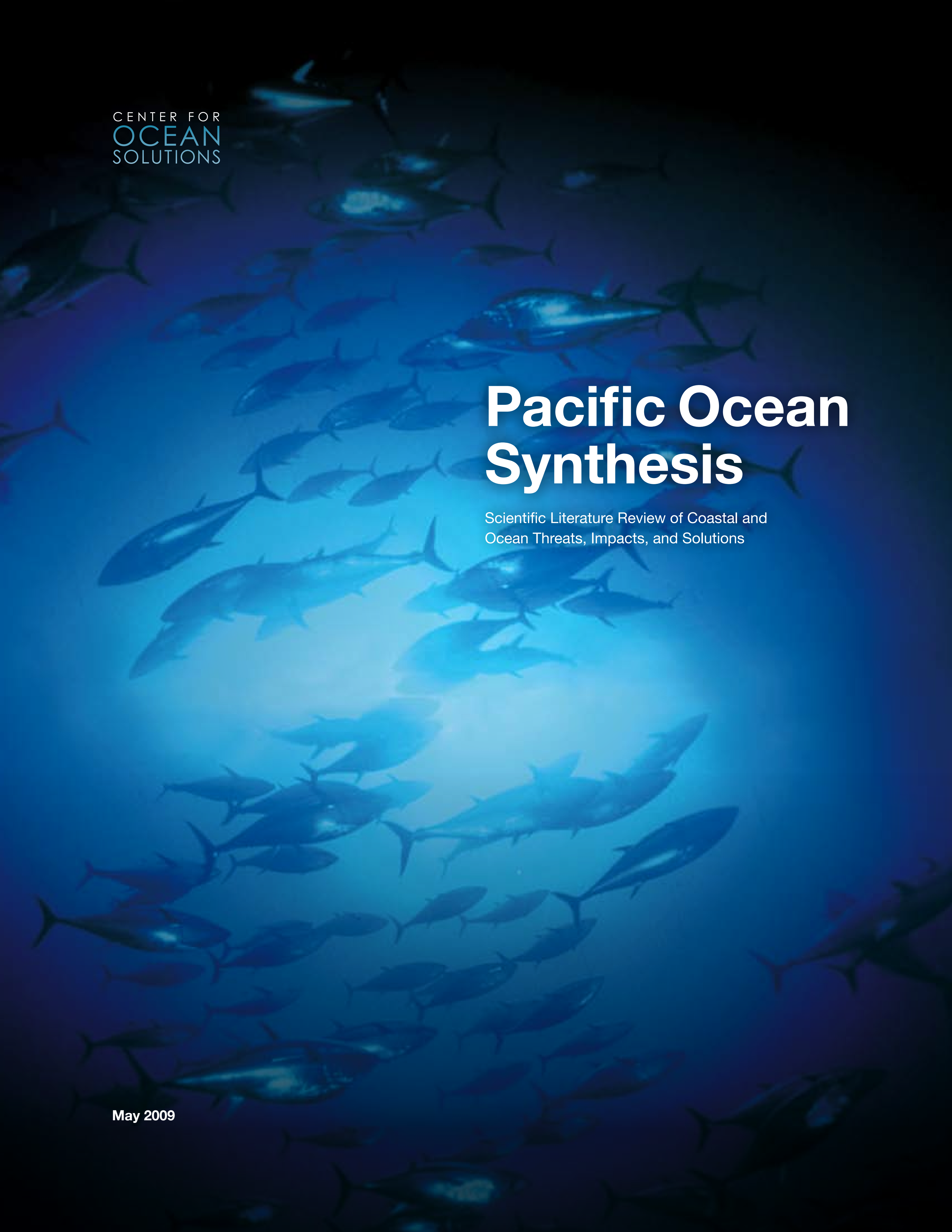

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SOLUTIONS

Pacific Ocean Synthesis

Scientific Literature Review of Coastal and Ocean Threats, Impacts, and Solutions

May 2009

This literature review was completed as of October 2008. The authors comprehensively reviewed the literature, but may have missed important reports and papers. If you know of a report or paper we have not included in this literature review documenting Pacific Ocean threats, impacts, or solutions please send the reference to library@centerforoceansolutions.org.

Center for Ocean Solutions. 2009. Pacific Ocean Synthesis: Scientific Literature Review of Coastal and Ocean Threats, Impacts, and Solutions. The Woods Center for the Environment, Stanford University. California.

The Center for Ocean Solutions is a collaboration between Stanford University (including the Hopkins Marine Station) (www.stanford.edu), the Monterey Bay Aquarium, and the Monterey Bay Aquarium Research Institute (MBARI) (www.mbayaq.org). The Center for Ocean Solutions is administered by the Woods Institute for the Environment at Stanford University.

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Cover Photo: Schooling Tuna (Danilo Cedrone, Courtesy of United Nations Food and Agriculture Organization)
Photo on the right: School of fish in Palau (David Burdick)

Abstract

The objective of this Pacific Ocean synthesis is to comprehensively and systematically survey the published scientific literature, government publications and other peer-reviewed reports to identify Pacific Ocean and regional threats as well as the environmental and socioeconomic impacts of those threats. In addition, the report highlights select regional and Pacific Ocean solutions presented by the literature.

This report summarizes and distills the scientific literature and highlights common trends in and around the Pacific Ocean regarding threats, impacts and solutions through the review of more than 3,400 scientific articles and reports. It also reveals gaps in knowledge and areas where more natural and social science research is needed that could inform coastal and ocean policy and management. For this analysis, the Pacific Ocean was organized into seven regions representing 50 countries or territories. Results from this synthesis were vetted and verified by over 30 natural, physical, and social scientists from around the Pacific who convened in Honolulu, Hawaii in August 2008 (Appendix A). The meeting, which used the synthesis as the foundation for discussion, resulted in the creation of the document, *"Ecosystems and People of the Pacific Ocean — Threats and Opportunities for Action: A Consensus Statement."* This statement, which has been signed by more than 400 scientists, identifies and prioritizes key threats to the health and productivity of the Pacific Ocean, many accelerated by global climate change, for which broad consensus exists in the scientific community. It also highlights the environmental and socioeconomic impacts of these threats and outlines a "road map" that identifies available solutions for these threats.

In both the synthesis and the consensus statement, a review of environmental threats across the Pacific Ocean shows remarkable similarity between the major problems experienced in poor and rich countries or territories alike, in densely settled areas and in rural zones, in populous countries and on small islands. Across these diverse areas, there are three pervasive and serious local threats: pollution from sewage and land runoff, habitat destruction, and overfishing and exploitation. We classify invasive species, which can be considered under both pollution and habitat destruction, as a fourth threat, in a category of its own. Finally, climate change imperils all Pacific ecosystems. These threats interact with each other to damage natural ecosystems, reduce biological and human economic diversity, reduce productivity, and hinder human use of the sea.

Key findings from the synthesis, as well as important themes from the consensus statement, include:

1. **Pollution:** The literature identifies nutrients (in 36 countries or territories) as an overall "severe" impact threat throughout the Pacific. Chemical pollution is also a large, "moderate" threat, but the research does not document the extent of such pollution, nor identify all of the chemical inputs that could affect marine coastal systems. This category includes nutrient pollution from fertilizer runoff and organic pollutants from sewage, plastic marine debris and solid waste disposal, toxic dumping and oil spills, and urban runoff. These forms of pollution can create dead zones, algal blooms, and acidic areas, alter the basic ecosystem structure, pose human health risks, and stress economies.

2. **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 an overall "severe" impact threat, identified in 35 countries or territories throughout the Pacific. Coastal development and land reclamation have been

identified as an overall "moderate" impact threat, leading to the destruction of critical ecosystems that produce invaluable services and products for society in 35 countries or territories.

3. **Overfishing and Exploitation:** Commercial, industrial fishing is identified in 40 countries or territories as an overall "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 areas and productivity.

4. **Climate Change:** Increasing sea surface temperature (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 and territories lack research documenting place-based, present and 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 deaths of reef-building corals caused by warm water pulses have 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 numbers of impoverished people and reduce the stability of many countries and territories.

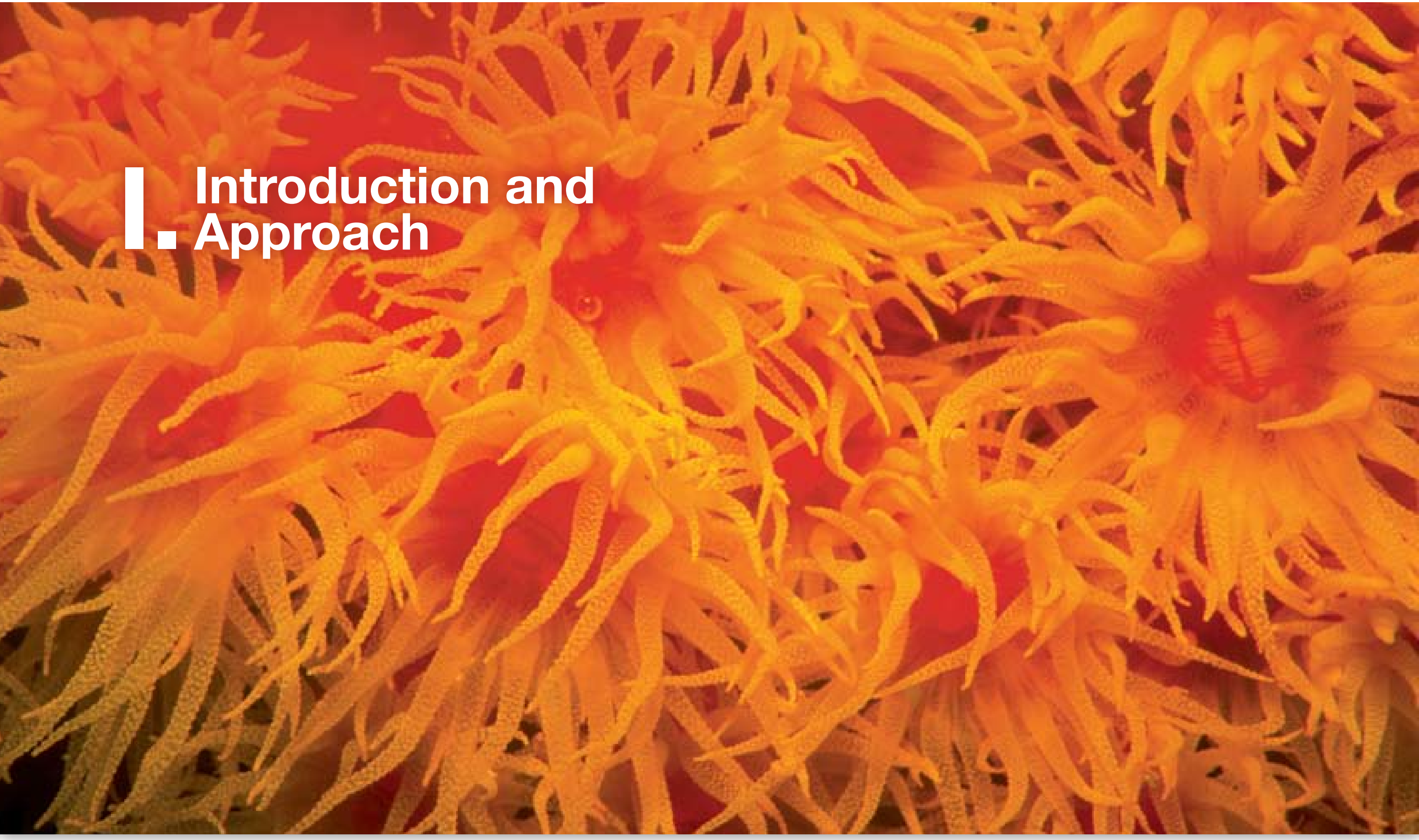
5. **Invasive Species:** While few countries and territories have documented research on invasive (non-indigenous) species, evidence suggests that marine invasives, identified in 18 locations, can adversely affect the habitats they invade both ecologically and economically. Invasives compete with other 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.

6. **Multiple Stressors:** When marine life is subjected to multiple stressors, including 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.

7. **Solutions:** 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 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.

8. **Research Gaps:** This synthesis identifies key gaps of knowledge in such areas as multiple threats, climate change, chemical pollution, marine invasives, and studies of regional and country/territory-specific policies and management. All regions could better link threats, environmental impacts, and socioeconomic impacts.

Contents



I. Introduction and Approach

Photo: Close up of Orange Cup Coral *(Tubastraea coccinea)* polyps with tentacles extended. While native to the East Asian Seas, it is an invasive species in the Eastern Pacific and elsewhere, competing with native sponges and corals for habitat. (© www.willisgreinerphoto.com)

Comprising half the world's ocean area and one third of the Earth's surface, the Pacific Ocean is the largest single geographic feature on our planet. It hosts complex ecosystems and ocean-based economies that produce a wealth of resources for local and global consumption; it also serves as the engine room of Earth's climate and plays a vital role in the Earth's carbon and water cycles. Despite its importance, the Pacific Ocean is not being managed sustainably. In order for our climate to remain healthy, the ocean must remain healthy as well.

The Pacific Ocean hosts much of the world's marine and terrestrial biodiversity. The ecosystems of the Pacific islands support more rare, endangered, and threatened species than anywhere else on Earth. The region's total biodiversity, however, is at risk. The threats continue to expand as over-harvesting of resources and runoff from land to sea increase, which affect life from shallow corals, mangroves, and seagrasses to previously inaccessible deep sea beds. Rapidly declining populations of large tuna, sharks, and turtles reveal the progressive depletion of the top predators of the Pacific, which in turn affects economies, local livelihoods, and food security across the globe. Climate change exacerbates these threats and increases the vulnerability of coastal and ocean ecosystems, resources, and people.

