further pressure on marine resources—such as fisheries and coral reefs that supply food, tourism, and other economic and aesthetic benefits.

Over time, climate change will also produce long-term range shifts of marine organisms. There is limited research on this topic in the Pacific, but Tian et al. (2006, 2008) document a regime shift in the ecosystem of the Tsushima warm current off the coast of Japan, showing changes in fish populations (Parmesan 2006; Tian, Kidokoro et al. 2008). However, many more studies need to be conducted on this topic.

Accurate projections of the effects of climate change largely rest on questions about the evolution of greenhouse gas emissions in the future, the sensitivity of different parts of the ocean to changes in atmospheric composition, the response by both individual species and large ocean ecosystems, and earth systems feedback loops. Many of these questions still have no answers.

Box 1: Summary of Pacific Threats with Severe Impacts

THREAT	ENVIRONMENTAL IMPACTS	SOCIOECONOMIC IMPACTS
Overfishing & Exploitation: Commercial Fishing	• **Removal of highly fished top predators »** altered recruitment, changes in food web dynamics, ecosystem, biodiversity	• Threatened food security and livelihood • Reduced tourism, recreation, aesthetics
Pollution: Nutrients	• **Eutrophication »** increase in primary productivity leading to algal blooms (» HABs), oxygen depletion, reduction in water quality, fish, coral, other marine populations » changes in food web dynamics, ecosystem, biodiversity • **Disease/Outbreaks »** impaired marine ecosystem health, especially coral reef health and mortality • **Polluted beaches and coastal waters** • **Possible coral reef "phase shift"**	• Threatened food security and livelihood • Human health risks (biotoxins in fish from HABs) » paralytic shellfish poisoning; ciguatera; illnesses from other pathogens and bacteria • Reduced tourism, recreation, aesthetics
Habitat Destruction: Land-Based Sedimentation	• **Turbidity in water »** decreased penetration of sunlight » decrease in primary producers » decrease in secondary producers » changes in food web dynamics, ecosystem, biodiversity • **Smothering of coral reefs »** decreased fish » changes in food web dynamics, ecosystem, biodiversity • **Chemicals in sediments »** toxic bioaccumulation in marine life » marine organism mortality » changes in food web dynamics, ecosystem, biodiversity	• Threatened food security and livelihood • Human health risks from toxic fish/shellfish • From coral reef destruction, reduced food security, tourism, recreation, aesthetics, increased impact of storms

Pacific Ocean Trends: Primary Threats and Associated Environmental and Socioeconomic Impacts

The bullets below highlight significant severe and moderate impact threats in the entire Pacific Ocean based on the impact assessment methodology described in the Introduction.

Based on this assessment, the threats with the most severe impacts throughout the Pacific Ocean are:

- commercial overfishing identified in 40 countries or territories.
- nutrient pollution identified in 36 countries or territories.
- land-based sedimentation identified in 36 countries or territories.

The threats with moderate impacts throughout the Pacific Ocean are:

- coastal development/land reclamation identified in 35 countries or territories.
- sea surface temperature increase from climate change identified in 36 countries or territories.
- land-based chemical pollution identified in 32 countries or territories.
- artisanal/recreational/subsistence fishing identified in 38 countries or territories.
- oil spills and antifouling chemicals identified in 37 countries or territories;
- sea level rise identified in 30 countries or territories.
- solid waste disposal identified in 22 countries or territories.
- wastewater from aquaculture identified in 26 countries or territories.
- destructive fishing identified in 22 countries or territories.
- coastal modification from aquaculture identified in 24 countries or territories.
- by-catch and discharge identified in 23 countries or territories.

Trends:

- North West Pacific contains the greatest number of moderate to severe impacts (8 moderate, 9 severe).
- South East Pacific contains the second greatest number of moderate to severe impacts (7 moderate, 8 severe), while also including the least total documented number of identified threats.

- In Polynesia, the majority of impacts are low, and none of them are severe.
- For the Pacific Ocean in general, most known threats have low to moderate impacts (15 and 11, respectively), and relatively few severe impacts (3).

There is considerable variation in the availability of scientific literature in the Pacific, as discussions of the seven individual regions reveal.

Pacific Ocean Literature Review of Severe and Moderate Impact Threats

The discussion that follows highlights the greatest severe and moderate impact threats to the Pacific Ocean. The most severe threats are discussed (see box 1 and 2 below), and each threat category explains the threat as well as environmental and socioeconomic impacts, where available in the research. It should be noted, however, that the literature does not always link threats to socioeconomic impacts.

● Severe Impact Threats

Overfishing and Exploitation: Commercial Fishing

Commercial, industrial fishing, one of the most important economic activities throughout the Pacific Ocean, has been identified in 40 locations. Many studies have been conducted on commercial fisheries around the Pacific, particularly the largest and most productive ones. However, some research still needs to be done to provide a more complete picture of overfishing in the entire Pacific.

Many of the commercially important fisheries throughout the Pacific have collapsed or shown severe declines. The Okhotsk Sea sub-system, in Russian waters, is regarded as the richest marine fishery in the world; in 2000, the fishing industry contributed USD $1.2 billion to the economy of the Russian Far East and accounted for 18.2% of gross regional product in 1999. But since the early 1990s, total catches in the Okhotsk Sea have been reduced by 2 to 2.5 times due to overfishing (Alekseev, Baklanov et al. 2006). Regionally, overfishing is a large problem. In the late 1990s, the economic values of some of the largest Pacific island fisheries ranged from USD $146 million (Kiribati) to USD $161 million (Papua New Guinea). But, as in Russia, unregulated fishing has severely reduced many of these islands' stocks (Dalzell, Adams et al. 1996). Studies show that 55% of the Pacific's island countries and territories overexploit their coral reef fisheries, although this statistic is uncertain due to limited data (Newton, Cote et al. 2007). In parts of Asia, such as Thailand, fish stocks are also overexploited, with major fluctuations in annual total catches (Pauly, Chuenpagdee et al. 2003).

Commercial fishing has many impacts on the marine ecosystem. First, overfishing leads to depleted stocks, endangered species, and even extinction. For example, research suggests that since 1950, large pelagic predators have declined 90% in the tropical Pacific (Lotze, Lenihan et al. 2006; Jackson 2008). Giant clams are almost extinct; endangered species include marine turtles, giant tritons, mangrove crabs, bêche-de-mer (processed sea cucumber), trochus and turban shells, and highly targeted reef fishes (South, Skelton et al. 2004). Second, the removal of these species alters the food web; highly fished top predators may disappear, and altered recruitment trends (the survival of juveniles is linked to adult populations) will, in turn, affect ecosystem dynamics. Another problem is the size-selective harvesting of marine fishes, which can also have long-lasting evolutionary effects on the life history traits that affect a population's overall fecundity (Hard 2008). Destructive fishing, a form of habitat destruction that indiscriminately kills large fish populations, exacerbates the problem. By-catch has likewise become a region-wide issue. In Thailand, about 35% of marine production is trash fish, most of it used in fish meal production; otter board trawlers contribute about 80% of the total trash fish production (Kaewnern and Wangvoralak 2005).

The human cost of inappropriately managed commercial fishing is also great. Many inhabitants of Pacific countries and territories, particularly those in Southeast Asia, Central America, and the South Pacific islands, depend on fishing on a daily basis. If fishing were to disappear, so would their livelihoods. Growing populations in these regions exacerbate the threat posed by commercial fishing. A recent study estimated that in the Pacific island countries and territories, an extra 196,000 square kilometers of coral reef fisheries area would be required by 2050 to support the anticipated growth in human populations (Newton, Cote et al. 2007). Such population growth would further stress livelihood and food security, and perhaps lead to large-scale migrations.

Pollution: Nutrients

Nutrient pollution, identified by the literature in 36 countries or territories throughout the Pacific, is a grave threat to the Pacific Ocean and exerts some of the greatest impacts on marine and human systems. While more research needs to be done in certain Pacific regions, it is clear that as human populations and urban centers in the region have grown, sewage and wastewater discharges, as well as agricultural runoff, have also increased and deposited heavier nutrient loads into coastal waters.

Nutrient inputs can lead to eutrophication, which increases the ecosystem's primary productivity, restricts oxygen, impairs water quality, and affects fish and other marine populations (Sien 2001). Some coastal systems have exceeded their ability to absorb nutrients, leading to hypoxia, or dead zones. Nutrient inputs also lead to outbreaks of certain species, such as crown-of-thorns starfish or HABs, as well as disease. HABs can affect living marine resources such as coral, fish, and mammals, and result in a change in food web dynamics and a reduction of biodiversity. Such blooms commonly occur throughout the Pacific Ocean. In 2003, a toxigenic diatom bloom in the Santa Barbara Channel led to massive mammal mortality (Anderson, Brzezinski et al. 2007). In 2002, 51 HABs were identified in the East China Sea and 17 in the Yellow Sea and Bohai Sea. In 2003, this number increased to 86 in the East China Sea, many stemming from pollution from the Yangtze River estuary (Qu, Xu et al. 2005). Nutrient pollution can also contribute to local ocean acidification (Doney 2007).