The 50 countries and territories that border the Pacific show remarkable diversity. They differ in size and population, from large countries like China to small Pacific islands like Nauru. They also vary in wealth, from the industrialized United States and Australia to the less developed, rural islands including Samoa and the Solomon Islands. Some of the countries and territories possess ample agricultural and marine-based natural resources, while others are comparatively resource poor. Resource management regimes, from market-based systems to traditional management, also differ. Yet across the Pacific, the five main threat categories—though they vary in scale and intensity in each country/territory—interact with each other to damage natural ecosystems, reduce biological and human economic productivity, and hinder human use of the sea.

Climate change is an increasing threat to both marine ecosystems and human populations. Sea level rise and sea surface temperature increases have been documented in many parts of the Pacific, but site specific research on ocean acidification and UV-B radiation are not well documented.

Purpose, Objectives, and Approach for Pacific Ocean Synthesis Report

Results from this Pacific Ocean synthesis were vetted and verified by over 30 scientists from around the Pacific who convened in Honolulu in August 2008. The meeting, which used the synthesis as the foundation for discussion, resulted in the creation of the consensus statement document, *"Ecosystems and People of the Pacific Ocean—Threats and Opportunities for Action: A Consensus Statement."*[1] This statement, which has been signed by more than 400 scientists, identifies and prioritizes key threats to the health and productivity of the Pacific Ocean, many accelerated by global climate change, for which broad consensus exists in the scientific community. It also highlights the environmental and socioeconomic impacts of these threats and outlines a "road map" that identifies available solutions for these threats. This synthesis thus provides the scientific evidence and foundation for the consensus statement, a region-wide and global call for action.

The main objective of this synthesis is to comprehensively and systematically present findings of the published scientific literature, government publications, and other peer-reviewed reports to identify Pacific Ocean and regional threats, as well as the environmental and socioeconomic impacts of those threats. This report summarizes and distills the scientific literature and highlights common trends in and around the Pacific Ocean regarding threats, impacts, and solutions. In addition, it outlines some regional and Pacific Ocean solutions presented by the literature. Although this report focuses primarily on threats rather than solutions, it briefly discusses some of the most effective management approaches and solutions being undertaken throughout the region, as identified in the literature. It also highlights gaps in knowledge and areas where more natural and social science research is needed.

[1] The Scientific Consensus Statement is being led by the Center for Ocean Solutions at Stanford University in partnership with the International Union Conservation of Nature (IUCN). The statement is foremost a summary of the environmental threats that loom largest across the Pacific Ocean, which affect marine ecosystems and resources, the people that depend on them, and the economies of coastal nations. The statement is one of the first steps in the IUCN Pacific Ocean 2020 Challenge. The Scientific Consensus Statement is available online at: www.centerforoceansolutions.org/data/consensus_statement.pdf

[2] These articles and reports are now available online through a fully searchable bibliographic database, www.centerforoceansolutions.org/library.

Pacific Ocean Synthesis Approach

The methodology for the Pacific Ocean synthesis followed six main steps.

1. **Scale:** We organized the Pacific Ocean into seven regions. The organization draws from both the United Nations Marine Assessment of Assessments and direct consultation with more than 30 scientists from across the Pacific who convened in Honolulu in August 2008.

2. **Literature Review:** We systematically reviewed literature on the Pacific, the seven individual regions, and each country or territory by coastal and ocean threats, impacts, and solutions. To conduct these reviews, we performed searches in library databases such as Web of Knowledge, WorldCat, and Google Scholar, using the keywords associated with these categories. Search results are summarized in tables one to seven. We reviewed the literature (a total of more than 3,400 papers and reports[2]) by region, country/territory, threat, impact, and solution, and documented key findings on these topics.

3. **Threat Identification:** We documented when an article identified an issue as a present or future threat. If no research on the topic was found, we did not put a check next to it in the tables. This does not necessarily mean the issue is not a threat; rather, it suggests that no scientific literature was found. Most of the scientific literature does not link the threat to a cause or assess the complete impact on the environment and people.

4. **Impact Assessment:** We assessed the impact of the threats, based on the literature when available. However, significantly less literature exists on impacts, especially socioeconomic ones, than on identification of threats. Furthermore, most scientific literature does not compare the impact of threats to each other. In these cases, we used information from sources based on expert opinion, not necessarily scientific data, such as the Global International Waters Assessments and Reefs at Risk. For understudied regions and topics, we extrapolated information, e.g. from impacts and solutions, and applied conclusions to other regions using our best judgment and estimate. When assessing the impact, we examine impacts and assess the frequency, resiliency, and scale of the impact on both the environment and socioeconomic factors, including human health and livelihood. We classified threats and associated impacts using the following guidelines:

Climate change will produce long-term range shifts of marine organisms; this area also requires further research.

- **Severe Impact**

  Threats classified as a severe impact both the environment and society to an extreme degree. Severe environmental impacts alter the environmental condition either by changing or destroying it to an extent that recovery will take years, if ever. Severe socioeconomic impacts affect economic livelihood of people and/or food security and can include extreme hardship and/or illness or death. Examples of threats with severe impacts include commercial fishing, which can cause the collapse of, or severe decline in, an entire fishery and lead to millions of dollars of economic loss; sea surface temperature increase, which produces mass coral bleaching events that could take coral years to recover and affect fisheries and/or tourism income; or severe, recurring, large-scale harmful algal blooms (HABs), which result in massive die-offs of species and illness or death in humans. In Indonesia destructive fishing is severe. Although illegal and highly destructive to coral reefs, blast fishing and other forms of destructive fishing are severe impact threats that occur throughout Indonesia.

- **Moderate Impact**

  Threats classified as a moderate impact the environment and society significantly. The environment may be altered or even destroyed, but it is more resilient and can recover in a shorter time frame than from a severe impact. Such recovery varies according to threat and location. Impacted habitats may be at a smaller scale than those with a severe impact. Socioeconomic impacts produce hardship or illness, for example. Many impacts are not quantified and the extent of impact unknown; when this was the case we documented the threat as having a moderate impact. Examples of threats with moderate impacts include commercial fishing, which can endanger species; sea surface temperature increase that causes localized coral bleaching with no recovery, or larger-scale bleaching where reefs are more resilient or where socioeconomic impacts are less profound; or HABs that are recurring or small-scale, but harm marine resources and cause some human illness. In Japan, destructive fishing is a moderate impact threat. Bottom-trawling is a common type of destructive fishing, but not well documented. Driftnet fishing, which catches everything that enters its path, is believed to have reduced the populations of such commercially viable fish as tuna, marlin, swordfish, and salmon.

- **Low Impact**

  Threats classified as low impact alter the environment, but do not destroy the ecosystem. Recovery from an altered state is possible. Furthermore, threats in this category may be moderate or severe in one or two locations in a country or territory, but not across the entire country or territory. Socioeconomic impacts exist, but affect few people and places. Examples of threats with low impacts include commercial fishing that causes the decline of a species, sea surface temperature increase that causes localized coral bleaching events, or small-scale HABs that occur infrequently. In the Federated States of Micronesia, there is some documentation of destructive fishing, but it is considered a low impact threat (Hasurmai, 2005).

5. **Regional Synthesis Threats and Impact Tables:** We synthesized the results of steps two, three, and four and developed regional threat and impact tables based on the literature. Refer to tables one to seven within this document. We put a check next to a threat when it was identified in the literature, and then ranked the environmental and socioeconomic impact as severe, moderate, or low according to the criteria discussed above. Solution Identification: The literature on solutions is limited, as well as inconsistently documented in the literature. Some research documents case studies, while other articles show the results of implementing marine protected areas or reserves. However, there is an opportunity for more research to assess, document, and analyze different approaches to solving coastal and ocean problems. For the purpose of this report, we identified and documented examples of solutions in regions gleaned from the research, and wrote up a very general summary of regional solutions and examples based on the threats and impacts identified.

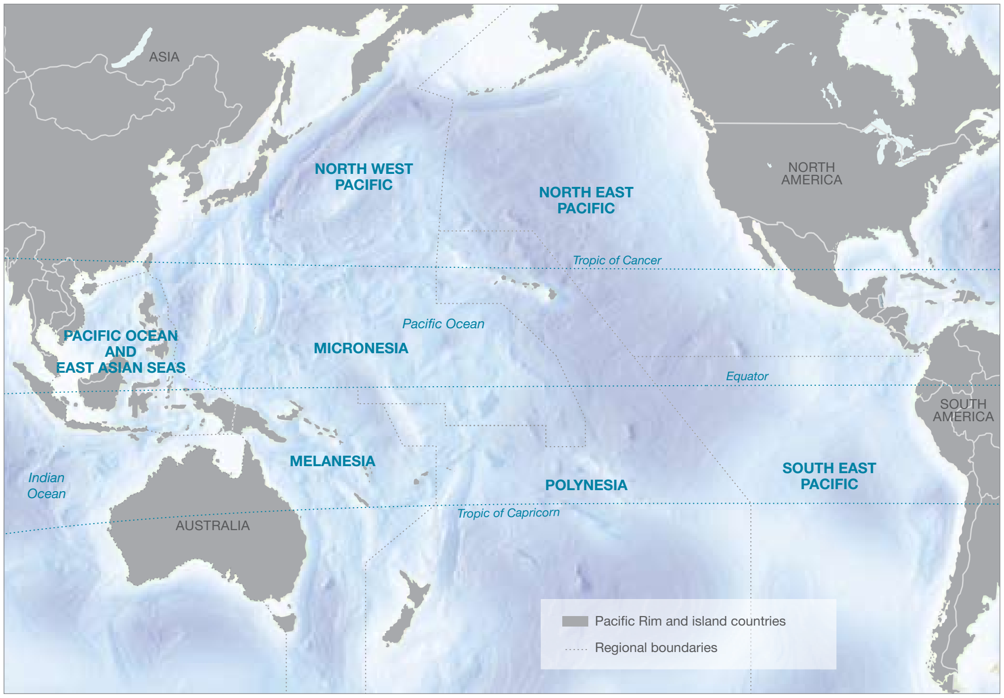
6. **Pacific Ocean Summaries:** The final synthesis is divided into eight sections: the Pacific Ocean overview and seven regional summaries. We established regional and overall Pacific trends for primary threats and impacts by averaging the impacts of the primary threats within each region and then identifying cross-cutting threats among all regions. Finally, we incorporated working solutions into the Pacific Ocean and regional summaries.

Regions

For the purpose of this analysis, we organized the Pacific Ocean into seven regions, with the following countries and/or territories in each.[3] This organization draws from both the UN Marine Assessment of Assessments and direct consultation with over 30 natural, physical, and social scientists from across the Pacific who convened in Honolulu in August 2008.

[3] As guided by the UN Marine Assessment of Assessments (In accordance with paragraph 64(a) of UNGA resolution 58/240, as well as scientific experts. Source: www.unga-regular-process.org/index.php?option=com_content&task=view&id=13), and Atlas of the World (Revised 8th Edition), National Geographic Society, 2004.

Map 1: Regions of the Pacific Ocean

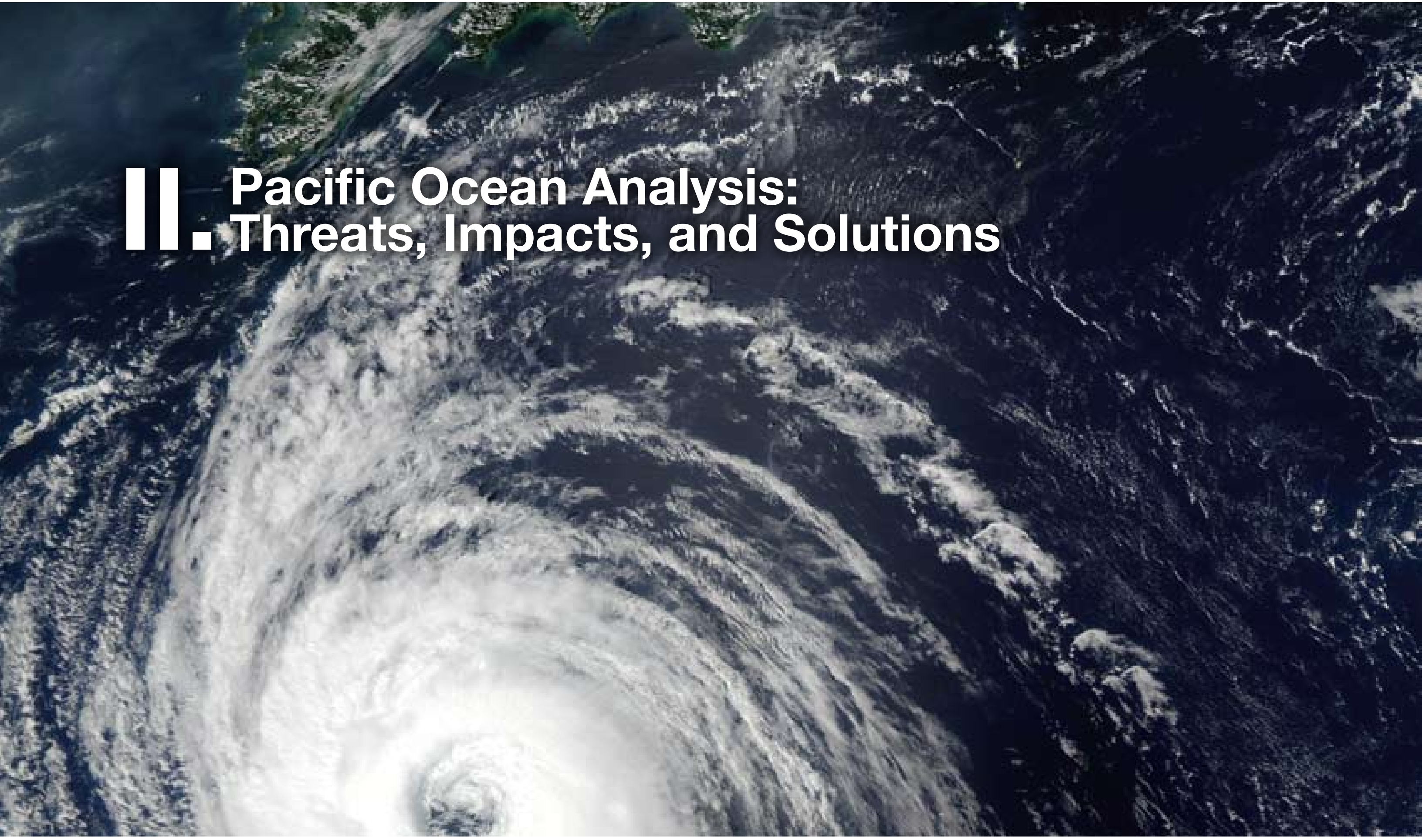


Source: International Ocean Commission and The United Nations (www.unep-wcmc.org/gramed) 2008 Lucidity Information Design, LLC

REGION	COUNTRIES OR TERRITORIES	
North East Pacific Ocean	Canada, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, United States	9
North West Pacific Ocean	China (including Taiwan), Japan, North Korea, South Korea, Russia	5
Pacific Ocean & East Asian Seas	Brunei Darussalam, Cambodia, East Timor, Indonesia, Malaysia, Philippines, Singapore, Thailand, Vietnam	9
Micronesia	Commonwealth of Northern Mariana Islands, Guam, Kiribati, Marshall Islands, Federated States of Micronesia, Nauru, Palau, Other U.S. Remote Islands	7
Melanesia	Australia, Fiji, New Caledonia (France), Papua New Guinea, Solomon Islands, Vanuatu	6
Polynesia	American Samoa, Cook Islands, French Polynesia (France), New Zealand, Niue, Pitcairn Islands (United Kingdom), Samoa, Tokelau (New Zealand), Tonga, Tuvalu, Hawaiian Islands (United States)	10
South East Pacific Ocean	Chile, Colombia, Ecuador, Peru	4
Total		**50**

Report Structure

This report presents the results of our scientific literature survey, which, in turn, forms the foundation of the consensus statement. The threat and impact assessment is shown in tables for each of the seven regions, accompanied by a written synthesis of the most common threats and associated impacts and solutions. Section II presents a summary of the Pacific Ocean threats, impacts, and solutions. This section summarizes the common threats and impacts found across the seven regions and highlights solutions. Section III presents the threats, impacts, and solutions for the North East Pacific; Section IV the North West Pacific; Section V the Pacific Ocean and East Asian Seas; Section VI Micronesia; Section VII Melanesia; Section VIII Polynesia; and Section IX the South East Pacific. In each section the threats with the most severe impacts are discussed, followed by examples of other threats and impacts in the region. The diversity of threats throughout the Pacific Ocean is widespread. Many of the threats we discussed may not be documented as the greatest threat with the most severe impact, but they are stated as either emerging threats or threats that have not yet been adequately studied.



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 (in 36 countries or territories) as an overall severe impact threat throughout the Pacific. 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 an overall severe impact threat, identified in 35 countries or territories throughout the Pacific. Coastal development and land reclamation is an overall moderate impact threat 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 has been identified in 40 countries or territories. Across all seven regions on average, it is 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 runoff, plastic marine debris, toxic dumping and oil spills, urban runoff 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 17) and sea level rise (page 19). 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 Niño 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 (CO_2) 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 CO_2 and other greenhouse gases. Not only are these gases altering Earth's climate, but they are also acidifying the ocean as CO_2 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, Mahowald et al. 2007).

Marine organisms are especially vulnerable to altered seawater CO_2 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 system's feedback loops. Many of these questions still have no answers.

Box 1: Summary of Pacific Ocean Threats with Overall 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 overall 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 35 countries or territories.

The threats with overall 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 31 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.

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 one and two), and each threat category explains the threat as well as environmental and socio-economic 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 countries or territories. Across all seven regions on average, it is a severe impact threat. 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 two 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 sea 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 throughout the Pacific have grown, sewage and waste-water 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, Mahowald et al. 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 for people. 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 35 countries or territories throughout the Pacific, 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 Hawaii, 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 18. 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 studies

continued on page 16

Box 2: Summary of Pacific Ocean Threats with Overall Moderate 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

have been conducted to calculate the net benefits of coral reefs. In Hawaii, 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 21.) 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 ENSO 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 ENSO, 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. ENSO 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 triggered 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 ENSO event, sea surface temperature increase, and severe coral bleaching event in 1997–98 (Bruno, Siddon et al. 2001). Around the main islands of Hawaii, 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 31 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 southern California's 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 in Washington State 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 tributyltin (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 sea 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 on page 13–14 and page 18.) 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 polychlorinated biphenyls (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 17) 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 the 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).

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 sea 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 Hawaii, 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 have 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

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 (page 26) 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 sea floor 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. NAPAs work 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

[5] SPREP is an intergovernmental organization comprising of those 14 Pacific ACP member countries plus seven other Pacific island countries and territories and four metropolitan countries.

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, the National Oceanic and Atmospheric Administration (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 four 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, five biosphere reserves, three World Heritage sites, and two wetlands of international importance—between 30 and 50 of these protected areas contain coral reefs (Abdullah, Agustina et al. 2005). In the South China Sea area, about 125 MPAs have been gazetted (Wilkinson, DeVantier et al. 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 sea floor 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.

Photo: Humpback whale *(Megaptera novaeangliae)* The calf weans to around ten or eleven months of age and is inseparable from its mother until its second winter. (OAR/National Undersea Research Program, NURP)

III. North East Pacific Ocean Regional Analysis: Threats, Impacts, and Solutions

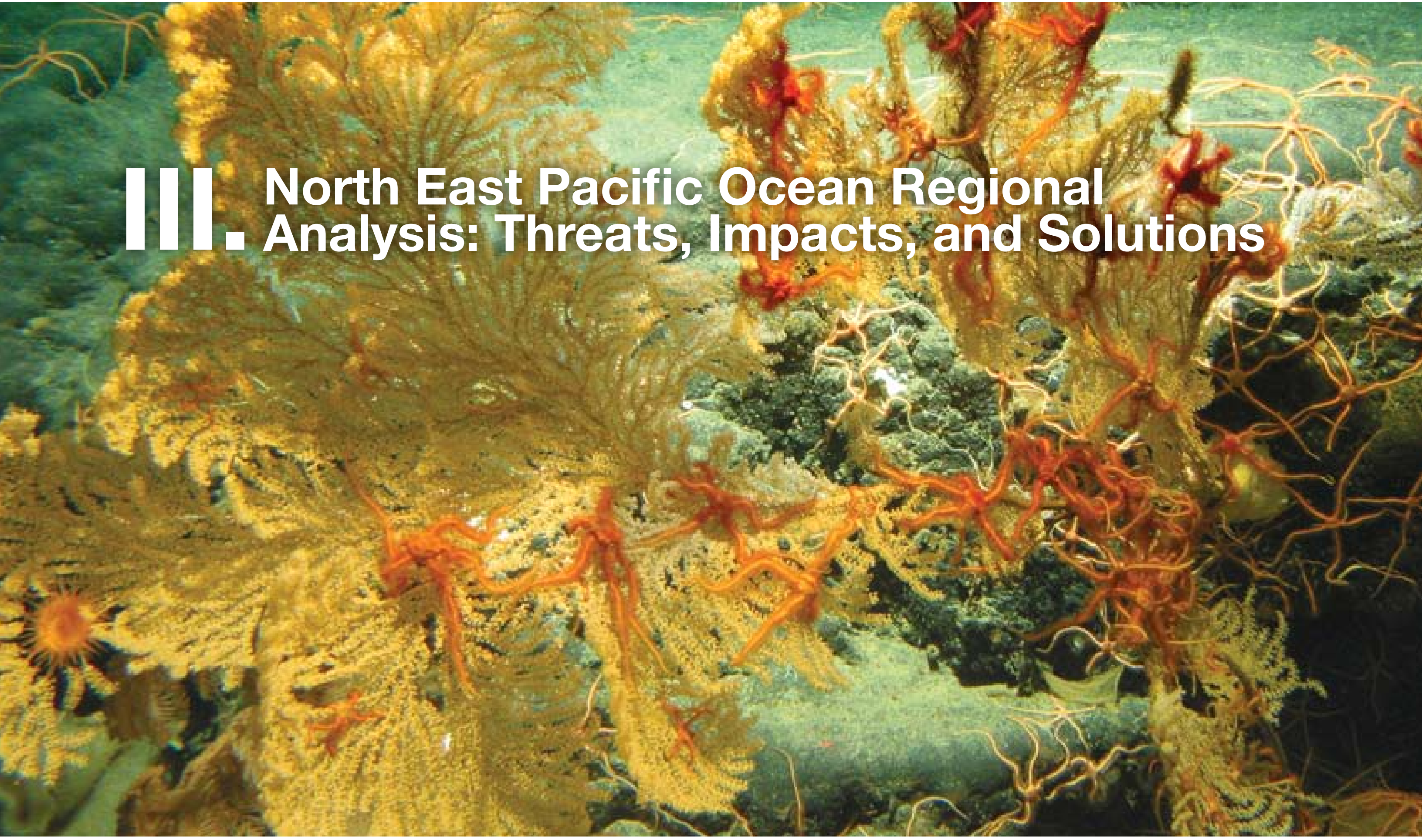


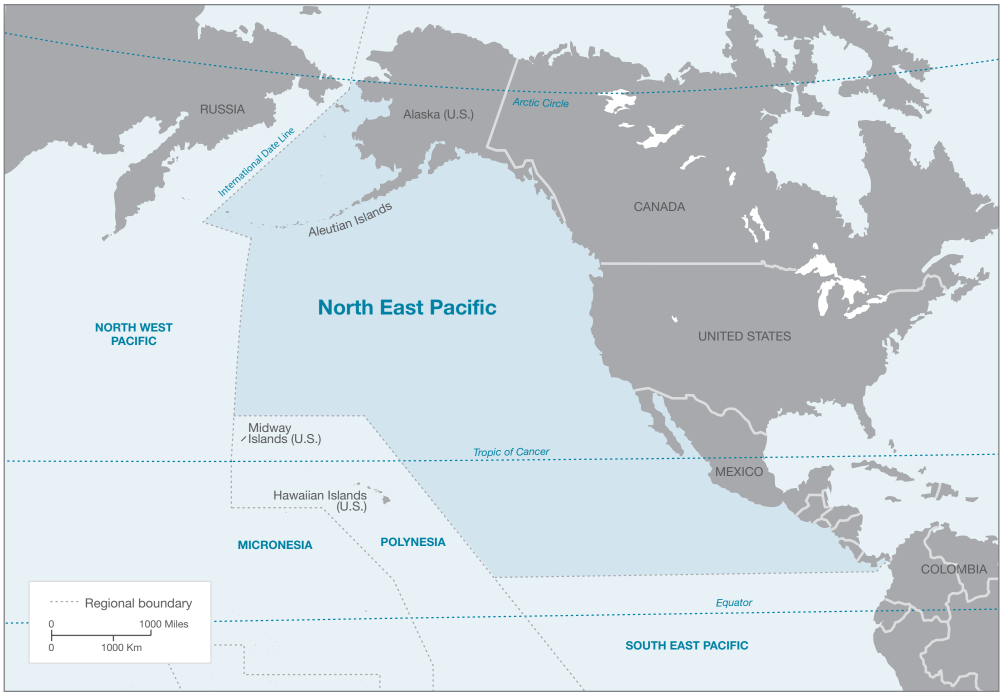
Photo: Alaska offers an example of successful ecosystem-based management, inclusive of protections for deep water corals from destructive fishing practices. (Gulf of Alaska 2004. NOAA Office of Exploration)

The North East Pacific Ocean, stretching from Alaska and the Aleutian Islands to Panama, encompasses the largest north-to-south ecosystem of this study. It includes the Pacific Coast of North America and Central America, and nine countries: Canada, Costa Rica, El Salvador, Guatemala, Honduras, Mexico, Nicaragua, Panama, and the United States.

The Pacific Coast of North America is influenced by the California Current system, which extends from southern British Columbia to Baja California; it is one of the most biologically important regions in the Pacific Ocean. Characterized by a temperate climate, this region comprises a transitional ecosystem between subtropical and subarctic water bodies. The California Current is the feeding ground of the northern Pacific Ocean for millions of marine birds, mammals, and fish, including many far-ranging, highly-migratory species from the southern hemisphere. It hosts amazing marine life, from blue and gray whales to elephant seals, loggerhead turtles, sea otters, dolphins, and more than 80 species of groundfish. The Central American Pacific Coast (Eastern Equatorial Pacific) stretches from Mexico to El Salvador, Guatemala, Nicaragua, Costa Rica, and Panama, and is characterized by its tropical climate and upwelling system. Much of the region lies within the Intertropical Convergence Zone (ITCZ). Situated between the California and the Humboldt Currents, the coast has much warmer upper ocean layers than its northern neighbor. As in North America, the currents produce upwelling zones that support productive fisheries. Overall, the Central American coast, with the exception of Mexico, is less developed than its North American counterpart.

Two of the most serious problems facing the North East include pollution (stemming from agricultural and industrial activities) and exploitation in the form of overfishing, a result of North America's productive industrial fisheries and commercial and artisanal/recreational/subsistence fishing in Central America. As the table and box below show, pollution from both nutrients and chemicals may be the most serious, the former affecting all nine countries in this region (with a severe impact in six) and the latter identified in eight countries (with a severe impact in four). Other moderate

Map 2: North East Pacific Ocean



Source: International Ocean Commission and The United Nations (www.unep-wcmc.org/gramed) 2008 Lucidity Information Design, LLC

impact forms of pollution in the region include oil spills, antifouling chemicals, and solid waste disposal. Such pollution can create dead zones and algal blooms, alter the ecosystem structure, and jeopardize human systems. Commercial and artisanal/recreational/subsistence fishing causes ecological shifts, reduces fish stocks, and endangers food security. Eight countries show evidence of both types of overfishing, with commercial fishing a severe impact threat in four countries and artisanal/recreational/subsistence fishing a severe impact threat in five. Habitat destruction—in particular sedimentation, coastal development and land reclamation, and coastal modification from aquaculture—exists region-wide as a moderate impact threat. These forms of habitat destruction lead to the degradation of critical ecosystems that produce invaluable services and products for society. Finally, climate change (specifically sea surface temperature increases, noted in five countries) exacerbates the threats above. Significantly, none of these threats operate in isolation, but rather function as multiple, compounded stressors that together can significantly disrupt marine and human systems.