Besides threatening marine life, nutrient pollution creates economic, social, and health problems. By causing mortality of economically important species, nutrient pollution can lower the productivity of fisheries and aquaculture operations. Along the west coast of Canada, HABs caused significant mortality to farmed salmon, amounting to CAN $2 million in economic losses (Whyte, Haigh et al. 2001). Throughout parts of Central America, eutrophication and HABs stemming from fertilizer runoff led to closed fishing seasons, which resulted in approximately USD $200 million loss to the fisheries industry (Espinoza 2002). Nutrient pollution also poses severe health risks. In Central America, eutrophication has led to more than 300 recorded cases of paralytic shellfish poisoning (PSP), with 17 deaths. Malaysia has reported a total of 609 PSP cases and 44 deaths. In Tahiti, ciguatera, a food-borne illness caused by a toxin in algae (which then becomes biomagnified in fish), has been linked with algal blooms (Chateau-Degat, Chinain et al. 2005). This illness is common in tropical and subtropical countries and territories. But cases of fish poisoning have been recorded all throughout the Pacific, from Vanuatu (in Melanesia) to Southern California (Goodman, Williams et al. 2003). Such illnesses result in economic loss; those caused by polluted beaches in Southern California lead to losses of USD $21-51 million annually (Given, Pendleton et al. 2006).

Habitat Destruction: Land-Based Sedimentation

Like nutrient pollution, sedimentation—the deposition of sediment by the settling of a suspended material—into coastal waters is a serious and prevalent threat around the Pacific. Documented in 36 countries or territories, with research still necessary for many countries and territories, land-based sedimentation has increased as human populations have modified the nearshore marine environment, from building urban centers to heightening agricultural output and putting new pressure on resources. Even changes in land use far from the coast can negatively affect marine ecosystems (Salvat, Aubanel et al. 2008). Deforestation (including of mangroves, which are often located in areas of the world with coral reefs), poor agricultural practices, coastal erosion, mining, and the construction of roads all have contributed to increased sediment loads in coastal and nearshore habitats, including coral reefs and other systems. In the South East Pacific (parts of South America), sedimentation affects almost 60% of the region's coasts, most resulting from erosion caused by deforestation and inadequate agricultural and land-use practices. Critical areas affected include parts of Ecuador, and, in Peru, from Pisco to the Chilean border. Extensive deforestation has also deposited sediment into Colombian waters (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006).

Sedimentation is both a natural process and a human-induced activity. In and of itself, it does not always have deleterious consequences. However, human activities have increased the rates and volumes of harmful sedimentation, which in turn impairs marine life in various ways. It produces turbidity, which decreases the depth that sunlight can penetrate. Without sunlight, plant growth (primary producers) is reduced, which has consequences for organisms (consumers) that feed on the plant material and the stability of the entire food web. If sunlight doesn't reach the symbiotic zooxanthellae algae that at times provide almost all the energy that coral polyps need, the coral may die. Sediment can also directly cover and thereby suffocate coral reefs. In Hawai'i, studies suggest that sedimentation severely impairs entire marine ecosystems (Dollar and Grigg 2004). Some sediments also contain dangerous chemicals—dichlorodiphenyltrichloroethane and its metabolites (DDTs), pesticides, and heavy metals, for example—which may be lethal to marine life and their habitat. Benthic animals such as clams are especially vulnerable to the bioaccumulation such toxic substances; if consumed, they can threaten human health (Carvalho, Montenegro-Guillen et al. 2003). Chemical pollution is also a major threat, as discussed on page 21. Because even very fine sediment directly reduces the biological productivity of marine systems, sedimentation directly affects operations that depend on the presence of marine resources, such as commercial fisheries, aquaculture, subsistence fishing, and even tourism. Reductions of these activities can create economic hardship and threaten livelihood and food security. Coral reefs, for example, are valuable for food security, tourism, and as storm barriers. A few coral reef stud

Box 2: Summary of Pacific Threats with Severe Impacts

THREAT	ENVIRONMENTAL IMPACTS	SOCIOECONOMIC IMPACTS
Habitat Destruction: Coastal Development/ Land Reclamation	• Altered currents, drainage patterns, and sediment delivery » erosion and/or reduced beaches • Increased salinization • Increased flood and storm damage » increased inputs of pollutants and sediments into coastal waters » changes in primary and secondary productivity, food web dynamics, ecosystem, biodiversity • Loss of mangroves, wetlands, seagrass, and other ecologically important ecosystems • Loss of mangroves » 1) loss of nursery grounds for coral reef fish, shellfish, other fish » changes in food web dynamics, ecosystem, biodiversity; 2) reduced sediment traps (mangrove roots) » greater nutrient and sediment inputs into coastal waters » eutrophication, HABs, coral and fish mortality » changes in food web dynamics, ecosystem, biodiversity; 3) loss of storm barrier » more storm runoff entering ocean » disturbed ecosystems	• From wetland loss, threatened food security and livelihood • From increased salinization, threatened water supplies • Increased flood storm damage (see Sea Level Rise below)
Climate Change: Sea Surface Temperature Increase	• Altered biochemical dynamics and ocean chemistry » altered distribution of primary and secondary producers; changes in food web dynamics, ecosystem, biodiversity • Disease / outbreaks of species (e.g. crown-of-thorns starfish, HABs) • Coral bleaching • Increasing frequency and intensity of extreme events (ENSO, tropical storms, storm surges)	• Threatened food security and livelihood • Increase in human health risks (biotoxins in fish from HABs) » paralytic shellfish poisoning; ciguatera; illnesses from other pathogens and bacteria • Loss of tourism, recreation, aesthetics • Increased storm damage (see Sea Level Rise below)
Pollution: Land-Based Chemicals	• Toxic bioaccumulation in fish » endangered fish reproduction, DNA » altered food web dynamics, ecosystem, biodiversity • Polluted beaches and coastal waters	• Human health risks (toxins in consumed fish/shellfish) » elevated levels of mercury and other metals » cancer risks; other illnesses • Threatened food security and livelihood • Loss of tourism, recreation, aesthetics
Overfishing and Exploitation: Artisanal/Recreational/ Subsistence Fishing	• Removal of highly fished top predators » altered recruitment, changes in food web dynamics, ecosystem, biodiversity	• Threatened food security and livelihood
Pollution: Oil Spills and Antifouling Chemicals	• Toxic oil waste» contamination of fish, plant, and other marine species » possible mass mortality, changes in food web dynamics, ecosystem, biodiversity • Antifouling chemicals » reproductive disruption in fish, plant, and other marine species » changes in food web dynamics, ecosystem, biodiversity • Pollution of fisheries, mariculture, coastal waters, beaches	• Threatened food security and livelihood, particularly relating to fishing • Human health risks • Possible interruption of coastal industries (ports, harbors, desalinization plants) • Loss of tourism, recreation, aesthetics
Climate Change: Sea Level Rise	• Likelihood of increasing frequency and intensity of extreme events (ENSO-like tropical storms, storm surges) » more runoff into coastal waters/ increased sedimentation, pollution and trash; destruction of wetland habitat by changing estuarine mixing, water quality, and carbon export, increasing wetland sediment supply and saltwater intrusion, and altering water chemistry and changes in food web dynamics, ecosystem, biodiversity • Stability of wetlands, mangroves, coral reefs threatened	• From increased storms, coastal erosion; intense flooding; threatened coastal development; changes in aquifer volume; compromised water quality/drinking water; loss of agriculture, artisanal fishing, food security, tourism » uninhabitable islands/threatened sovereignty of low-lying islands » population upheavals/ mass migrations • Human health risks (disease increases such as cholera due to flooding) • "Ecological refugees" from complete submersion of low-lying coastal areas/islands

THREAT	ENVIRONMENTAL IMPACTS	SOCIOECONOMIC IMPACTS
Pollution: Solid Waste Disposal	• Nutrients and toxic chemicals enter water (see Nutrient and Chemical above) • Marine debris » entangled mammals, sea turtles, seabirds » ingestion by mammals, seabirds, sea turtles » mortality, threaten endangered species » changes in food web dynamics, ecosystem, biodiversity • Polluted beaches and coastal waters	• See Nutrients and Land-Based Chemicals above • Impeded navigational safety/commerce • Loss of tourism, recreation, aesthetics
Pollution: Aquaculture: Wastewater	• Disease outbreaks (from chemicals, toxins, antibiotics, effluents, nutrient inputs) » fish and coral mortality; HABs » changes in food web dynamics, ecosystem, biodiversity • Polluted aquaculture farms	• Harvest failure, abandonment of farms, threatened food security and livelihood • Human health risks
Habitat Destruction: Destructive Fishing	• Removal of target and non-target marine species (including deep sea corals, coral reefs, sharks, turtles, birds) » altered recruitment, food web dynamics, ecosystem » changes in food web dynamics, ecosystem, biodiversity; further threats to endangered species • By-catch (see below)	• Threatened food security and livelihood
Habitat Destruction: Aquaculture: Coastal Modification	• Mangrove and seagrass destruction » disturbed nutrient cycling, reduced habitat for juvenile fish, reduced food production, reduced storm protection, reduced filtering of sediments and pollutants • See loss of mangroves and wetlands (above)	• Reduced tourism, recreation, aesthetics • Threatened food security and livelihood • Increased storm damage (see Sea Level Rise above)
Overfishing and Exploitation: By-catch and Discharge	• Mortality of target and non-target fish (including reproductively immature juveniles, marine mammals, sea turtles) » threatened endangered species; altered food web dynamics due to increased discards of food into ocean	• Threatened food security and livelihood

ies have been conducted to calculate the net benefits of coral reefs. In Hawai'i, they are estimated at USD $360 million a year, and the overall asset value of the state's potential reef area is estimated at nearly USD $10 billion (Cesar and van Beukering 2004). If the reefs are compromised, so too are these functions and services.