The North East Pacific Ocean discussion that follows first presents overall regional trends of severe and moderate impact threats, including a table listing the levels of threats and impacts in each country. Then, the literature review section offers a more in-depth discussion of the most severe impact threats. Moderate impact threats are also presented if they are prevalent or notable throughout the region. Finally, the last section provides a brief overview of potential solutions to the threats facing this region as a whole.

> Although the literature documents land-based nutrient pollution as a severe threat throughout the region, few studies link the threat to socioeconomic impacts.

North East Pacific Regional Trends: Primary Threats and Associated Environmental and Socioeconomic Impacts

The bullets below highlight severe and moderate impact threats in the North East Pacific based on the impact assessment methodology described in the Introduction.

Based on this assessment, the threats with overall severe impacts across the entire North East Pacific region are:

- nutrient pollution identified in all nine countries.
- land-based chemical pollution identified in eight countries.
- artisanal/recreational/subsistence fishing and commercial fishing identified in eight countries.

The threats with overall moderate impacts across the region are:

- land-based sedimentation identified in seven countries.
- coastal development/land reclamation identified in six countries.
- coastal modification from aquaculture identified in six countries.
- by-catch discharge identified in six countries.
- solid waste disposal identified in five countries.
- climate change (sea surface temperature) identified in five countries.
- oil spills and antifouling chemicals identified in four countries.

Key observations regarding research gaps and identified impacts:

- North America is the most comprehensively studied area in this region and in the Pacific Ocean as a whole.
- Canada, Mexico, and the United States contain the highest number of documented threat categories as well as the greatest numbers of moderate to severe impacts.
- The countries in Central America have fewer studies documenting threats and impacts. The threats with the least numbers of both moderate and severe impacts are documented in Guatemala (six), Honduras (five), and Nicaragua (five).
- For the Pacific Coast of Central America, large research gaps exist for climate change, invasive species, pollution (such as offshore oil/mining, radionuclides, ocean waste, and toxic dumping), and habitat destruction. Studies on land-based chemicals and nutrient pollution exist, but they are not comprehensive and do not link to socioeconomic impacts.

Climate change research is not documented in Central America, although sea level rise has been documented in Canada and the United States.

The following table distills the findings from the literature, documented by country, threats and environmental and socioeconomic impacts. There is considerable variation in the availability of scientific literature in this region. Research on threats in North America is relatively more abundant. Many studies document the impact of these threats on the environment and society; in terms of impacts, North America is the most comprehensively studied region in the Pacific Ocean. However, Central America has far fewer studies documenting threats and impacts. For the Pacific Coast of Central America, large gaps exist in climate change research, invasive species, pollution, and coastal development and land reclamation. While studies on pollution exist, they are not comprehensive and do not link to socioeconomic impacts. Because scientists have not conducted complete research on some of these threats and impacts for all of this region's countries (i.e. El Salvador, Honduras, and Guatemala), significant need exists for research and monitoring of coastal and ocean systems and resources to assess the status of these systems in order to inform policy and management for Central America in particular.

TABLE 1: North East Pacific Threats Based on Scientific Literature and Impact Assessment

✓ Identified as Threat
● Severe Impact ● Moderate Impact ● Low Impact

It was documented when an article identified an issue as a present or future threat. If no scientific literature was found on the topic, then no check was assigned. This does not necessarily mean the topic is not a threat; rather, it suggests that no scientific literature was found on the topic.

	CANADA		COSTA RICA		EL SALVADOR		GUATEMALA		HONDURAS		MEXICO		NICARAGUA		PANAMA		UNITED STATES	
	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts
POLLUTION																		
Aquaculture: Wastewater	✓	Low			✓	Low	✓	Low	✓	Moderate	✓	Moderate					✓	Moderate
Land-based Chemicals	✓	Moderate	✓	Moderate	✓	Severe	✓	Moderate			✓	Severe	✓	Severe	✓	Moderate	✓	Severe
Fishing Lines/Nets																	✓	Moderate
Nutrients	✓	Moderate	✓	Moderate	✓	Severe	✓	Severe	✓	Severe	✓	Severe	✓	Severe	✓	Moderate	✓	Severe
Offshore Oil/Mining																	✓	Low
Oil Spills & Antifouling Chemicals	✓	Severe									✓	Moderate			✓	Moderate	✓	Severe
Radionuclide																		
Solid Waste Disposal	✓	Low	✓	Severe	✓	Severe					✓	Severe					✓	Moderate
Thermal	✓	Low															✓	Low
Ocean Waste & Toxic Dumping	✓	Moderate															✓	Moderate
HABITAT DESTRUCTION																		
Anchor Damage															✓	Low		
Aquaculture: Coastal Modification	✓	Moderate			✓	Low	✓	Moderate	✓	Severe	✓	Moderate					✓	Moderate
Coastal Development/Land Reclamation	✓	Moderate	✓	Moderate	✓	Severe					✓	Severe			✓	Severe	✓	Severe
Destructive Fishing	✓	Moderate	✓	Moderate							✓	Severe					✓	Low
Dredging															✓	Severe	✓	Severe
Marine Recreation																		
Land-based Sedimentation	✓	Moderate	✓	Moderate	✓	Severe					✓	Severe	✓	Severe	✓	Severe	✓	Moderate
Ship Groundings	✓	Moderate																
Tsunamis	✓	Low											✓	Low	✓	Low	✓	Low
Typhoons/Cyclones/Hurricanes & Storm Surge	✓	Moderate	✓	Severe							✓	Severe						
Wrecks/Military Equipment																		
OVERFISHING & EXPLOITATION																		
Aquaria Trade					✓	Severe									✓	Severe		
Artisanal/Recreational/Subsistence Fishing	✓	Low	✓	Severe	✓	Severe	✓	Severe	✓	Moderate	✓	Severe	✓	Severe			✓	Low
By-Catch & Discharge	✓	Moderate	✓	Moderate			✓	Moderate			✓	Severe			✓	Severe	✓	Moderate
Commercial Fishing	✓	Severe	✓	Severe	✓	Low	✓	Moderate	✓	Moderate	✓	Severe	✓	Moderate			✓	Severe
CLIMATE CHANGE																		
Acidification	✓	Moderate									✓	Moderate					✓	Moderate
Sea Level Rise	✓	Moderate															✓	Severe
Sea Surface Temperature**	✓	Severe	✓	Severe							✓	Moderate			✓	Low	✓	Severe
INVASIVES																		
Invasive Species (Different Vectors)	✓	Low													✓	Severe	✓	Moderate

**Changes in SST is strongly associated with El Niño Southern Oscillation (ENSO) events, which are predicted to increase in frequency and intensity over time due to climate change.
For a complete list of references used for the literature review and synthesis to create this table see Appendix C, Table 1 p.126.

North East Pacific Literature Review of Severe and Moderate Impact Threats

The discussion that follows highlights the greatest threats to the North East Pacific. The most severe threats are discussed (see bullets and table on pages 32–33), and each threat category includes country-specific details on threats as well as documented 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.

Pollution: Nutrients

Land-based nutrient pollution, identified in all nine countries in this region (six with severe impacts), is one of the major forms of pollution identified in the North East Pacific region. Much research has been conducted on nutrient pollution in North America, but less so in parts of Central America. Few studies link pollution threats to socioeconomic impacts. What is known, however, is that agriculture, wastewater, and other sources contribute to the pollution problem, which is exacerbated by the lack of infrastructure in parts of Central America. Except in Costa Rica, there is a low level of sanitation coverage, so nutrient pollution from human sewage remains a prevalent threat in many Central American countries. Throughout the region, no matter the source, nutrient pollution may result in adverse impacts on the marine environment, including HABs. Algal blooms, in turn, can cause fish and coral mortality, as well as affect the communities that depend on the marine ecosystem for livelihood (United Nations Environment Programme (UNEP) 2006).

In Canada, rivers such as the Fraser River deposit dissolved and particulate organic carbon into the ocean (Johannessen, Macdonald et al. 2003). Such river-based discharges can lead to harmful algal blooms of Cochlodinium, a planktonic dinoflagellate species. First monitored on the west coast of Vancouver Island in late 1999, such blooms caused significant mortality to farmed salmon, amounting to CAN $2 million in economic losses (Whyte, Haigh et al. 2001).

Nutrient pollution also threatens Costa Rican waters, though the extent of the problem is unknown. In May 2002, an HAB caused massive fish mortality and human illness. However, more research needs to be conducted on this topic to gain a clearer picture of the impacts of such pollution (Vargas-Montero and Freer 2004).

The waters of Guatemala, like large portions of the tropics and subtropics, are defined by extreme nitrogen depletion. In general, the West Coast of North America is a "nitrogen sink," where active microbial denitrification occurs. High biological activity generates large amounts of organic material, which reduces oxygen concentrations and leads to low-oxygen environments that favor denitrification (Beman, Arrigo et al. 2005). Despite naturally high nutrient concentrations and productivity, these waters are highly vulnerable to land-based nutrient (in particular nitrogen) pollution. Nitrogen-rich agricultural runoff from Central American countries fuels large phytoplankton blooms in the Gulf of California, which strongly affect biological processes. One study predicted that by 2050, more than half of all nitrogen fertilizer will be applied in developing regions located upstream of nitrogen deficient marine ecosystems, thus exacerbating the problem (Beman, Arrigo et al. 2005). Another major source of pollution in Guatemala is untreated sewage wastewater; only 15 out of 344 municipalities apply treatment to their wastewater from urban areas. Sanitation/sewerage infrastructure, however, has greatly improved since the 1990s, though cholera is still prevalent in Guatemala, which, indeed, shows the highest levels of the illness among Central American countries (United Nations Environment Programme (UNEP) 2006).

Mexico similarly suffers from nutrient pollution. Two thirds of this country's sewage wastewater is discharged into the Pacific Ocean, causing microbiological pollution on beaches that affects both human health and tourism. Only 23% of municipal wastewater receives treatment (CNA 2002). Sewage also introduces harmful nutrients into the ocean (United Nations Environment Programme (UNEP) 2006). One study found high levels of phosphate-sewage pollution along the southern part of the U.S.-Mexico border, a result of poor sewage treatment (Segovia-Zavala, Delgadillo-Hinojosa et al. 2007). Similarly, another study showed that during dry weather, water quality standards were exceeded five times more often on Mexican beaches than on U.S. beaches (Noble, Dorsey et al. 2000). Agricultural runoff, however, may be the largest source of nutrient runoff in Mexico. Fertilizer application increased from 2.87 million tons in 1980 to 3.93 million tons in 2000, and use per hectare increased over this period from 110 kg/ha to 160 kg/ha (Espinoza 2002; United Nations Environment Programme (UNEP) 2006). Fertilizer use has caused eutrophication and HABs to the detriment of marine life and economic livelihood. Closed fishing seasons during algal blooms have resulted in economic losses of more than USD $200 million to the fisheries industry. Eutrophication has also led to more than 300 cases of paralytic shellfish poisoning, with 17 human mortalities (Schoijet 2002).

One area of particularly high concern is the Gulf of California transboundary marine ecosystem (Enriquez-Andrade, Anaya-Reyna et al. 2005; Hyun 2005). In the Altata-Ensenada del Pabellon lagoon in Sinaloa, waste effluents from intensive agriculture (especially sugarcane) and urban sewage pollute the waters

(Ruelas-Inzunza and Paez-Osuna 2004). Some solutions to these environmental problems may be to implement land-based pollution controls, marine protected areas, and stricter fisheries regulations. Tighter fisheries regulations, for example, can be applied to shrimp aquaculture in the Gulf, since aquaculture wastewater is a significant source of pollution for coastal and marine waters (Paez-Osuna et al. 2003). Reconnecting the Gulf of California with the Colorado River and its larger watershed may also be a solution (Hyun 2005).

Wastewater discharges in Panama are among the highest in Central America (United Nations Environment Programme (UNEP) 2006). Discharges of untreated domestic sewage far exceed national and international standards, polluting both marine life and jeopardizing human health (Defew, Mair et al. 2005). In El Salvador, most domestic wastewater discharged into nearshore waters is untreated. Such discharge in close proximity to swimming beaches and shellfish harvesting areas can cause microbial contamination and pose human health risks. A red tide event occurred in El Salvador from August 2001 to January 2002. Following the red tide occurrence in 2001, 41 slight to moderate poisonings associated with bivalve mollusks consumption were reported (Barraza, Armero-Guardado et al. 2004).

Certain parts of the Pacific Coast of the United States also suffer from nutrient pollution. Red tide has been recognized along the California coast for more than 80 years, with outbreaks documented most frequently in Santa Cruz and San Luis Obispo counties (Curtiss, Langlois et al. 2008). Diatom blooms have been responsible for numerous marine mammal and bird mortality events in Monterey Bay (Bargu, Powell et al. 2008). Nonpoint source runoff concerns are well documented in southern California, where most rivers are highly modified stormwater conveyance systems that are independent of the sewage treatment systems, so urban runoff flows unimpeded to the ocean. When storm events occur, runoff plumes can become large oceanographic features that extend for many kilometers (Noble, Weisberg et al. 2003). Newport Bay—a large estuary—shows evidence of anthropogenic nutrient loading, eutrophication, and hypoxia (Nezlin, Kamer et al. 2007). In 2003, a toxigenic diatom bloom occurred in the Santa Barbara Channel and caused massive mammal mortality (Anderson, Brzezinski et al. 2007). Toxic blooms of Pseudo-nitzschia recur along one of the most densely populated coastal stretches of the southern California Bight. The severity and magnitude of these localized events can be comparable to or greater than similar events in other geographical regions affected by domoic acid, which is associated with certain algal blooms (Schnetzer, Miller et al. 2007). Domoic acid can cause amnesic shellfish poisoning, and has also been documented (but is not a severe threat) in Puget Sound, Washington (Bando 2006).

Pollution: Land-Based Chemicals

Like nutrients, land-based chemical pollution is one of the major threats to the North East Pacific region. Chemical pollution has been identified in eight countries, four with severe impacts and four with moderate impacts. More research has been conducted on chemical pollution in North America than in Central America, leading to a more complete picture of the former. Nonetheless, chemical pollution derives from similar sources across the region, including agricultural pesticides and industrial wastewater-prevalent throughout both North and Central America-and mining, particularly in parts of Central America. Not surprisingly, higher levels of chemical pollution are found in urban, densely populated areas. Along with population growth, toxic discharges associated with expanding industrial activities are expected to increase in the future (Glover and Smith 2003).

When chemicals accumulate through the food chain or pollute sediments, they affect all functional parts of the marine ecosystem. Studies show that chemicals can endanger fishes' reproductive capacities, DNA, and immediate survival. Such changes have great potential to alter the entire food web. Chemicals can also jeopardize human health. Heavy metals bioaccumulate through the food chain and then pose a risk to people who consume toxic fish; such pollution is prevalent throughout the North East. As agriculture, mining, and industrial activities intensify and new synthetic compounds are developed, chemical pollution has proceeded unregulated and unmonitored. Many of the impacts of chemical pollution on marine ecosystems and humans are unknown.

In Canada, toxic chemicals threaten marine organisms and ecosystem health. British Columbia is subject to land-based chemical pollution from wastewater effluent, forestry and forest products, and mining, as well as the global atmospheric transport and deposition of "legacy" persistent organic pollutants, new pollutants, and metals. PCBs, polychlorinated dibenzodioxins (PCDDs) and polychlorodibenzofuran (PCDFs) have been found in sockeye salmon (Kelly, Gray et al. 2007), and other persistent toxic chemicals, such as polybrominated diphenyl ethers (PBDEs), in orca's, killer whales (Baird 2001; Rayne, Ikonomou et al. 2004). Chemicals have been shown to penetrate high-trophic marine mammals such as orcas, which in British Columbia have revealed very high concentrations of pesticides, industrial byproducts, and flame retardants. These endocrine disruptors affect the top of the food web (Ross 2006). The patterns of the PCDDs and PCDFs in British Columbia's porpoises were consistent with implication of chlorophenols as the source

of the PCDDs and PCDFs from wood and paper mills (Jarman, Norstrom et al. 1996). Regulations designed to reduce the production of dioxins and furans through pulp processes and wood preservative applications, however, have helped to reduce the discharges of these harmful substances into Canada's waters. Significant local PCB contamination has also been identified in Saglek Bay, Labrador (Kuzyk, Stow et al. 2005).

Land-based chemical contaminants also threaten Costa Rican waters, though the extent is unknown. Some coastal industries—such as Costa Rica's coffee industry—use large amounts of water, which is discharged into coastal waters without treatment (United Nations Environment Programme (UNEP) 2006). Research showed that the Gulf of Nicoya, an area of high biodiversity and extensive mangrove habitat, contains relatively high levels of PCBs (Spongberg 2006). Another study, however, suggested that environmental contamination in the gulf's shore does not adversely stress the area's mangroves (Rojas, Pizarro et al. 1994). Similarly, one study illustrated that the Gulf of Golfito, with its high PCB levels, exceeds the standard for safe swimming 200 times over, but other research revealed that most main estuaries in the tropical mangrove forests of Golfito Bay do not suffer from significantly polluted waters (Silva and Acuna-Gonzalez 2006). The Gulf of Dulce has moderate levels of PCBs, despite its surrounding protected environments (national parks) (Spongberg 2004). Although the exact impacts are debated, adverse affects on marine life are documented. Public health impacts have also been recorded. At Ostional anidation beach, 31% of olive ridley sea turtle nests near the estuary harbored Vibrio mimicus bacteria, which can cause gastroenteritis and ear infections if the eggs are ingested (Acuna, Diaz et al. 1999).

In El Salvador mining threatens marine life; areas influenced by mine tailings (such as Caleta Palito) showed heavy concentrations of chemicals near the discharge point (Ramirez, Massolo et al. 2005). Trace metal concentrations in oysters and sediments have also been found (though PCBs are low), but their wide variation reflects differences in loadings and the degree of bioavailability. Zinc and copper in oysters were elevated to levels considered representative of moderately polluted sites, although arsenic, cadmium, lead, and nickel were not elevated at most sites. More studies are needed to determine the extent of these metals' risks to ecological and human health (Michel and Zengel 1998).

While Mexico also suffers from land-based chemical pollution, chemicals may pose a relatively lower threat than nutrient pollution. For example, chlorinated hydrocarbon (CHC) pollution was found in lower amounts in sea lions in Baja California, Mexico, than in California (Del Toro, Heckel et al. 2006). Similarly, dioxin was also found in fish samples (Canedo-Lopez and Macias-Zamora 2007). None of the fish sampled throughout coastal Mexico reached the tolerable daily intake established by the World Health Organization (Canedo-Lopez and Macias-Zamora 2007). However, one area of particularly high concern is the Gulf of California transboundary marine ecosystem (Hyun 2005). La Paz Bay and La Paz Lagoon, for example, are vulnerable to wastewater discharges from the city of La Paz and from phosphorite mining in the region (Rodriguez-Castaneda, Sanchez-Rodriguez et al. 2006).

Land-based chemical pollution poses a grave threat to Nicaragua; much of the pollution derives from agricultural pesticides, which are discharged into the country's coastal lagoons. Although toxaphene (cotton pesticide) and DDT have been banned, residues of these compounds (which have long environmental half-lives) still enter Nicaragua's waters due to erosion of, and leaching from, agricultural soils in the region. High levels of toxaphene-tainted runoff in the Chinandega district (the site of much of the country's agriculture on the Pacific side) have contaminated nearshore marine sediments. Benthic animals such as clams are especially vulnerable to bioaccumulation of this toxic substance; if consumed, they can also threaten human health (Carvalho, Montenegro-Guillen et al. 1999; Carvalho, Montenegro-Guillen et al. 2003). Lower levels of chlorpyrifos, hexachlorocyclohexane and its isomer (HCHs), chlordane, and other residues were also found in lagoons in concentrations in lagoon sediments far above the threshold guideline values for the protection of aquatic life (Caselle, Love et al. 2002).

In Panama, an analysis of various metals showed that iron, zinc, and lead existed in high enough concentrations to pose moderate to serious contamination threats within the bay—and thus hinder the regeneration and growth of its mangroves. Previous surveys, however, indicate ongoing mangrove regeneration (Defew, Mair et al. 2005). Marine mammals are also indicators of pollution—or the lack thereof. Blubber and skin samples from 63 spotted dolphins collected in the waters of the Coiba archipelago showed relatively low, non-threatening levels of hexachlorobenzene (HCB), PCBs, and DDT. The ratio of DDT/PCB indicated predominantly agrarian versus industrial activities in the area; other statistics suggested both a local reduction of DDT inputs and a high rate of DDT degradation in the area (Borrell, Cantos et al. 2004).

The Pacific Coast of the United States suffers greatly from land-based chemical pollution—in particular PCBs and DDT, despite the phase out and ban of DDT in the 1970s and the ban on the sale and manufacture of PCBs in 1979. Many new, unregulated emerging contaminants such as endocrine disruptors and pharmaceuticals are not monitored and little research has examined

the impacts on marine systems, as well as on society (T.C. Hoffmann and Associates, LLC. 2008). A study conducted between 1984 and 1990 along the coast showed that the highest concentrations of most sediment-associated organic contaminants were present in the most highly urbanized areas, with several marine fish species showing bioaccumulation of contaminants. While during this period the concentrations of chlordanes, dieldrin, DDT, polycyclic aromatic hydrocarbons (PAHs) and PCBs in sediment and fish showed no consistent temporal trends, levels of PAHs (nonpoint source contaminants) showed consistent increases at urban and non-urban near-coastal sites (Brown, McCain et al. 1999). The highest concentrations of both PCDD/PCDF/coPCBs and PBDEs were found in the highly populated areas of Los Angeles, San Diego Bay, and San Francisco Bay, where PCB concentrations in fish still appear at levels 10 times higher than the threshold for human health. PBDEs and PCBs have also been found in marine mammals such as sea otters (Brown, Winkler et al. 2006; Davis, Hetzel et al. 2007; Kannan, Perrotta et al. 2007).

In northern and central California, runoff from California's Central Valley, municipal and industrial wastewater, atmospheric deposition, the erosion of historically contaminated sediment deposits, and the dredging and disposal of dredge material deposit contaminants into the water and sediment of San Francisco Bay. PCB concentrations in sport fish were, along with mercury, a primary cause of a consumption advisory for San Francisco Bay and its classification as an impaired water body under the federal Clean Water Act. The recovery of the bay from PCB contamination will take many more decades (Davis, Hetzel et al. 2007). In the San Francisco Estuary, studies conducted in the early 1990s found sediment toxicity (Anderson, Hunt et al. 2007). Annual monitoring data and modeling on Sigma PAH concentration in the bay since 1993 show levels elevated enough to harm estuarine fish. Research suggests that unless external loading levels of PAHs are controlled, San Francisco Bay is not expected to recover rapidly (Oros, Ross et al. 2007).

In southern California, nonpoint source runoff concerns are exacerbated because its rivers are highly modified stormwater conveyance systems that are independent of sewage treatment systems, so urban runoff flows unimpeded to the ocean (Noble, Weisberg et al. 2003). An estimated 99% of northern anchovy, 83% of Pacific sardine, and 33% of Pacific chub mackerel exceeded wildlife risk screening values for DDT (Jarvis, Schiff et al. 2007). Chromium and silver concentrations in fish and invertebrate species in Mugu Lagoon, Malibu Lagoon, and Ballona Wetlands also pose health hazards (Cohen, Hee et al. 2001). Elevated levels of estrogen, which can damage DNA, were found in flatfish at Orange County Sanitation District (Rempel, Reyes et al. 2006). Finally, significant cases of gastrointestinal illnesses from contamination in southern California beaches result in a loss of USD $21–51 million per year (Given, Pendleton et al. 2006).

Agro-industrial areas in California also show evidence of land-based chemical pollution, with far-ranging impacts. Runoff from small, urbanized tributaries may contribute as much or more to the loads than runoff from the agricultural Central Valley (Connor, Davis et al. 2007). Agricultural runoff has affected different species, such as mallards, northern pintails, and American coots, which reveal the effects of long-term cycling of selenium (Paveglio and Kilbride 2007). While mercury levels were significantly elevated in the Feather River, Cosumnes River, and San Joaquin River regions, the central Delta had concentrations that were relatively low (Davis, Hetzel et al. 2007). Along central California's coast (between Half Moon and Monterey bays), DDT—primarily from the Monterey Bay watershed—pollutes the waters (Hartwell 2008).

Other parts of the North American Pacific reveal chemical pollution as well. In the Pacific Northwest, where the partly protected coast harbors unique tide pools, seabirds, and pinnipeds, concentrations of PCBs exceeded NOAA Fisheries' estimated threshold for adverse health effects in chinook salmon, and DDTs was high in the Duwamish Estuary, the Columbia River, Yaquina Bay, and Nisqually Estuary (Yazvenko, McDonald et al. 2007). A study on fish DNA in Puget Sound revealed that environmental chemicals contribute to DNA changes in the gill (Malins, Stegeman et al. 2004). In western and northern Alaska, concentrations of 20 trace elements were measured in livers of polar bears; studies showed extremely high levels of copper in these mammals (Kannan, Agusa et al. 2007). Finally, in the Aleutian Islands, arsenic, lead, and mercury threaten predators that consume flathead fish containing the chemicals (Burger, Gochfeld et al. 2007).

Overfishing and Exploitation: Commercial Fishing

Commercial and industrial fishing are major threats in eight countries (four with severe impacts, and three with moderate impacts) in the North East Pacific. Overall, this region, with its coastal upwelling biome influenced by ENSO events, is extremely productive and supports economically valuable fisheries and aquaculture activities. But like nutrient and chemical pollution, more studies on commercial fishing's threats and socioeconomic impacts have been conducted for North America than for Central America, though both regions contribute to the threat.

Commercial and industrial fishing, while important industries, can lead to overexploitation of resources, marine degradation, and economic decline. In North America, habitat degradation, overharvesting, hydroelectric dams and other fish barriers, and

hatchery production have rapidly reduced northeast chinook salmon populations (Hoekstra, Bartz et al. 2007). Exploitative commercial fishing has led to the closure of many fisheries throughout the Pacific Northwest (Beamish, Noakes et al. 2000). In both the United States and Mexico, elasmobranch (sharks, rays, skates) landings exceeded 600,000 metric tons annually, significantly affecting that resource. In the Eastern North Pacific, catches of common thresher, shortfin mako, and blue sharks may exceed 14,000 metric tons annually (Holts, Julian et al. 1998). In Central America (in particular Costa Rica, Mexico, and Panama), the dried and live seahorse trade has led to substantial declines in seahorse abundance—exacerbated by incidental catches in shrimp trawl fisheries (Baum and Vincent 2005). An estimated 80% of the resources of greatest commercial interest in the Eastern Pacific (except tuna) are fully exploited or overexploited, and management plans have been implemented or are being developed to prevent the collapse of these fisheries, as has been the case in Mexico and Honduras (Beltran 2005). To aggravate the situation, fisheries management in Central America is generally failing to control illegal fishing. The depletion of fish stocks has a direct impact on coastal populations in that it reduces income and increases unemployment, thus weakening social stability and food security.