● Moderate Impact Threats

Habitat Destruction: Coastal Development and Land Reclamation

Coastal development and land reclamation have been documented in 35 countries or territories. As human populations continue to expand throughout the Pacific, the pressure to modify and develop the coastline for industry, tourism, infrastructure, agriculture, and aquaculture intensifies. (Aquaculture often requires the conversion of coastal areas, which is considered a threat. This section discusses mangrove loss, much of it resulting from aquaculture development; for more discussion on coastal modification as a result of the aquaculture industry, see page 25.) Of particular concern is the loss of wetlands, seagrass fields, and mangroves. Over the last 50 years, extensive losses of these valuable ecosystems have ranged anywhere from 5-80% in countries and territories surrounding the East Asian Seas, with the South East Pacific affected the most. For example, recent estimates indicate that by the early 1990s, Malaysia had lost 75% of its original mangrove cover (Burke, Kura et al. 2001).

Healthy mangrove stands provide key ecological and economic functions. First, they act as important nursery grounds for different species of fish (some coral reef fish as well as shellfish). They provide a source of food and refuge from predators to a variety of juvenile fishes. These essential juvenile habitats contribute to the sustainability of many commercial fisheries. Second, the mangroves' roots act as a sediment trap, filtering out harmful sediments and nutrient pollutants and keeping surrounding water clean, which is necessary for coral reef and seagrass health. Mangroves also act as significant biofilters of shrimp pond effluents (Paez-Osuna 2001). Third, mangroves act as an essential storm barrier, and prevent storm runoff from entering the ocean and further disturbing ecosystems.

Coastal modification produces great ecological and economic costs. By altering natural drainage patterns and increasing salinization, it can threaten water supplies. Physical modification also leaves areas exposed to erosion; hotels in Bali and Lombok, for example, spend an estimated USD $100,000 per year to mitigate beach erosion (Abdullah, Agustina et al. 2005). Coastal modification can also exacerbate flooding and storm damage — which, in turn, increases the discharge of pollutants and sediments into coastal waters and threaten marine species, their habitats, and biodiversity. Such habitat loss not only has serious implications for the species that depend on wetlands and mangroves (and, in turn, the potential to alter the entire food web), but also affects commercial activities like aquaculture and commercial fisheries. In the Gulf of Fonseca (shared by El Salvador, Honduras, and Nicaragua), 820,000 people depend directly on the gulf's marine/coastal resources, including mangroves, which serve as nursery and recruitment areas for important commercial fisheries. The destruction of large areas of mangrove forest, however, has resulted in lower incomes from fishing, reduced local food production, and extreme poverty in some communities (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). The estimated annual losses of mangrove deforestation in Thailand (about 30 square kilometers annually) range from USD $12,000 to USD $408,000 (Barbier, Strand et al. 2002).

Climate Change: Sea Surface Temperature Increase

Climate-induced sea surface temperature increases affect the entire Pacific Ocean and will continue to do so in the future, with potentially grave consequences. It has been documented in 36 countries or territories though more research has yet to be done. When combined with more localized stresses like overfishing, tourism, coastal development, and pollution, global climate change can negatively affect not only the ocean ecosystem, but the economic viability of islands as well. Warmer waters can create an environment in which certain species and pathogens may thrive and, as a result, produce more harmful algal blooms or disease. Many climate change models suggest that climate change will cause the average climate to produce events that resemble those caused by ENSO, which, in turn, would further increase sea surface temperatures.

Sea surface temperature increases can alter biochemical dynamics and ocean chemistry, which, in turn, can directly affect the physiology, behavior, growth, development, reproductive capacity, mortality, and distribution of primary and secondary producers (Karl, Bidigare et al. 2001). Sea ice associated phytoplankton blooms, for example, are part of what make the Bering Sea ecosystem so productive, and seasonal ice melt has associated blooms. However, the timing and extent of such blooms are critical issues of concern. During the last decade, the southeastern Bering Sea shelf underwent a warming of 3°C that was associated with a decrease of sea ice over the area. Melting sea ice produced sea ice-associated phytoplankton blooms in the southeastern part of the Bering Sea that critically affected the entire food web structure — from lower trophic level production and the timing of the spring phytoplankton blooms, to marine fisheries, to the northward advance of subarctic species and the northward retreat of arctic species (Stabeno, Bond et al. 2007). Sea warming in the Bering Sea thus alters the productivity, structure, and composition of the entire ecosystem (Brander 2007; Jin, Deal et al. 2007). The links between climate change and species fluctuations, however, are only starting to be understood. But what is clear is that sea warming is linked to the long-term viability of populations in the southeastern Bering Sea (Baduini, Hyrenbach et al. 2001). Sea warming and El Niño events (which also reduce productive foraging opportunities) have affected sperm whale conception (Whitehead 1997), reduced pinniped populations (Alava and Salazar 2006), and decreased sea lion breeding (Majluf 1998). Indeed, changes in sea ice thickness, snow depths, and the timing of break-up all influence pupping and foraging success for many ice-associated mammals (Hunt, Stabeno et al. 2002).

Because sea warming alters food web relationships, it by extension threatens fisheries (Karl, Bidigare et al. 2001). East Asia, South America, and small islands and developing states are particularly vulnerable to naturally occurring variations in sea temperature (Brander 2007). Off the coast of Peru and Chile, decadal-scale, natural variations occur as part of a larger regional phenomenon (i.e. the mid-1970s shift from a cool "anchovy regime" to a warmer "sardine regime," then back to a cooler one) (Chavez, Ryan et al. 2003). Like an El Niño, the warm periods change trophic relationships, exposing the Peruvian anchovy to adverse conditions. ENSO events may exacerbate this situation, though studies show that the strong 1972–1973 ENSO event did not cause the 1970s Peruvian anchovy crash (Alheit and Niquen 2004). When trophic relationships change so drastically, commercial and artisanal fishers find their industries, livelihoods, and food security threatened. El Niño events also threaten the shrimp industry in Ecuador (Cornejo 1999). Overall, however, much of ENSO's impact on the fisheries still remains unknown (Cornejo 2007/2008; Thatje, Heilmayer et al. 2008). Climate change effects will be exacerbated during warm periods and ameliorated during cooler periods.

Devastating coral bleaching events throughout the Pacific also result from sea surface warming. Mass coral bleaching and mortality have altered the world's coral reefs with increasing frequency since the late 1970s; bleaching events, which often cover thousands of square kilometers of coral reefs, are trig gered by small increases (+1–3 °C) in water temperature. Such increases are often seen during warm phase weather conditions (such as ENSO), but are increasing in size and magnitude (Hoegh-Guldberg 2004; Hoegh-Guldberg, Rosenberg et al. 2004). The link between increased greenhouse gases, climate change, and regional bleaching events, strongly associated with elevated sea surface temperatures during recurrent ENSO events, is widely accepted (Hoegh-Guldberg 1999). For example, Palau experienced an El Niño event, sea surface temperature increase, and severe coral bleaching event in 1997-98 (Bruno, Siddon et al. 2001). Around the main islands of Hawai'i, increased sea surface temperature resulted in severe coral reef bleaching in 1996 and 2002 (Jokiel and Brown 2004). Not only do these events kill coral and affect those species associated with it, but they also decrease local food supplies and affect important industries like tourism.

Pollution: Land-Based Chemicals

Land-based chemical pollution, identified in 32 countries or territories but understudied throughout parts of the Pacific, deposits heavy metals and persistent organic pollutants into the ocean. Mining tailings, land-based oil discharge, and waste all contribute to the problem. Not surprisingly, higher levels of chemical pollution are found in urban, densely populated areas, like the large cities of East Asia and Central America. Along with population growth, toxic industrial activities are expected to increase in the future (Glover and Smith 2003).

When chemicals accumulate through the food chain or pollute the sediment to toxic levels, they affect all parts of the marine ecosystem. Studies show that chemicals can endanger fishes' reproductive capacities and DNA. Abnormal levels of estrogen were found in flatfish at the Orange County Sanitation District discharge area, which have damaging effects on fish DNA (Rempel, Reyes et al. 2006). A study on fish DNA in Puget Sound revealed that environmental chemicals contribute to DNA changes in the gill (Malins, Stegeman et al. 2004). Such changes not only endanger the fish, but have great potential to alter the entire food web. Chemicals also penetrate high-trophic marine mammals such as orcas, which in British Columbia have shown very high concentrations of pesticides, industrial byproducts, and flame retardants. Kajiwara (2006) found high values of polybrominated diphenyl ethers (PBDEs), which are used as flame retardants, and organochlorines in Indo-Pacific dolphins off the coasts of Japan, Hong Kong, and the Philippines. These endocrine disruptors affect the top of the food web (Ross 2006).

Like nutrient pollution, chemical pollution jeopardizes human health. Heavy metals bioaccumulate through the food chain and then pose a risk to people who consume the toxic fish; such pollution is rampant across coastal areas. Chromium and silver concentrations in fish and invertebrate species in Mugu Lagoon, Malibu Lagoon, and Ballona Wetlands in Southern California have been shown to pose health hazards (Cohen, Hee et al. 2001). In Hong Kong, elevated mercury levels of children were correlated with the frequency of fish consumption (Ip, Wong et al. 2004). In general, DDTs and other synthetic chemical compounds in fish expose humans to potential cancer risks and other illnesses (Qiu, Guo et al. 2008). As agriculture, mining, and industrial activities intensify throughout parts of the Pacific Ocean, and new synthetic compounds are developed, chemical pollution has proceeded unregulated and unmonitored. Most of the impacts upon marine ecosystems and humans are unknown.

Overfishing and Exploitation: Artisanal/Recreational/Subsistence Fishing

Artisanal, recreational, and subsistence fishing is an important part of many coastal communities' economic health, but like commercial fishing, it can threaten both human and marine systems. In some instances, these types of fishing pose as severe a threat as commercial fishing to the ocean. Identified region-wide as a moderate threat and prevalent throughout most of the Pacific, it has been documented as a threat in 38 countries or territories.

Many coastal communities rely on artisanal/recreational/subsistence fishing for livelihood but engage in unsustainable use of their resources. In some parts of Central America, overfishing occurs mainly by artisanal fleets. In Palau, subsistence overfishing is a major stress to the coral reef fisheries (Maragos and Cook 1995). In American Samoa's artisanal, small-boat sector and subsistence sector, catch reconstruction (with large pelagic species removed) suggested a 79% decrease in catches between 1950 and 2002 (Zeller, Booth et al. 2007). In Costa Rica, trophy sizes of recreationally caught sailfish have declined at least 35% from their pre-exploitation trophy sizes (Ehrhardt and Fitchett 2006). Along the Pacific Coast of Guatemala and Honduras, shrimp trawlers and artisanal fleets have exploited the rose-spotted snapper to near depletion (Rodriguez and Antonio 2003). In the Philippines, the benthic areas of 28 nearshore, artisanal, coral reef fishing grounds showed an abiotic structure—one filled with rubble, sand/silt, and dead coral—dominating the fishing grounds (Marcus, Samoilys et al. 2007).

Overfishing has both ecological and socioeconomic impacts. The removal of highly-fished top predators leads to altered recruitment, which in turn can affect coral reef health, affect food web dynamics, and impair the ocean's biodiversity. Overfishing can endanger species and even lead to extinction. The human cost of overfishing is also great. Depleted fish stocks decrease food security and livelihood and create the need for alternate livelihoods. Many people in Southeast Asia, Central America, and the South Pacific islands depend on fishing on a daily basis, and if fishing were to disappear, so would their livelihoods. Tourism is also affected; impaired coral reefs, for example, affect popular recreational activities.

Pollution: Oil Spills and Antifouling Chemicals

Ocean-based pollution—in particular oil spills and antifouling chemicals (found in paint additives on ship and boat hulls, docks, fishnets, and buoys to discourage the growth of marine organisms such as barnacles), documented by the literature in 37 locations—is prevalent throughout the Pacific. Shipping and industrial activities contribute to oil pollution, especially in dense shipping pathways like Asia's Malacca and Lombok Straits (Chiu, Ho et al. 2006; Basheer, Tan et al. 2002). In Malaysia, the use of leaded petrol may be responsible for the high concentrations of zinc and lead found in coastal sediments off Juru in Penang and in the Johor Strait (Shazili, Yunus et al. 2006).

Oil spills have far-ranging impacts on the marine ecosystem. Even after the volatile compounds evaporate, oil remains floating on the surface of the water, disperses, and forms a thin, toxic film that can cover large areas of water. Such oil can suffocate phytoplankton and plants, thus affecting the fish and other marine life that depend on these organisms. Oil can also suffocate birds and mammals, as well as bioaccumulate in clams, mussels, and oysters. It also has chronic effects on the growth and hatching rate of marine organisms (Law and Hii 2006). Overall, spills can affect multiple levels of the food web, thereby affecting the entire ecosystem.

Oil spills also have socioeconomic impacts. Reduced fish populations can impair commercial, artisanal, subsistence, and recreational fishing; oil spills can also pollute fisheries. Yet, as the 2007 "Jessica" cargo oil spill in the Galapagos illustrates, some oil spills have widespread but only minor long-term impacts on artisanal fisheries; natural ENSO events can have much more catastrophic consequences (Banks 2003; Born, Espinoza et al. 2003). But the pollution of coastal waters can reduce aesthetics, recreation, and tourism. Oil spills and their cleanups can also disrupt the normal operations of other coastal industries, such as ports, harbors, and desalination plants. Finally, oil spills can pose health risks for humans who consume tainted seafood.

Antifouling chemicals, found in paint additives on ship and boat hulls, docks, fishnets, and buoys to discourage the growth of marine organisms such as barnacles, bacteria, and algae, also endanger marine life. One of the most toxic chemicals used is TBT, which is moderately toxic to mammals and lethal to crustaceans and some fish. It can cause endocrine, reproductive, and immunological disruption, thereby causing fish mortality. Large-scale mortalities can alter food web dynamics and decrease biodiversity. Reductions in marine life, in turn, can threaten fishing and human livelihood. Antifouling chemical pollution affects other human activities as well. The seas surrounding Singapore, for example, are principally used by the shipping industry, but they are increasingly being used for desalination for drinking water supplies and intensive aquaculture of food fish. Stringent environmental pollution standards are in place for industrial effluents, but no legislation exists for pollution from antifouling paints in Singapore (Basheer, Tan et al. 2002).

Climate Change: Sea Level Rise

Sea level rise is a growing reality—and threat—throughout the Pacific. Although documented in only 30 locations, it is a growing—albeit vastly understudied—threat. As temperatures rise with global climate change, oceans absorb more heat from the atmosphere, causing them to expand and rise. Globally, eustatic sea level increased 10 to 20 centimeters during the 20th century. However, local and regional lea levels are also influenced by tectonic factors, including rebound from glacial melting, sinking from sediment loading, and deformation of plates. Therefore, the rate of sea level change around the Pacific can vary greatly. Yet due largely to melting glaciers and ice sheets coupled with thermal expansion of warming seawater, conservative estimates project the ocean to rise another 18 to 59 centimeters by 2100, although new information is emerging (Intergovernmental Panel on Climate Change (IPCC) 2007). In some parts of the Pacific, however, sea level rise has not been well documented nor future rise modeled, nor have impacts on the environment and society been estimated.

Sea level rise (along with elevated sea surface temperatures, also documented as a serious and growing moderate impact threat), combined with poor coastal development and planning, increases the vulnerability of coastal communities to storm damage. If scientific predictions that warmer seas will lead to more frequent and intense storms are correct, the situation could get worse. Sea level rise could have many negative ecological impacts and create the potential for more frequent and intense storms and typhoons; both the United States and Canada have documented increases in tropical storms, coastal erosion, intense flooding, and sea level rise along the Pacific Coast

(United States Climate Change Science Program (CCSP) 2008). These storms can devastate coastal areas, particularly atolls and low-lying coastal regions with wetlands, seagrass beds, mangroves, and shallow reefs, thereby impairing many ecosystems (Hoegh-Guldberg, Hoegh-Guldberg et al. 2000). Sea level rise can alter or destroy wetland habitat by changing estuarine mixing, water quality, and carbon export; increasing wetland sediment supply and saltwater intrusion; and altering water chemistry and habitat diversity, abundance, and distribution of marine species (Grossman 2008). High latitude coasts are especially vulnerable to these impacts.

Sea level rise also poses very serious socioeconomic threats. Increased storm surges can flood developed coastlines, decrease water quality as more nonpoint source pollutants enter the water, and even threaten entire island states with total submersion. Perhaps the greatest threat is to low-lying islands such as Kiribati, Tokelau, Tuvalu, and other coral-rubble atolls with land rising rarely more than a few meters above present sea level. An 80-centimeter sea level rise could inundate two-thirds of both Kiribati and the Marshall Islands (Gaffin and Oneill 1997). Tonga, the Federated States of Micronesia, and the Cook Islands are also vulnerable to permanent inundation. Associated impacts include changes in aquifer volume and water quality, with increased saline intrusion that renders water undrinkable; and loss of agriculture and vegetation, artisanal fishing, food security, and income resulting from reduced tourism (Roy and Connell 1991; South, Skelton et al. 2004; Nurse and Moore 2007). All of these impacts limit the long-term ability of people to inhabit many of these low-lying island states. Sea level rise, may, in the end, produce major population upheavals, inter-island migrations (accompanied by social instability), and greater pressure on those countries and territories that will need to accommodate these refugees (Gaffin and Oneill 1997; Barnett and Adger 2003; Hunt 2003).