In Canada, commercial fishing, combined with other factors including climate change, has led to a reduction in certain fish species. One study revealed that the mean trophic level of fish (including Pacific herring and Pacific hake) landed in fisheries on the west (and east) coast of Canada is declining by 0.03–0.10 decade (-1)[6], similar to global trends (Pauly, Palomares et al. 2001). Pacific salmon abundance along the west coast of Canada has also been in sharp decline since the 1990s; reductions have been most severe for coho and chinook salmon, despite the large additions of hatchery-reared fry. Populations of wild coho are of particular concern (Noakes, Beamish et al. 2000). Steelhead populations have also declined since the 1980s (Welch, Ward et al. 2000). Destructive fishing practices, a type of habitat destruction, exacerbate the problem, as a study conducted on the effects of a shrimp beam trawl and prawn traps on sea whips at two bays on Clio channel, British Columbia, revealed. Further data, however, are needed to investigate the effects of trawling and trapping on fish, crustaceans, and mammals in Canadian waters (Troffe, Levings et al. 2005).

In Costa Rica, commercial fishing largely revolves around tuna, shark, other major pelagic species, and crustaceans (Beltran 2005; Wehrtmann and Echeverria-Saenz 2007). Forty-three percent of the tropical eastern Pacific species of shrimps are found on the Pacific coast of Costa Rica, which also harbors 117 species of shrimp and lobster (Vargas and Cortes 1999). The Terraba-Sierpe wetlands and fisheries provide fish and shellfish worth USD $6 million to local families (Reyes et al. 2004; Conservation International 2008). However, many species are overexploited, particularly in the Gulf of Nicoya. All species that reached maximum sustainable yields in the 1970s and 1980s are now considered overharvested, including two species of prawn (Tabash-Blanco and Palacios 1996; Wolff, Koch et al. 1998; Tabash-Blanco 2007). Blue crabs are similarly declining and affecting the market (Fischer and Wolff 2006).

Commercial fishing in El Salvador has not been thoroughly studied, though tuna, prawn, and other shrimp seem to be the most highly fished (Beltran 2005). Relative to other countries in the North East Pacific, El Salvador, which is primarily agricultural, contributes relatively little to the overall commercial fishing activity in the region—only about 0.3% of total fishing catches in Central America (United Nations Environment Programme (UNEP) 2006). Uncontrolled commercial fishing does, however, affect the coral reefs at Los Cobanos, a small rocky area in western El Salvador. Removal of carbonate rocks and coral to produce cement and extraction of coral colonies to be sold as souvenirs also play a role in the reefs' impairment (Reyes-Bonilla and Barraza 2003).

Guatemala, like El Salvador, contributes only a small fraction of the overall commercial fishing activity in Central America—about 0.09% of total fishing catches (United Nations Environment Programme (UNEP) 2006). But along the Pacific Coast of Guatemala, shrimp trawlers and the artisanal fleets seem to have exploited the rose-spotted snapper (Rodriguez and Antonio 2003). Tuna, shrimp, and shark are also highly fished species (Beltran 2005).

Like Guatemala, Honduras, which is primarily agricultural, has a very small (considered negligible) commercial fishing sector—and contributes about 0.5% of the total fishing catches in Central America (United Nations Environment Programme (UNEP) 2006). While Honduras's total fish catches are relatively small in the region, aquaculture has been increasing; 70% of Central America's total aquaculture production comes from Honduras and Panama (United Nations Environment Programme (UNEP) 2006).

In Mexico, which produces 77.6% of the fishing catches in Central America and has by far the greatest population in Central America, commercial fishing is a major threat (United Nations Environment Programme (UNEP) 2006). Although fisheries seem not to cause a significant impact to the ecosystem as a whole, target species (sardine, tuna, shrimp, and others) show signs of being fully exploited by fisheries. Red snapper and sharks

[6] According to Pauly, Palomares et al., trophic levels (TLs) are calculated from diet composition and TL of prey (for example, TL for plants and detritus are defined as 1, herbivores as 2, etc.) The findings of this report are based on data from United Nations Food and Agriculture Organization and the Canadian Department of Fisheries and Oceans and other Canadian sources for the period 1873–1997. See Pauly, Palomares et al. (2001) for details on calculations and trophic levels of major species studied.

showed the highest exploitation rates (Diaz-Uribe, Arreguin-Sanchez et al. 2007), with grouper and octopus at maximum exploitation levels (Beltran 2005). Commercial exploitation of abalone, which began about 1956 and collapsed in 1963, 1984, and, more recently, between 1994 and 1997, also occurs. Overfishing, combined with periodic ENSO that cause elevated sea surface temperatures, produced these fluctuations (Shepherd, Turrubiates-Morales et al. 1998). Scallop catches also declined steadily between 1991 and 1993 as a result of overexploitation, forcing the adoption of management measures such as reseeding programs (Felix-Pico, TrippQuezada et al. 1997).

While commercial fishing does not threaten all species or habitats, a 2005 study found that the mangroves on Mexcaltitán Island protect and act as nurseries for fish and shrimp, providing residents with direct fishing benefits of more than USD $1 million annually (Sanjurjo, Cadena, and Erbstoesser, 2005 in (Conservation International 2008)). Other management plans have been implemented or are being developed to prevent collapse of the fisheries in Mexico (Beltran 2005). Marine mammals and turtles are also commercially fished and exploited in Mexico. Grey whales, which were overexploited in the 19th and early 20th century, are now protected by national legislation—although still threatened (Urban, Rojas-Bracho et al. 2003).

Panama, although the smallest country by population in Central America, accounts for 10.6% of the total fishing catches in Central America and shows signs of overfishing (United Nations Environment Programme (UNEP) 2006). The highly fished species include anchoveta and herring (Beltran 2005), snappers and groupers, and shrimp (Beltran 2005). A 2001 study in the Gulf of Panama estimated that each kilometer of coastline generated an estimated USD $95,000 in shrimp and fish annually (Talbot and Wilkinson 2001). This is not, however, without other costs, as the scallop industry reveals. Between 1981 and 1990, the Gulf of Panama supported an important scallop fishery, but it collapsed in 1991. The population's failure to recover may relate to its lack of suitable available habitat for juveniles, predation, and variation in local oceanographic conditions. Further studies, however, are needed to fully determine causes (Medina, Guzman et al. 2007). Panama's seahorse trade also poses a major threat through commercial fishing. Seahorses (genus Hippocampus) are traded globally for use in traditional medicines, as souvenirs, and as aquarium fishes. The seahorse trade has expanded in Latin America in response to increasing demand; Ecuador, Peru, and Mexico export hundreds of kilograms per year. The live seahorse trade is more confined to Costa Rica, Mexico, Panama, and Brazil. However, reports showed substantial declines in seahorse abundance, attributed primarily to incidental catches in shrimp trawl fisheries. Additional conservation measures and monitored trade are needed to address fishing pressures on seahorse populations (Baum and Vincent 2005).

Along the Pacific Coast of the United States, commercial fishing produces great economic benefits, but has led to overexploitation of many species. In California, the commercial fishing industry generates approximately USD $550 million in total incomes and provides nearly 17,000 jobs. Along with overfishing, natural factors such ENSO events, which cause elevated sea surface temperatures, have reduced certain fish stocks such as market squid—by volume, the most valuable in the state, generating up to USD $40 million annually. The sardine industry, which had been the largest in the world during the early 1900s, radically declined in the 1960s, reappeared under precautionary management in the 1990s, and recovered by 1998 (Leet 2001).

Abalone, once abundant enough to support commercial fishing in both Washington State and Canada, are now extremely rare in the southern portion of their range in southern and central California. In Washington, northern abalones are in decline and exhibit recruitment failure, despite fishery closures. Similarly, flat abalones no longer occur in southern California, and have declined from 32% to 8% of the total number of abalones, Haliotis spp., inside a marine reserve in central California. Given its now limited range, both abalones are jeopardized by fisheries, sea otter predation, and ocean warming (Rogers-Bennett 2007). Most of the Pacific Coast of North America (including Alaska and British Columbia) has also seen severe declines in salmon, despite large additions of hatchery-reared fry and smolts. In some parts along the coast, such as central California, coho salmon are in danger of extinction (NOAA Technical Memo website 1995). The most likely reasons for the decline in Pacific salmon stocks include a combination of climate-related change, overfishing, and habitat destruction (Noakes, Beamish et al. 2000).

Overfishing and Exploitation: Artisanal/Recreational/ Subsistence Fishing

Artisanal, recreational, and subsistence fishing is also a major threat throughout parts of the North East Pacific, particularly Central America. Such fishing has been identified in eight countries; the five with severe threats are all in Central America, which also exhibits the largest research gaps. Recreational fisheries, for example, are not recorded in Central America, and most countries have no capture statistics (Beltran 2005). Artisanal/recreational/subsistence fishing pressures have much lower impact in Canada and the United States.

For those countries most affected by artisanal/recreational/subsistence fishing, depletion of fish stocks has a direct impact on coastal populations. Most of the catch from artisanal fisheries in

the North East Pacific consists of finfish (coastal demersal and pelagic species), shrimp, and some coastal crustaceans and mollusks, extracted using nets and, to a lesser extent, hooks and lines. Artisanal fishers often target high-value fish species such as snappers and groupers, which leads to conflicts between artisanal and commercial, industrial fishers competing for access to the same resources. A United Nations Food and Agriculture Organization (FAO) study showed a decrease in the fisheries catch from more than 200,000 tons in 1990 to 190,000 tons in 1999 (NOAA LME Website 2004). By reducing fish populations, smaller-scale fishers threaten income and increase unemployment, thus weakening social stability and food security.

In Costa Rica, exploitation of mud cockle clams (Anadara tuberculosa), of high economic importance to local resource users, exceeds sustainable levels; the clam is in danger of becoming extinct like the formerly abundant and bigger sister species, Anadara grandis (Stern-Pirlot and Wolff 2006). Other fish threatened by artisanal and recreational fishing include the sailfish, which has the greatest catch rates in the world in the Pacific off Central America. The species supports multi-million dollar catch-and-release sport fisheries associated with tourism in Costa Rica, Panama, and Guatemala. However, sailfish is often caught as by-catch in expanding coastal artisanal longline fisheries. Overall, regional sailfish abundance is 80% below its initial 1960s levels, and trophy sizes of recreationally caught sailfish have declined at least 35% from their unexploited trophy sizes (Ehrhardt and Fitchett 2006).

Along the Pacific Coast of Guatemala (as well as in Honduras), shrimp trawlers and artisanal fleets seem to have exploited the rose-spotted snapper (Rodriguez and Antonio 2003). Sharks and mahi-mahi are also exploited, and sea turtle numbers have declined while demand and commerce have increased. Local people observed more sea turtles nesting in the 1960s than in the 1980s along the Pacific coast between Puerto San José and the border with El Salvador. At that time, people noted collecting enough turtle eggs to fill a 100-pound size grain sack in one night; today, those eggs are rare, and virtually all are being harvested (Higginson 1989).

In Mexico, North Pacific loggerhead turtles remain casualties of artisanal fishing. Research showed that the minimum annual by-catch mortality in two fleets in Baja California Sur exceeded 1,000 loggerheads per year, rivaling that of oceanwide industrial-scale fisheries and threatening the existence of this endangered species (Peckham, Diaz et al. 2007). Giant squid, shark, and shrimp are also exploited by artisanal fisheries (Beltran 2005).

In Nicaragua, overfishing occurs mainly by artisanal fleets, which have moved significantly offshore within the past decade, with ranges of up to 50 kilometers. Primary targets include finfish, lobster, and shrimp, though little data exists on these fisheries (Beltran 2005). More studies need to be conducted to gain a more complete picture of overfishing in this region, which is expanding.

Although the effect of recreational fishing on local stocks is significant in the United States, catch of large stocks of migratory species such as albacore tuna seems negligible compared to commercial landings (Dotson and Charter 2003). Still, recreational fisheries generate USD $5 billion and account for more than 150,000 jobs in California (Leet 2001).

Other Regional Threats

The moderate impact threats discussed briefly below are worth mentioning due to the prevalent impacts they have now, as well as the impacts they could have in the future. Some of these threats, like climate change, still require more research.

Habitat Destruction: Aquaculture: Coastal Modification

Aquaculture-related coastal development and land reclamation, documented in six countries, is another pressing threat throughout the North East Pacific. Aquaculture is already a large industry in parts of Central America, where it provides employment for about half of the economically active population, and it is expanding in North America. In Central America, 70% of total aquaculture production comes from Panama and Honduras; the United States imports about 95% of the cultured shrimp exports (United Nations Environment Programme (UNEP) 2006). Starting in the mid-1980s, the Gulf of California ecoregion experienced a boom in shrimp aquaculture and became the second largest producer in the western hemisphere. Abalone aquaculture in California and Baja California is also expanding; between 1992 and 1997, production resulted in sales of more than USD $2 million annually (McBride 1998).

Aquaculture is responsible for many of the changes along the Pacific coastline. In Central America, which boasts 8% of the world's mangroves, continual development of shrimp farming has led to concern about the reduction of mangrove forests (Windevoxhel, Rodri´guez et al. 1999; Paez-Osuna, Gracia et al. 2003). More than 90% of the shrimp ponds have been constructed on former mangrove or salt pond areas (NOAA LME Website 2004). Other coastal lowlands have been converted from salt flats, marshes, and agricultural lands into shrimp ponds (Paez-Osuna 2001). Modification and deterioration of these ecosystems, particularly mangroves, affect the communities that depend on the valuable resources provided by these ecosystems. 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. Large areas of forest have been destroyed, resulting in lower incomes from fishing and extreme poverty in some communities (United Nations Environment Programme (UNEP) 2006).

Aquaculture produces other associated environmental problems as well, including pollution from municipal and agricultural effluents, risks to wild salmon, and safety problems. In Canada, salmon farms even create issues of environmental justice for coastal First Nations that other Canadians lack (Page 2007). Aquaculture also may give rise to diseases, whose treatment, in turn, threatens marine life. Studies showed that sea lice infection rates were between four and 73 times higher in farmed salmon than in wild, migrating salmon (Krkosek, Lewis et al. 2005). Chemicals used in the treatment of sea-lice infestations, however, may be lethal to shrimp and lobsters (Haya, Burridge et al. 2001). In Pacific Northwest salmon hatcheries, bacterial kidney disease caused by Renibacterium salmoninarum has become a serious problem, raising concerns that salmon reared in hatcheries may spread the disease to natural populations (O'Connor and Hoffnagle 2007).

Climate Change

Although this threat is not well researched in Central America, studies from the United States and Canada have documented climate change and its potential impacts. Sea surface temperature increases have been identified in five countries, with all existing gaps in Central America. Sea level rise has been documented only in Canada and the United States. Nonetheless, climate change is a threat that is expected to increase and compound all other threats in the entire North East Pacific.

According to a 2008 report assessing the impact of climate change along the U.S. Pacific Coast, an increase in tropical storms, intense flooding, and sea level rise should be expected (United States Climate Change Science Program (CCSP) 2008). During the ENSO of 1982–1983 and 1997–1998, sea levels from California to Alaska rose as much as 100 centimeters above average (Subbotina, Thomson et al. 2001), and more energetic wave conditions produced extensive coastal erosion and infrastructure damage (Allan and Komar 2002). Sea level rise leads to loss of wetland habitat due to submergence, changes to coastal watersheds and habitats, and increased vulnerability of agricultural and industrial infrastructure, especially in deltaic wetlands.

Throughout the Pacific, due to the tectonic activity of the region, local variation in relative sea level rise is prevalent. In British Columbia, relative sea level change differs from the global trend due to vertical land movements. During the 20th century, sea level rose four centimeters in Vancouver, eight centimeters in Victoria, and 12 centimeters in Prince Rupert, and dropped by 13 centimeters in Tofino (Natural Resources Canada 2007). Sea level rise in British Columbia affects coastal infrastructure, such as highways, sewer systems, shipping terminals, and Vancouver International Airport. 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 (Yin 2001). According to a government report, approximately 220,000 people live near or below sea level in Richmond and Delta in Greater Vancouver, and are protected by 127 kilometers of dykes that were not built to accommodate sea level rise (Natural Resources Canada 2007). Furthermore, many remote coastal communities and First Nations' heritage sites are vulnerable to enhanced erosion and storm surge flooding associated with sea level rise (Natural Resources Canada 2007). Sea level rise can also result in saltwater intrusion into freshwater aquifers, affecting the quality and quantity of drinking and irrigation water supplies (Natural Resources Canada 2007). Finally, climate affects sea turtles and other megafauna, although this is not well documented in this region. As documented in other regions, sea turtles' nesting beaches can be destroyed, their nests flooded, and their sex ratios altered—all caused by warmer air and sea surface temperature increases (Weishampel, Bagley et al. 2004; Chaloupka, Kamezaki et al. 2008).

Ocean acidification, which also results from increasing atmospheric CO2, has the potential to cause a variety of devastating effects (Kleypas 2006; Guinotte and Fabry 2008). The decrease in ocean pH is occurring more rapidly than expected. A recent study along the western coast of North America found that during upwelling events, water with a pH low enough to dissolve the shells of some planktonic organisms was reaching the coast (Feely, Sabine et al. 2008).

Highlighting Regional Solutions

This section highlights regional solutions to the threats facing the North East Pacific. Case studies and analysis documenting solutions are not prevalent in the literature and gaps exist in this region; below are some highlights gleaned from the research.

Regional Governance, Agreements, and Approaches

Regional policy mechanisms, regulations, and enforcement are crucial aspects of marine conservation efforts in the North East Pacific. Some regional agreements, as well as attempts to forge regional agreements, have taken place. Such efforts include the U.S. West Coast Governor's Agreement (2008), 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).

Regulations and Enforcement

Throughout much of the region, regulatory frameworks are weak, uncoordinated, conflicting, or nonexistent. Even the United States lacks effective frameworks in different areas—from ones governing water quality (e.g. emerging contaminants) to destructive fishing (a prevalent practice), and aquaculture. Marine aquaculture in the exclusive economic zone (EEZ), for example, does not operate within a regulatory framework that allows it to develop to its full (and sustainable) potential (Arsenault 2002). In parts of Central America, including Honduras and Nicaragua, general regulations regarding water management are shared among several institutions, leading to confusion in defining responsibilities. Costa Rica's water laws are obsolete (United Nations Environment Programme (UNEP) 2006).

The relatively successful regulatory frameworks illustrate their potential. The Washington (State) Department of Fish and Wildlife and the Native American Treaty Tribes of Washington are responsible for management of wild and cultured salmon, including disease prevention and control; the Department 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. Furthermore, many governments are unwilling to regulate economic activities for fear of constraining development—even if such development ultimately contributes to coastal and marine pollution (United Nations Environment Programme (UNEP) 2006). Another solution may be to strengthen the self-regulation of coastal communities, particularly those in Central America, so that they have greater responsibilities than the government and participate more fully in managing and regulating their resources (United Nations Environment Programme (UNEP) 2006).

Integrated Coastal and Ocean Zone Management

ICOZM, an approach for coastal and ocean management regarding all aspects of the coastal and ocean zone, including geographical and political boundaries, is an effort towards achieving sustainability (see the discussion in the Pacific Ocean overview section). Throughout Central America, fishing activities produce at least USD $750 million annually and support 450,000 people. The region's natural heritage is conserved in approximately 11 protected areas, and about 50% of the coastal zones support tourism. ICOZM in this region, however, has been limited by information gaps, restricted technical and financial capacity, and sectoralism. Regional projects by governmental agencies and NGOs, however, are creating a more effective framework for ICOZM (Windevoxhel, Rodri´guez et al. 1999). In Mexico, for example, where the main industries (oil and gas, fisheries, aquaculture, tourism, maritime transportation and ports, chemical industries, and minerals) are located in the coastal and marine zones, an environmental legal framework based on the Ley General del Equilibrio Ecologico y la Proteccion al Ambiente (LGEEPA) identifies ICOZM as an important strategy that considers both ecosystems and socioeconomic issues (Rivera-Arriaga and Villalobos 2001). And, throughout the Gulf of California ecoregion, where the threats caused by shrimp aquaculture have led to serious harm to the coastal and marine ecosystem, ICOZM—together with an effective regulatory program—offers a solution for sustainability (Paez-Osuna, Gracia et al. 2003).

ICOZM is place-based and can take an ecosystem-based approach to management. Like ICOZM, ecosystem-based management, or EBM 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. Taking into account the whole ecosystem, including humans and the environment, offers one solution to the problems facing the North East Pacific, particularly those related to fisheries management. EBM pilots are occurring in Morro Bay and Elkhorn Slough in California as well as other places.

Some management activity in commercial marine fisheries shows progress. In Mexico, the main fisheries (sardine, tuna, and shrimp) have been regulated and have had management plans since 1994, and some specific environmental provisions have been established. In Guatemala, no new licenses have been issued for shrimp since 1987 (though there is open access for artisanal fishers). El Salvador and Costa Rica both have existing management plans. Work still needs to be done, however; Nicaragua's main fisheries lack management plans (Beltran 2005).

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

MPAs provide valuable ecological and socioeconomic benefits to the Pacific North East. The region has begun to implement MPA networks; transboundary and/or serial MPAs offer further protection for larger, connected ecosystems. The recent Marine Life Protection Act led to the implementation of MPA networks along the central California coast, and a process is in place to complete a statewide network in 2011. Indeed, continued fishery closures and protection in no-take reserves have been shown to be effective tools for allowing the persistence of depleted red and black abalone populations in central California (Micheli,

Shelton et al. 2008). In the Gulf of California, a network of MPAs is being developed and a marine endowment has been established to support management (Lluch-Cota, Aragon-Noriega et al. 2007). In Central America, transboundary MPA networks are being implemented; United Nations Educational, Scientific and Cultural Organization (UNESCO) and Conservation International have initiated a transboundary project with Costa Rica, Panama, and Ecuador, which already have World Heritage sites (UNESCO website 2008). In British Columbia, marine reserves showed healthier and more abundant northern abalone than in non-reserve areas (Wallace 1999).

Market-Based Solutions and Alternative Livelihoods

Canada has implemented various policies to help negate the effects of commercial overfishing, which often involves use of destructive fishing practices such as shrimp beam trawls (Troffe, Levings et al. 2005). In 1997, British Columbia fisheries management moved from trip limits and turned to individual transferable quotas (ITQs) for multispecies fisheries. Total catches have remained stable, while individual incentives to retain marketable catches and improve economic efficiency resulted in low discards of marketable fish, increased ex-vessel prices, and higher per-vessel revenue (Branch 2006). Stock-specific estimates are used for delegating ITQs in chinook salmon (Winther and Beacham 2006). Another approach is area licensing, which was instituted in British Columbia's coastal fisheries in 1996 and was made available to fishers who wished to participate in more than one area fishery. A license retirement program was also initiated to reduce the commercial fishing fleet by 50%, which was successful (Shaw, Preston et al. 2001). Harvest closures also protect fish; Northern (Pinto) abalone has been protected by harvest closures since 1990, due to its low population levels (Atkins and Lessard 2004). Finally, in the 1990s, Fisheries and Oceans Canada developed an approach for evaluating proposals for new fisheries for lightly/underexploited species and for providing scientific advice to fisheries managers. This approach has shown that the development of new fisheries can proceed while preventing overexploitation; it also builds partnerships between fishery assessment, regulatory agencies, and fishing proponents (Perry, Purdon et al. 2005).

In the United States, Alaska offers an example of successful EBM. 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 sea floor habitat, marine mammals, and seabirds (Witherell, Pautzke et al. 2000). A U.S.-based study also explored the efficiency and effectiveness of an individual habitat quota (IHQ) versus MPAs for conserving habitat-dependent, sessile species. It concluded that an IHQ policy with a conservatively established habitat target is better suited to the protection of these species than a rotating or fixed MPA policy (Holland and Schnier 2006). Fishery cooperatives are an alternative to ITQ management; the U.S. Congress recently passed a law that promises the ability to "rationalize" one of the world's largest fisheries, the North Pacific pollock fishery, by enabling pollock fishers to form cooperative bargaining units that are guaranteed a fixed share of the total allowable catch (Matulich, Sever et al. 2001).

North America is currently reforming its fishery business models due to closures or stock decline. For example, in the State of California, a new initiative, the California Fisheries Fund, is a revolving loan program to help fishers develop sustainable business plans with higher investment returns. Loans will support new ideas for eco-labeling for premium local markets and technology to reduce waste and by-catch. The Nature Conservancy (TNC) purchased seven federal trawling permits and four trawling vessels from commercial fishers in Morro Bay, California to buy out Pacific fishing permits and boats for conservation purposes; as of early 2009, TNC was still trawling with at least one of the boats. The acquisitions are part of a collaborative effort with fishers and government regulators to protect 3.8 million acres of ocean and help reform a troubled fishery. Other innovative solutions are being developed in San Diego, where the San Diego Waterman's Association is piloting a new permitting system called Territorial Use Rights Fisheries (TURFs). Similar in concept to customary marine tenure systems throughout the Pacific, TURFs fishing rights and access are assigned over a particular area.

Acute poverty exists throughout much of Central America, and 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 reduce the impact of commercial fishing and the expanding artisanal fishing, there needs to be a focus on reducing fishing effort and increasing alternative livelihoods for fishers. No-take zones could be established as well. Tourism, which is a major industry in the region, could provide alternative livelihoods, especially in Central America. One study found that ecotourism in the Bahia de los Angeles, Mexico, could provide an important source of income for the 700 residents, between USD $78,030 and $111,843 annually (Low-Pfeng, de la Cuera and Enríquez, 2005 in (Conservation International 2008)). Aquaculture in Central America is another avenue, yet it needs to be developed in a sustainable manner.

IV. North West Pacific Ocean Regional Analysis: Threats, Impacts, and Solutions

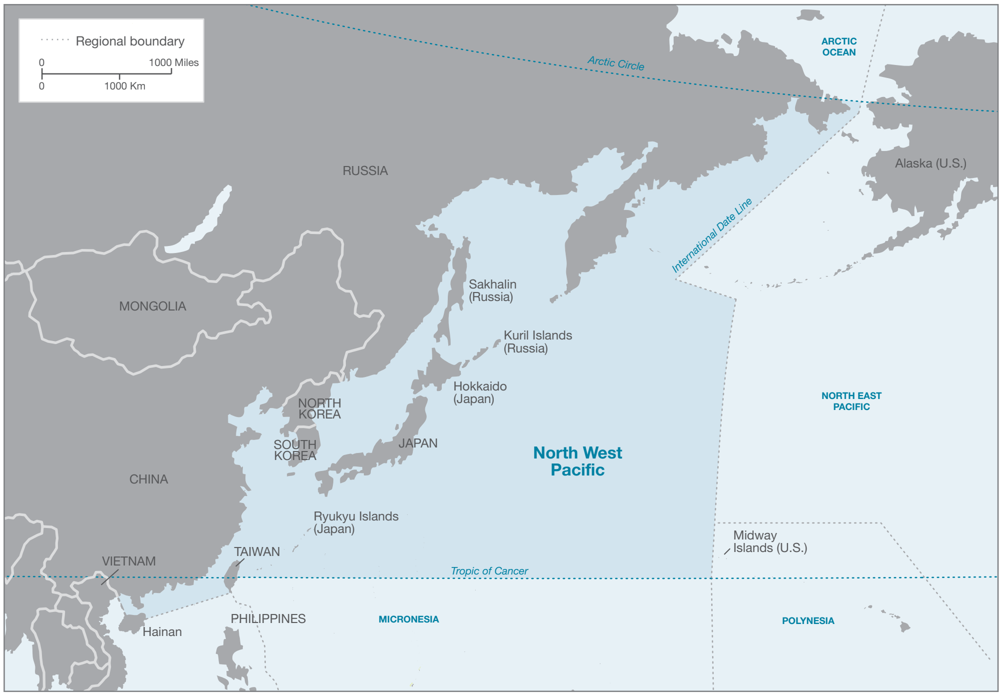
Photo: Lion's mane jellyfish *(Cyanea capillata)* at the rocky reef of the Peter the Great Bay, Sea of Japan. (© Konstantin Tkachenko/ Marine Photobank)

The North West Pacific Ocean comprises the countries of China (including Hong Kong and Taiwan), Japan, North Korea (The Democratic Republic of Korea), South Korea (The Republic of Korea), and Russia. Because scientific studies often report results in this manner, in this report we have grouped North and South Korea as one country, and China, Hong Kong, and Taiwan as one country.