Other Pacific regions, though not threatened by total submersion, also face sea level rise threats. In British Columbia, sea level rise affects coastal infrastructure, such as highways, sewer systems, shipping terminals, and, as in island states, drinking water supplies. A one meter rise in sea level would inundate more than 4,600 hectares of farmland and more than 15,000 hectares of industrial and residential urban areas just in British Columbia (Yin 2001). Sea level rise also presents an environmental/social justice issue; in Canada, many remote coastal communities and First Nations' heritage sites remain vulnerable to erosion and storm-surge flooding associated with sea level rise (Natural Resources Canada 2007).

Pollution: Solid Waste Disposal

The Pacific Ocean suffers from different kinds of marine debris, garbage, and solid waste disposal. Though it is greatly understudied throughout the Pacific, solid waste disposal has been documented as a threat in 22 countries or territories. Solid waste on small Pacific islands is challenging to manage, and much of it ends up in the sea. In the South East Pacific, for example, of the 2.3 million tons of solid waste produced daily, between 0.5 and 1% is discharged on beaches and some of it directly into oceans (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006).

Solid waste deposits nutrients and toxic chemicals into coastal waters. (The impacts of land-based nutrient and chemical pollution are described in more depth above.) Nutrient inputs can cause eutrophication, which increases primary productivity and algal blooms (including HABs), oxygen depletion, and reductions in water quality, fish, coral, and other marine populations. These changes, in turn, alter food web dynamics and the entire ecosystem. Nutrient pollution can also lead to disease/outbreaks, which similarly impair ecosystem health. Chemical pollution deposits toxic chemicals into coastal waters, which can bioaccumulate in fish, endanger fish reproduction and public health, and alter food web dynamics, ecosystem functions, and biodiversity.

Plastics pose a particularly severe threat; it is estimated that 90% of floating debris in the ocean is plastic. Plastic is so durable that it can take hundreds of years for it to break down at sea, and some kinds never truly biodegrade. A section of the North Pacific Ocean (the North Pacific Gyre) is home to the world's largest floating "island" of trash, known as the "Great Pacific Garbage Patch," "Pacific Trash Vortex," or "Eastern Garbage Patch." The polluted area is estimated to cover eight million square kilometers—larger than the entire United States. A study shows that an average of 334,271 pieces of plastic pollute each square mile in the North Pacific Gyre (Moore, Moore et al. 2001). Other areas of high concern include the South East Pacific off the coast of Chile, where almost 90% of the floating marine debris is plastic (Thiel, Hinojosa et al. 2003). Plastics are a very serious form of marine debris pollution because marine organisms in open ocean or nearshore marine habitats can become entangled by plastics or ingest disintegrated or whole pieces of it, thereby further threatening endangered species (Henderson 2001; Boland and Donohue 2003). Floating debris also absorbs persistent organic pollutants like PCBs, which then bioaccumulate in fish, marine mammals, and seabirds and disrupt ocean food web dynamics (Moore, Lattin et al. undated) (Derraik 2002; Rios, Moore et al. 2007).

Solid waste disposal affects human systems as well. It can impede navigational safety and commerce and pollute beaches, which can lead to a loss of recreation, tourism, aesthetic value, and threatened livelihood. Finally, solid waste disposal poses human health risks: the toxins consumed in polluted fish/shellfish often produce life-threatening illnesses.

Pollution and Habitat Destruction: Aquaculture[4]: Wastewater and Coastal Modification

Aquaculture in and of itself is not a severe threat to the Pacific region; indeed, it can bring many socioeconomic benefits. The wastewater and coastal modification caused by aquaculture, however, have emerged as large threats in the Pacific. Wastewater pollution has been identified in 26 countries or territories, while coastal modification from aquaculture has been documented in 24.

Increasingly more countries and territories are engaging in aquaculture operations around the Pacific. In the last two decades, Vietnam has experienced a rapid growth in the aquaculture industry; in 2004, it contributed more than 60% of the USD $2.397 billion in export turnover earned from the fisheries sector. In 2004, the production of shrimp reached 290,000 tons, representing 56.8% of the total for coastal aquaculture production (Halfyard, Akester et al. 2004; Food and Agriculture Organization of the United Nations (FAO) 2006-2008). In the 1980s, shrimp farming in the Mekong Delta increased 3,500% (de Graaf and Xuan 1999). In China, aquaculture represents the fastest growing sector of total fisheries production; the country now boasts the highest mariculture production in the world, especially of kelp, mollusks, shrimp, and finfish (Yu 1991; Biao and Yu 2007). In Central America, aquaculture provides employment for about half of the economically active population. Shrimp farming in particular is expanding throughout the region, with 70% of Central America's total production coming from Honduras and Panama (United Nations Environment Programme (UNEP) 2006).

One threat resulting from aquaculture is pollution caused by wastewater. The wastewater produced by the industry can be severe enough to cause disease outbreaks, massive fish and coral mortality, and harvest failure—thus threatening food security and livelihood in communities where aquaculture is a primary economic activity. Intensive shrimp farming in particular—prevalent throughout much of Central America and Southeast Asia—discharges large quantities of effluents (Flaherty and Karnjanakesorn 1995). In the Philippines, much of the wastewater is generated by imported feeds that, when kept in humid conditions or past its shelf life, contain toxins that cause high shrimp mortality (Kongkeo 1997). Antibiotics used to treat or prevent diseases common in water and mud in shrimp ponds in mangrove areas in southern Vietnam by farmed species have also contaminated local waters (Le and Munekage 2004). In Indonesia, by 2001, operators abandoned about 70% of shrimp farms because of the high concentrations of chemicals in the waters (Abdullah, Agustina et al. 2005). The increased nutrient inputs from aquaculture wastewater can also generate HABs. In China, the bloom that occurred in 2000 in the Yangtze River estuary and the coastal waters of the Zhejiang covered more than 7,000 square kilometers and threatened the region's seawater aquaculture; it led to a loss for the Zhoushan Islands of about USD $3 million (Qu, Xu et al. 2005).

A second threat resulting from aquaculture is habitat destruction caused by coastal modification. The conversion of wetlands and mangrove forests (discussed on page 25) into fish farms is increasing rapidly, and the loss of such ecosystems has major impacts on both marine and human systems. Coastal modification can lead to disturbed nutrient cycling, as well as reduced habitat for juvenile fish, food production, storm protection, and filtering of sediments and pollutants. Mangrove loss is a particularly serious impact. In Indonesia, intensive tiger prawn farming has led to the conversion and clearance of about half of the country's mangrove forests. Such loss reduces nursery grounds for coral reef fish, shellfish, and other fish, and changes food web dynamics. When mangroves are destroyed, their roots no longer act as sediment traps, thereby leading to greater nutrient and sediment discharge into coastal waters. Mangroves also act as important storm barriers and prevent storm runoff from entering the ocean and further disturbing ecosystems. Once mangroves disappear, eutrophication, HABs, coral and fish mortality, and changes in food web dynamics can ensue. Habitat modification poses a large problem not only in the tropics, but also in temperate regions as well, especially in the North East and North West Pacific (Kennish 2001; Zuo, Wan et al. 2004).

The socioeconomic impacts of coastal modification due to aquaculture are no less severe. Mangrove deforestation (one-third of the shrimp ponds are built in mangrove areas) is a potential cause for the scarcity of post-larval shrimp inputs to shrimp mariculture, which, compounded with other factors, ultimately decreases economic efficiency. This can lead to abandonment of the farms, economic loss, and loss of liveli

4 Small and large-scale aquaculture can be a solution to the exploitation of marine resources and overfishing by creating alternative livelihoods for fishers and producing additional food sources, thus providing food security. However, as discussed throughout this document, if not done in a sustainable manner, aquaculture can be a threat to both environment and society.

hood (Parks and and Bonifaz 1995; Borbor-Cordova 1999). In Pacific Colombia, shrimp farms (along with logging, construction, and wastewater contamination) have led to the destruction of mangrove forests, upon which animal and human populations depend (United Nations Environment Programme (UNEP) 2006). Overall, the conversion of mangrove ecosystems to shrimp ponds may sacrifice long-term productivity for short-term profit (Parks and Bonifaz 1995).

Aquaculture may also affect native species by introducing pathogens and invasive species, which can harm or cause mass mortalities among farmed and native species and lead to abrupt production decline (Amos, Thomas et al. 2001; Camus 2005; Castilla, Uribe et al. 2005). Once aquaculture farms are no longer productive, they are abandoned—leaving destroyed ecosystems, loss of fisheries livelihoods, food insecurity, and displaced communities in their wake (Primavera 2006).

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Habitat Destruction: Destructive Fishing

Commercial and artisanal fleets, as well as recreational users, often use destructive fishing techniques throughout the Pacific. The literature has identified 22 locations where destructive fishing is a threat. However, the use of such practices is under-reported, with large gaps in the research. Nonetheless, destructive fishing seems to be increasing (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006 ; Hines, Adulyanukosol et al. 2008). Ecuador's shrimp trawling fisheries, for example, operate two-thirds of the month, 10 months of the year (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). Fishing gear, from bottom trawls (large nets for catching groundfish and other commercially targeted species) to gillnets (nets for snaring fish) to longlines (baited hooks on kilometers-long lines), while designed to catch the most fish possible, can be highly destructive to other species, especially when operated continually. They can also physically destroy entire habitats. Other destructive methods include cyanide fishing, which, though outlawed, is still used in reef crevices where fish hide, and blast fishing, which catches food fish quickly but devastates fish and coral reefs.

Destructive fishing, which indiscriminately kills large numbers of fish and other nearby marine life, has many negative impacts on the marine ecosystem. By removing target and non-target fish, crustaceans, and other marine organisms (including deep sea corals, coral reefs, sharks, turtles, and birds as by-catch, discussed in further detail below), destructive fishing leads to mortality, altered recruitment, and changes in food web dynamics. A single blast fishing event, for example, can destroy thousands of years of coral growth. In some regions of Indonesia, fishing with explosives has reduced coral cover by as much as 80% (Cesar, Lundin et al. 1997). Such changes further threaten endangered species and biodiversity in general.

Depleted fish stocks, in turn, reduce food security and livelihood. Often, artisanal fishers employ destructive fishing methods to compete with larger fishers in a declining, exploited market (Cesar, Lundin et al. 1997). But research in Indonesia on the benefits of blast fishing to individual fishing households and Indonesian society as a whole showed it to be unsustainable and costly (Pet-Soede, Cesar et al. 1999). Destructive fishing can also be a political issue: in Russian waters, driftnet fishing, the most destructive pelagic fishing method, is a transboundary concern. Not only does it have a major impact on targeted fish populations and non-target species caught as by-catch, but, because Russia sells the right to fish inside the Russian EEZ, it has also incited international controversy for the indiscriminate destruction of marine life and poaching (Greenpeace 2000).

Overfishing and Exploitation: By-catch and Discharge

As mentioned above, fishing gear produces excessive by-catch—unwanted and unintentional catch—often discarded or tossed out dead or dying. The discarded animals may have no market value, are not taken to shore because there is no room on the boat, or are reproductively immature species. Dolphins, sea turtles, seals, whales, and seabirds can get caught by accident in gear and drown. By-catch has been identified as a threat in only 23 countries or territories but it is prevalent throughout the entire Pacific Ocean. However, lack of information and incomplete reporting on by-catch renders its exact impacts unquantifiable (Baker, Lukoschek et al. 2006). One study estimated that in 1991, Ecuador's trawling catch produced 75% discards (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006).

In New Zealand, trawling is the predominant anthropogenic impact on sea lions, through mortality as a result of by-catch. Despite protection and fisheries management measures, the species has shown a 30% decline in pup production over the last decade (Chilvers 2007). In Costa Rica, sailfish is often caught as by-catch in expanding coastal artisanal longline fisheries; overall, regional sailfish abundance is 80% below its 1960s levels. In Pacific Colombia, shrimp trawling nets and gillnets caught more than 8,000 marine turtles, including the olive ridley and black turtles, in 1998 (Ministerio del Medio Ambiente (MMA) 2002; United Nations Environment Programme (UNEP) 2006).

Similarly, in Mexico, more than 1,000 endangered North Pacific loggerhead turtles are casualties of by-catch each year (Peckham, Diaz et al. 2007). Along the Ecuadorian coast, gillnets have led to entanglements with and incidental catches and strandings of Pacific humpback whales (Alava 2005). In 2001 in Malaysia, at least 565,000 seahorses were caught as trawl by-catch and traded as traditional Chinese medicines, mostly overseas (Johnston 2007). Australia is a major supplier of dried pipehorses, which are caught via trawl by-catch (Martin-Smith and Vincent 2006).

By-catch incurs both ecological and human impacts. The mortality of target and non-target fish from the ocean, as well as the increased discards of fish that enter the ocean as food, can alter food web dynamics. By-catch can also further threaten endangered species. Depleted fish stocks, in turn, reduce food security and livelihood for those that depend on the ocean's resources.

Discharge occurs when many of the less commercially valuable "trash" fish are discarded back into the ocean. In Thailand, about 35% of marine production is trash fish, most of it used in fish meal production; otter board trawlers contribute about 80% of the total trash fish production (Ehrhardt and Fitchett 2006).

Research Gaps

Throughout the Pacific there is a scarcity of relevant applied natural and especially social science research to inform ocean and coastal policy and management. Throughout this literature review and these tables we highlight research gaps, where needs and opportunities exist to target certain issues to improve understanding of the threat and impact on both the environment and society. We hope by highlighting gaps the scientific community will be more likely to conduct applied research that responds to policy and management needs and questions. This information can then be shared with policy makers and managers to help make better informed coastal and ocean decisions. Our research reveals the following general research gaps:

Pollution

- **Land-Based Chemicals:** Chemical pollutants are typically not monitored, and few studies link water quality and, in particular, chemical discharges with the impacts on the marine environment. Because more than 70,000 synthetic compounds are discharged into the ocean (Burke, Kura et al. 2001), it is difficult to ascertain present and future impacts to both the environment and society.
- **Fishing Lines/Nets, Oil Spills and Antifouling Chemicals, Ocean Waste, and Toxic Dumping:** A few studies have documented fishing line and net debris impacts on the marine environment. Many studies on oil spills and hydrocarbons have been conducted in areas where spills occurred near or in large harbors. Most of these studies discuss impacts to sediment and water quality, but do not link the impact to the marine ecosystem. Finally, toxic dumping is not well documented, especially where it is illegal.
- **Radionuclides:** Radionuclide studies have been conducted in many locations, but not in others. Additionally, socioeconomic impacts have not been documented.
- **Solid Waste Disposal:** There is a need to do more research on solid waste disposal and removal, an increasing problem on islands where the threat exists. In Hawai'i, solid waste and marine debris are well documented, but in other locations they are not.
- **Other Threats:** Other threats listed in this category have impacts that are poorly documented. Offshore mining, for instance, could increase significantly in the future (Glover and Smith 2003). Additionally, only a small minority of countries and territories has documented thermal pollution.

Habitat Destruction

- **Aquaculture: Coastal Modification:** While many countries and territories engage in intensive aquaculture production, there is scant documentation of coastal modification resulting from aquaculture. Many studies show the environmental impact of aquaculture wastewater, but few have been conducted documenting the cost to society.
- **Coastal Development/Land Reclamation:** The biggest gap in this threat category is the lack of coastal habitat mapping in many parts of the Pacific. Without it, scientists cannot observe changes over time or quantify habitat changes and impacts.
- **Land-Based Sedimentation:** While nutrients and eutrophication are well documented in the Pacific Ocean, sedimentation is not; research gaps exist in Guatemala and Honduras, for example.
- **Typhoons/Cyclones/Hurricanes/Storm Surges:** Some countries and territories have conducted studies examining impacts of tsunamis and typhoons, for example, both on the coastal and ocean environment and society, but few in the most vulnerable islands.

Overfishing and Exploitation

Fisheries statistics are incomplete; only limited studies accurately document by-catch and illegal and destructive fishing activities. More studies throughout the Pacific are also needed to document the fishing effort and value from subsistence, artisanal, and recreational fishing.

Climate Change

While sea surface temperature is well documented throughout the Pacific Ocean, the socioeconomic impacts are not. Many Pacific countries and territories also lack information on sea level rise. For example, many small islands and developing states have only just begun to monitor and analyze sea level data. Because few have documented potential impacts and costs to society, the development of adaptation and mitigation strategies is extremely challenging. Ocean acidification is an emerging issue, and although a few studies have been conducted off the coast of North America and experiments been done on coral reefs, scientists do not know the extent of ocean acidification's impact on marine and human systems. Scientists also need to examine how climate change will affect and/or compound other threats, such as land-based pollution, invasive species, etc., and magnify their impacts. Range shifts related to climate change are also understudied. While scant research has been conducted on this topic, historic and more recent evidence suggests that marine communities, in response to climate change, exhibit geographical range shifts that, in some instances, may lead to significant morphological evolution (Hellberg, Balch et al. 2001; Parmesan and Yohe 2003).

Other Critical Gaps

- Both biodiversity monitoring programs and water quality monitoring programs are inconsistent and not standardized across the Pacific.
- Many studies identify threats, but do not examine the impact on the environment, or compare or prioritize the threat relative to another threat.
- Socioeconomic research and data are minimal. However, such information is increasingly important in order to connect the threat to the impact on the environment and society. There is limited socioeconomic impacts data on fisheries, marine protected areas, HABs, climate change, and pollution, for example. A few, but not many, places have documented ecosystem services and the value of such systems.
- Monitoring and analyzing multiple threats is extremely challenging. However, understanding threats in relation to each other is crucial in order to create cause-and-effect relationships between threats and impacts, and properly regulate those threats.

A Summary of Pacific Ocean Solutions

This document presents potential and available solutions to Pacific Ocean threats, based on the following principles: Maintaining ecosystem health and sustainability should be as fundamental a goal as economic development; New technologies, innovative market mechanisms, and financial tools that promote adoption of sustainable practices can empower local communities, help maintain the cultural richness of the Pacific Ocean countries and territories, and reduce the human footprint on the Pacific; Climate change mitigation is a global task, and yet a united Pacific can be instrumental in promoting frank global dialogue about establishing and achieving mitigation targets; In addition to mitigation, each region within the Pacific must adopt sustainable adaptation strategies for ecosystems and human communities in the face of climate change; Effective and enduring solutions require capacity-building within the Pacific Ocean Community and integrated problem solving.

General solutions identified in the literature, and presented in this synthesis include:

Ecosystem-Based Management inclusive of Integrated Coastal and Ocean Zone Management (ICOZM)

An ecosystem-based management (EBM) approach to a location considers multiple external influences, values ecosystem services, integrates natural and social science into decision-making, is adaptive, identifies and strives to balance diverse environmental and socioeconomic objectives, and makes tradeoffs transparent. Pilots for EBM are being tested throughout the Pacific, and scientists have posited EBM as one solution to the threats facing the region as a whole. Both integrated coastal zone management (ICZM) and ocean zoning can be used as EBM frameworks that address the ecological and human complexity of interconnected systems.

Many coastal and ocean activities conflict with each other and endanger the marine and human populations that depend on the ocean. For example, many citizens' livelihoods depend on the same resources, leading to more competition for scarce resources, unsustainable management practices, and constraints on coastal and marine spatial planning. ICZM and ocean zoning are two management frameworks that, in the past, have been considered as separate concepts. Both attempt, on different scales, to divide up geographic areas (including, in the case of ocean zoning, entire bodies of water) into districts in which different activities are permitted and clearly defined—from "no-take" zones and marine protected areas (MPAs) to multiple use zones that permit multiple oil and gas exploration/development, fisheries, aquaculture, tourism, recreation, maritime transportation and ports, chemical industries, and mining, among others.

It is useful here, however, to consider ICZM and ocean zoning together as "integrated coastal and ocean zone management"

(ICOZM), since the holistic management of the coastal and ocean systems is essential to alleviating threats to these systems. ICOZM is an integrated, adaptive approach for coastal management that addresses all aspects of the coastal and ocean zone, including land–coastal interactions, climate change, geographical and political boundaries, in an effort to achieve long-term sustainable use and reduce conflicts. It requires the careful balancing of a wide range of ecological, social, cultural, governance, and economic concerns, and has been successfully applied in parts of the Pacific Ocean as a solution.

Many Pacific countries and territories have initiated or implemented variations of the ICOZM management concept. New Zealand's Ocean Policy (2000) covers the country's entire EEZ up to 322 nautical kilometers offshore. Australia has also successfully implemented ocean zoning at the Great Barrier Reef. In China, between 1989 and 1995, 3,663 marine zones were divided into development and utilization zones, control and protection zones, nature preservation zones, special function zones, and reserved zones. Further sectoral conflicts involving coral and sand mining, aquaculture, fisheries, coastal construction, offshore oil drilling, and environmental projection produced The China Ocean Agenda 21 (1996), which aims to develop a sustainable marine economy while enhancing the role of a healthy, productive coastal marine environment. In Mexico, an environmental legal framework based on the Ley General del Equilibrio Ecologico y la Proteccion al Ambiente (LGEEPA) identifies ICZM as an important strategy that considers both ecosystems and socioeconomic issues (Rivera-Arriaga and Villalobos 2001). Throughout the Gulf of California ecoregion, where threats resulting from shrimp aquaculture (such as coastal modification, wastewater, etc.) have caused serious harm to the coastal and marine ecosystem, ICZM—together with an effective regulatory program—offers a solution for sustainability (Paez-Osuna, Gracia et al. 2003). Despite these examples of progress, however, comprehensive coastal management in the Pacific remains a daunting challenge.

Regional Governance Agreements and Approaches

Because the waters of the Pacific are transboundary in nature (many fish stocks and pelagic migrate beyond the jurisdiction of any one country or territory, for example), regional cooperation and policy structures are necessary for sustainable use and management of the ocean resources in EEZs and in the high seas. Such cooperation can effectively protect the marine ecosystem and sidestep conflicts that could further deteriorate ecological and socioeconomic conditions. Overall, however, international and regional institutions remain weak; the efforts of the public, NGOs, national governments, international institutions, and transnational scientific networks in establishing regional environmental governance must be strengthened (Haas 2000).

Some regional progress has been made. In Asia, regional initiatives such as the Asia Pacific Economic Cooperation (APEC) Fisheries and Marine Resources Working Group and the Association of Southeast Asian Nations (ASEAN) exemplify good cooperation and partnership (Glover and Earle 2004). They both fund projects in the region supporting marine conservation, and have adopted criteria to ensure that national action is coordinated across the regions, particularly in shared waters. Some of the countries in the East Asian Seas, such as Indonesia, also participate in international treaties and regulations (UN Convention on the Law of the Sea, International Convention on the Protection of Pollution from Ships, UN Convention on Conservation on Biological Diversity, Ramsar Wetlands Convention, etc.). Furthermore, the East Asian Seas Action Plan (Indonesia, Malaysia, Philippines, Singapore, and Thailand) is an initiative for the protection and sustainable development of the marine and coastal areas of the region. However, implementation is slow, with only modest progress to date (Gomez 1988). In Central America, attempts to forge regional agreements include the Central American Ecological Summit on Sustainable Development (1994) and the Convention for Cooperation in the Protection and Sustainable Development of the Marine and Coastal Environment of the North East Pacific (2002). In Melanesia, Micronesia, and Polynesia, the Pacific Islands Forum in 2002 endorsed the Pacific Islands Regional Ocean Policy, which envisions a healthy ocean that sustains the livelihoods of Pacific Islanders (Glover and Earle 2004). Still, all Pacific Island countries and territories need to develop laws and regulations necessary for their compliance with global conventions and agreements to which they are signatories (South, Skelton et al. 2004).

Fishing management (below) is one pressing issue that regional agreements could help address; studies have identified the importance of regional economic intergovernmental institutions and agreements, such as APEC and NAFTA, in protecting marine resource like fisheries (Cid 2004).

Regulation and Enforcement

Policy mechanisms, regulations, and enforcement are crucial aspects of marine conservation efforts in the Pacific. Throughout much of the region, regulatory frameworks are weak, uncoordinated, conflicting, or nonexistent. Some, however, serve as exemplary approaches. In the United States, the Washington (State) Department of Fish and Wildlife and the Native American Treaty Tribes of Washington are responsible for the management of wild and cultured salmon, including disease prevention and control; the Department of Fish and Wildlife also regulates commercial aquaculture (Amos, Thomas et al. 2001). In Mexico, regulatory agencies have achieved some success in controlling large-volume industrial polluters whose wastes flow into federal waterways. Implementation, however, remains a problem. Korea has started to develop frameworks for transitioning its fisheries to more sustainable practices; it has long operated a conventional fishery management regime (CFMR), which includes gear restrictions, closed seas and areas, and limited entry. However, social problems and post-harvest practices have not yet been adequately addressed (Park and Ryu 1999). In China, a recognized need also exists to create national development strategies and legal frameworks to protect the marine environment and economy (Zhang, Dong et al. 2004).

The regulation/enforcement of marine resources is intricately tied not only to local and national capacity and policy, but also to the signing and enforcement of regional agreements and policies (below).

Fisheries Management

Although in the 1990s a number of international fisheries instruments provided an impetus for countries and territories to strengthen their fisheries management, the growth of aquaculture and fisheries sectors in many regions, including the South East Pacific, has outpaced regional agreements and enforcement designed for aquaculture and fishing. While individual countries and territories implement measures aimed at reducing fishing impacts (e.g. Ecuador's annual closed seasons for shrimp trawling, and Peru's closed seasons for anchovy and other fish), overall, a lack of regional governance exists (United Nations Environment Programme (UNEP) 2006). Rapid development of certain commercial fisheries, such as the Eastern Pacific tuna industry, reveals the importance of better management policies and an international management regime (Barrett 1980; De Young 2007). Regional management plans may also help alleviate the socioeconomic effects of ENSO events (Thatje, Heilmayer et al. 2008). Enforcing regulations for illegal and destructive fishing is essential. Along the West Coast of the United States, bottom trawling is prohibited in certain areas. Changing technology and equipment to limit by-catch have successfully decreased the number of species being harmed by 99%; for example, turtle excluder devices (TEDS) are used in the United States, and the U.S. State Department has worked with 15 other countries or territories that import shrimp to use TEDs (Brewer, Heales et al. 2006).

Recently, some regions have been moving away from single species management in order to create a more sustainable market-based solution for fisheries. The move toward an ecosystem-based approach to management is geographically specified, adaptive, takes account of ecosystem knowledge, considers multiple external influences, manages issues and resources together, and strives to balance diverse social and economic objectives. Creating market-based incentives, like individual transferable quotas (ITQs), is an important tool for fisheries and EBM. Some countries and territories have already done this. In 1997, British Columbia moved from trip limits and turned to ITQs for multispecies fisheries. Total catches remained stable, and economic efficiency increased (Branch, Hilborn et al. 2006). Stock-specific estimates are used for delegating ITQs in chinook salmon (Winther and Beacham 2006). British Columbia has also instituted area licensing for fishers who wanted to participate in more than one area fishery. A license retirement program was also initiated to reduce the commercial fishing fleet by 50% (Winther and Beacham 2006). In the United States, Alaska offers an example of successful EBM (Holland and Schnier 2006). Off the coast, all groundfish stocks are considered healthy, while providing sustained yields of about two million tons annually. Management actions also minimize potential impacts of fishing on seafloor habitat, marine mammals, and seabirds (Witherell, Pautzke et al. 2000).

Integrating Climate Change Adaptation and Mitigation into Coastal and Ocean Policy, Planning, and Management

With the growing threat of global climate change, adaptation is a key response strategy to minimize potential impacts of climate change and reduce adverse effects on human and ecological systems. Adaptation strategies need to be integrated into coastal and ocean policy, planning, and management frameworks. The UN Framework Convention on Climate Change's National Adaptation Program for Action (NAPAs) provides a process for least-developed countries and territories with limited capacity—Cambodia, Kiribati, Samoa, Solomon Islands, Tuvalu, and Vanuatu are among the 39 countries or territories worldwide—to respond immediately to the adverse impacts of climate change. NAPA works at the grassroots level to identify priority activities for these communities, though most small island Pacific countries and territories do not have NAPAs and NAPAs focus on just a few sectors (United Nations Framework Convention on Climate Change (UNFCCC) 2008). Various governments and intergovernmental parties have taken action to develop strategies designed to mitigate climate change's impacts. In 1987, the UNEP South Pacific Task Team evaluated the impacts of and solutions to climate change on Pacific island states.

The Secretariat of the Pacific Regional Environment Program's (SPREP) Pacific Islands Climate Change Assistance Programme was implemented between 1997 and 2000 to assist 10 Pacific island countries and territories with their reporting, training, and capacity-building responsibilities; it had partial success (South, Skelton et al. 2004). SPREP[5] has also facilitated the Framework for Action on Climate Change 2006-2015, endorsed by leaders, which establishes a set of priorities for action on climate change at the local, national, regional, and international levels. Adaptation focuses on multi-stakeholder engagement, risk management, and improving safe secure livelihoods, with a particular focus on the most vulnerable areas and on integration into national strategies. Other adaptation strategies must be built into fisheries, aquaculture, and other marine-based industries. Managers are a key part of such strategies. With respect to coral reef systems, for example, coastal resource policy makers and managers can work to reduce local stressors (by decreasing land-based coastal pollution, overexploitation of herbivores, etc.). Their activities can then strengthen the reefs and help them recover from major adversities like climate change and ocean acidification (Hoegh-Guldberg, Mumby et al. 2007).

Alternative Livelihoods

Acute poverty exists throughout much of the Pacific region, including Central and South America, Asia, and the developing island countries and territories. The daily needs of the people who depend on marine resources for subsistence often conflict with the need to protect these resources. In order to diminish the impact of commercial fishing, for example, there could potentially be a focus on reducing fishing efforts and increasing alternative livelihoods for fishers. Reducing fishing requires changing equipment to more sustainable methods and could result in less effort for higher value. In China—representing 31% of the world's fishers and fish farmers—policy tools aimed at reducing overfishing include scrapping vessels and training redundant fishers in fish farming. The number of people engaged in capture fisheries declined by 13% between 2001 and 2004; by 2007, many fishers had been transferred to other jobs (Food and Agriculture Organization of the United Nations (FAO) 2006). Other countries with significant numbers of fishers and fish farmers include Indonesia and Vietnam. Yet while the number of people in developing countries and territories employed in fisheries and aquaculture has been increasing steadily, the numbers in most industrialized countries and territories have been declining or remaining steady. The decline has occurred mainly for fishers working in capture fisheries, while the number of fish farmers has increased (Food and Agriculture Organization of the United Nations (FAO) 2006). As marine reserves are established in intensely fished regions, displaced fishers can pursue ecotourism and help monitor MPAs. In Fiji, for example, NOAA and the Marine Protected Areas Center are partnering with local groups to develop ecotourism and train locals on guiding tourists, creating snorkel trails, and marketing for ecotourism. And, in California, some fishers assist with MPA monitoring and research.

Marine Managed Areas: Networks, Marine Protected Areas, Reserves, and Locally Managed Marine Areas

Throughout the Pacific, MPAs, MPA networks, and marine reserves are recognized solutions for coastal and ocean protection; they are also being used as a fisheries resource management tool. MPAs have been shown to have beneficial ecological and sociological impacts. One study, which analyzed 44 marine reserves and 4 large-scale fisheries closures worldwide (including marine reserves and fisheries closures in the Pacific), charted a 23% average increase in species diversity, which in turn heightened fisheries productivity in areas around the reserves (Worm, Barbier et al. 2006). MPAs can also significantly contribute to poverty reduction. Fish "spilling over" from no-fishing zones lead to improved fish catches for fishers, thus improving livelihood, food security, and nutrition and health (Craig, van Beukering et al. 2008). MPAs also create new jobs, mostly in tourism, that lead to long-term gains for local communities. Importantly, in Fiji (Navakavu), the Solomon Islands (Arnavon Islands), Indonesia (Bunaken), and the Philippines (Apo Island), both increased fish and tourism have helped empower women by creating more economic opportunities for them. New governance mechanisms for MPAs also involve local communities in decision making, thereby creating more effective, participatory local governance (Craig, van Beukering et al. 2008).

Protected areas—from national parks to monuments, managed resource protected areas, locally managed marine areas, marine reserves, protected seascapes, and habitat management areas—exist throughout the Pacific. One MPA success is the Great Barrier Reef World Heritage Area (Australia); 33% of it has been protected from extractive industries such as fishing and collecting (Wilkinson 2000). The recreational value of the Great Barrier Reef ranges from USD $700 million to $1.6 billion per year (Carr and Mendelsohn 2003). Other successes include Indonesia, which has 102 gazetted MPAs, 5 biosphere reserves, 3 World Heritage sites, and 2 wetlands of international importance—between 30 and 50 of these protected areas contain coral reefs (Abdullah, Agustina et al. 2005). In the South China

5 SPREP is an intergovernmental organization comprising of those 14 Pacific ACP member countries plus 7 other Pacific island states and territories and 4 metropolitan countries.

Sea area, about 125 MPAs have been gazetted (Wilkinson 2005). Individual MPAs, like Tubbataha Reef World Heritage (Philippines), Bunaken National Park (Indonesia), and Komodo National Park (Indonesia), offer models of both effective marine management and grassroots involvement. The development of MPAs has been implemented in Samoa, the Solomon Islands, Tuvalu, and Vanuatu, and identified in Fiji and Nauru (Hoffmann 2002). Similarly, a proposed preservation area will prevent seafloor mining in the Clarion-Clipperton zone (off the Pacific Coast of Mexico) (International Seabed Authority 2008). Despite such progress, MPAs still have a long way to go in parts of the Pacific, and enforcement is crucial. Unfortunately, destructive fishing, sedimentation, and pollution, and a lack of enforcement threaten many such protected areas (United Nations Environment Programme (UNEP) 2006).

Community Involvement and Community-Based Conservation

Research shows that community-based conservation, which takes into account local peoples' traditional resource use and livelihoods while conserving areas, offers a potential solution to threats facing parts of the Pacific (Foster and Poggie 1993; Graham and Idechong 1998). Community-based MPAs have shown some levels of success, since the people who stand to benefit from sustainable resource use are those directly involved in managing those resources. However, there is also concern about the high failure rates of small, community-based, no-take marine reserves that are proliferating in Southeast Asia. As a study of 24 villages in North Sulawesi, Indonesia shows, many factors—including village complexity, level of development, project input levels, characteristics of community organizers, etc.—must be taken into account to increase success rates for these small, community-based reserves (Crawford, Kasmidi et al. 2006).

With respect to fisheries, studies support the need for comprehensive fisheries management that promotes both sustainable fishing practices (i.e. prohibiting nighttime spearfishing) as well as shared management and enforced responsibilities between communities and the state (Rhodes, Tupper et al. 2008). Another solution (identified for Central America) may be to strengthen the self-regulation of coastal communities, so that they accept greater responsibilities than the state governments currently undertake and actively participate in managing and conserving their local marine resources (United Nations Environment Programme (UNEP) 2006).

Strengthening Institutions and Building Capacity

Tremendous social, cultural, political, and environmental diversity exists within the Pacific, particularly in Micronesia, Melanesia, and Polynesia; with these differences comes variation in local capacity and institutions. Some regions, such as North America and Australia, generally have strong leadership, capacity and institutions. In other areas, however—especially Melanesian countries and territories—not enough leaders and skilled people exist to implement and maintain projects, whether they are management, monitoring, or research-based. MPA managers, for example, need training, equipment, and staffing to make management more effective. Overall, knowledge about the long-term effects of current actions and all aspects of ocean, coastal, and watershed management, research, and monitoring need to be strengthened, and capacity building should be made a high priority. This will entail a great effort on the parts of national, regional, and international education and training institutions, and will require significant funding.

Infrastructure Development

In many areas throughout the South East Pacific, the environmental and socioeconomic impacts of infrastructure (dams, roads, port facilities, sewage treatment plants, etc.) have not been adequately considered, leading to drained wetlands and other coastal habitat loss, beach erosion, and coastal and marine pollution. In particular, there is a greater need for greater investment in sewage treatment plants and sewage systems throughout the entire region. Some areas in Central America have, however, slowly improved their sewage and wastewater infrastructure, leading to environmental and public health improvements.