Covering a vast area, the North West Pacific contains some of the most diverse and commercially productive marine ecosystems and seas, from the Yellow Sea to the Bering Sea, Sea of Japan, and Sea of Okhotsk. Each country is unique; the southern Japanese archipelagos have globally significant coral reefs, while China's key coastal and marine habitats include mangroves, corals, wetlands, and seagrass beds. The intertidal mudflats of the Yellow Sea harbor important migratory shorebirds, Korean waters contain more than 850 fish species, and Russia's seas make up four ecoregions listed in the World Wildlife Fund Global 200 list of ecoregions vital for maintaining biological diversity (Sien 2001). The Sea of Okhotsk, surrounded by Russia and northern Japan, contains some of the world's richest fishery resources, with approximately 340 fish species (Alekseev, Baklanov et al. 2006). The Bering Sea, covering more than two million square kilometers and falling within the jurisdiction of both Russia and the United States, has extremely high productivity driven by nutrient upwelling and seasonal sea ice. It supports many endangered whale species, unique seabirds, and many species of commercially valuable fish, including the Pacific salmon and king crab.

Of all the regions, the North West Pacific contains the greatest number of moderate to severe impacts (seven moderate, nine severe). All four broad threats (overfishing and exploitation, climate change, habitat destruction, and pollution) have severe to moderate impacts across the region, though studies on invasive species are found only in China. Commercial fishing, identified as a severe impact threat in all four countries, is one of the most serious threats in the region. It can cause ecological shifts that reduce fish stocks and threaten food supply. Pollution, in particular land-based chemicals, nutrients, oil spills and antifouling chemicals, solid waste, and waste and

Map 3: North West Pacific Ocean



Source: International Ocean Commission and The United Nations (www.unep-wcmc.org/gramed) 2008 Lucidity Information Design, LLC

toxic dumping, represents another severe threat, with chemical pollution (identified in all countries, with severe impacts in three) as extremely serious region-wide. All can create dead zones and algal blooms, alter the ecosystem structure, and jeopardize human systems. Destructive fishing and sedimentation, forms of habitat destruction that lead to the degradation of critical ecosystems that produce invaluable services and products for society, are also severe threats. Finally, climate change—in particular sea surface temperature increases and sea level rise—exacerbates all of the threats above. It not only destroys marine ecosystems, but can create uninhabitable areas. Significantly, none of these various threats operate in isolation, but rather function as multiple, compound stressors that together can devastate marine and human systems.

The North West Pacific Ocean discussion that follows first presents overall regional trends of severe and moderate impact threats, including a table listing the levels of threats and impacts in each country. Then, the literature review section offers a more in-depth discussion of the most severe impact threats. Moderate impact threats are also presented if they are prevalent or notable throughout the region. Finally, the last section provides a brief overview of potential solutions to the threats facing this region as a whole.

Generally, more research needs to be done on Russia in all major threat categories.

North West Pacific Regional Trends: Primary Threats and Associated Environmental and Socioeconomic Impacts

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

Based on this assessment, the threats with overall severe impacts across the entire North West Pacific region are:

- commercial overfishing identified in all countries.
- sea surface temperature increase and land-based chemical pollution identified in all countries. with a majority of severe impact ratings.
- nutrient pollution identified in all countries.
- land-based sedimentation identified in all countries.
- solid waste disposal identified in all countries.
- destructive fishing identified in all countries.
- oil spills, antifouling chemicals, ocean waste, and toxic dumping found in all countries.

The threats with overall moderate impacts across the region are:

- sea level rise identified in all countries.
- coastal modification from aquaculture identified in three countries.
- wastewater pollution from aquaculture identified in three countries.
- coastal development/land reclamation identified in three countries.
- radionuclides identified in three countries.
- artisanal/recreational/subsistence fishing identified in three countries.
- offshore oil/mining identified in two countries.

Key observations regarding research gaps and identified impacts:

- The North West Pacific is one of the largest regions, and the countries' marine environments are some of the least protected, and most exploited, in the Pacific Ocean.
- China contains the greatest total number of impacts in the region, most of which are moderate (nine) and severe (13).
- Large gaps in the research include studies on habitat destruction in Russia, invasive species, and the impacts of threats in Russia and North and South Korea.
- Russia contains the least documented number of identified threat categories, as well as the least total number of documented impacts.

The following table distills the findings from the literature, documenting by country, threats and environmental and socioeconomic impacts. There is considerable variation in availability of scientific literature in this region. Large gaps in the research include studies on climate change, land-based pollution, and the impacts of threats in Russia and North and South Korea. But as the table shows, the North West Pacific Ocean faces mounting threats. This region's marine environments are some of the least protected, and most exploited, in the Pacific Ocean.

TABLE 2: North West Pacific Threats Based on Scientific Literature and Impact Assessment

✓ Identified as Threat

● Severe Impact ● Moderate Impact ● Low Impact

It was documented when an article identified an issue as a present or future threat. If no scientific literature was found on the topic, then no check was assigned. This does not necessarily mean the topic is not a threat; rather, it suggests that no scientific literature was found on the topic.

	CHINA		KOREA (NORTH & SOUTH)		JAPAN		RUSSIA	
	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts
POLLUTION								
Aquaculture: Wastewater	✓	● Severe	✓	● Moderate	✓	● Moderate		
Land-based Chemicals	✓	● Severe	✓	● Severe	✓	● Severe	✓	● Moderate
Fishing Lines/Nets	✓	● Moderate			✓	● Moderate		
Nutrients	✓	● Severe	✓	● Severe	✓	● Severe	✓	● Low
Offshore Oil/Mining	✓	● Moderate					✓	● Severe
Oil Spills & Antifouling Chemicals	✓	● Severe	✓	● Moderate	✓	● Moderate	✓	● Severe
Radionuclide			✓	● Moderate	✓	● Moderate	✓	● Moderate
Solid Waste Disposal	✓	● Severe	✓	● Severe	✓	● Severe	✓	● Low
Thermal	✓	● Moderate	✓	● Moderate				
Ocean Waste & Toxic Dumping	✓	● Severe	✓	● Moderate	✓	● Moderate	✓	● Moderate
HABITAT DESTRUCTION								
Anchor Damage								
Aquaculture: Coastal Modification	✓	● Severe	✓	● Moderate	✓	● Moderate		
Coastal Development/Land Reclamation	✓	● Severe	✓	● Moderate	✓	● Moderate		
Destructive Fishing	✓	● Severe	✓	● Moderate	✓	● Moderate	✓	● Severe
Dredging	✓	● Moderate	✓	● Moderate				
Marine Recreation	✓	● Low						
Land-based Sedimentation	✓	● Severe	✓	● Severe	✓	● Severe	✓	● Low
Ship Groundings								
Tsunamis					✓	● Severe		
Typhoons/Cyclones/Hurricanes & Storm Surge	✓	● Moderate			✓	● Moderate		
Wrecks/Military Equipment								
OVERFISHING & EXPLOITATION								
Aquaria Trade	✓	● Moderate			✓	● Low		
Artisanal/Recreational/Subsistence Fishing	✓	● Moderate	✓	● Moderate	✓	● Low		
By-Catch & Discharge	✓	● Moderate	✓	● Moderate	✓	● Moderate	✓	● Moderate
Commercial Fishing	✓	● Severe	✓	● Severe	✓	● Severe	✓	● Severe
CLIMATE CHANGE								
Acidification								
Sea Level Rise	✓	● Moderate	✓	● Moderate	✓	● Severe	✓	● Low
Sea Surface Temperature**	✓	● Severe	✓	● Moderate	✓	● Severe	✓	● Severe
INVASIVES								
Invasive Species (Different Vectors)	✓	● Severe						

**Changes in SST is strongly associated with El Niño Southern Oscillation (ENSO) events, which are predicted to increase in frequency and intensity over time due to climate change.
For a complete list of references used for the literature review and synthesis to create this table see Appendix C, Table 2 p.132.

North West Pacific Literature Review of Severe and Moderate Impact Threats

The discussion that follows highlights the greatest threats to the North West Pacific. The most severe threats are discussed (see bullets and table above), and each threat category includes country-specific details on threats 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.

Overfishing and Exploitation: Commercial Fishing

Commercial and industrial fishing, an overall severe threat to the North West Pacific region, illustrates the major impact of overexploitation and unsustainable use of ocean resources on marine life and human livelihood. Commercial fishing is documented in all four countries in this region, with a severe impact in each, though it is less researched in North and South Korea. Overall, the North West is an extremely commercially productive region. But the overexploitation of its vast resources can greatly reduce fish stock, alter food web dynamics, and lead to economic loss.

Like other threats in the region, commercial fishing is a serious transboundary issue. Fisheries resources in both the Chinese and Korean waters of the Yellow Sea (the northern part of the East China Sea, also associated with the Bohai Sea), for example, are among the most intensively exploited in the world. About 100 species of fish and crustaceans are commercially harvested, but due to overexploitation and natural fluctuations, the major fisheries are at an extremely low level compared with three decades ago, and are no longer economically sustainable (Teng, Yu et al. 2005). In the East China Sea, overexploitation of fish stocks is so serious that the Chinese government enacted an annual, three-month fishing ban for commercial fishing (Qu, Xu et al. 2005). Because the major commercial species caught in the Yellow Sea are largely migratory, the catches in waters from both the Chinese and Korean side could incite transboundary issues (Teng, Yu et al. 2005).

China's marine fisheries have grown rapidly for decades. In 1989, total fisheries production reached 1,148,000 tons, ranking China third among the leading fishing countries and territories of the world. However, China's marine fisheries have suffered from offshore overfishing and the depletion of fishery resources, particularly stocks of yellow croakers and hairtails, suggesting problems with offshore fisheries regulations (Yu 1991). In Hong Kong, overfishing has given rise to environmental and economic concerns (Morton 2005). Traditionally targeted fishes had already been overexploited by the 1970s, paralleling a dramatic expansion of fishing effort. The ecosystem structure shifted as the large predatory species became depleted, and small fishes and benthic invertebrates gained dominance. High demand for small fishes as fish-feed for aquaculture farms, high market price of benthic invertebrates, and reduced operational costs of fishing by small boats all contribute to continued depletion (Cheung and Sadovy 2004). Species most affected by unsustainable practices include abalones and sharks (Cheong 1996; Cheung and Chang 2003).

In Korea, fisheries products supply almost one third of the animal protein that Korean people consume (MyongSop and MoonBae 2002). Since the 1980s, there has been a decline in the deep sea fishing industry and a rise in the production of marine aquaculture. Between the 1950s and 1970s, the government expanded commercial fishing, especially in coastal areas. The commercial Korean longline fishery has existed for yellow fin, big eye, and albacore tunas since the mid-1960s, the Korean purse-seine fishery started in 1980, and commercial fishing activity began in the western tropical Pacific Ocean in 1982, mostly for skipjack tuna (Park, Yang et al. 1994). International pressure to reduce or abolish fisheries subsidies, among other threats, calls into question the long-term sustainability of the industry (MyongSop and MoonBae 2002).

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 (Alekseev, Baklanov et al. 2006). More than four million tons of bioresources are harvested annually in the Russian Far East EEZ; the most desirable species include salmon, walleye, pollock, crabs, shrimp, sea urchins, and sea cucumber. The fisheries industry thus greatly affects the local economy, as well as the culture of the region and distribution of fishing settlements (Alekseev, Khrapchenkov et al. 2006).

But since the early 1990s, total catches in the Okhotsk Sea have been reduced by two to 2.5 times. Catches of pollock, the major commercial species, have decreased due to overfishing by international fishing fleets, since the central area of the Okhotsk Sea lies outside any country's EEZ and is therefore unregulated (Alekseev, Khrapchenkov et al. 2006). Until recently, vessels from different countries fished intensively in the sea (its non-Russian fishery closed in 2003, with the exception of Japanese gillnet fishing for salmon). Poaching also occurs. Several crab species (including king, blue, snow, and hairy crab), sea urchins, sea cucumbers, and scallops have the highest illegal catches.
In 2000, the amount of king and blue crabs caught within the

Russian EEZ and delivered markets of Japan and the U.S. exceeded the total allowed catch volume 1.77 times; in 2001 the exceedance was 2.57 times; and in 2002 the exceedance was 2.40 times (Glotov and Blinov 2006). Another example is the under-reporting of wild sockeye salmon catches in Russia. In the years 2003–2005, the median quantities of annual excess catch were estimated to range from 8000 to 15,000 tons, representing a value of USD $40–74 million and demonstrating that actual catches are 60–90% above reported levels (Clarke, McAllister et al. 2009).

Habitat Destruction: Destructive Fishing

Destructive fishing, which is recorded in the entire region (with two severe and two moderate impacts, considering North and South Korea together), often accompanies the commercial and industrial exploitation of fish. While prevalent throughout the North West Pacific, it is not always thoroughly documented in the literature. Research gaps exist in North Korea and South Korea, for example. However, what is known is that not only does this practice indiscriminately kill large populations of fish and other marine organisms, it can also devastate their physical habitat. Bottom-trawling, a common type of destructive fishing in the North West Pacific, destroys benthic habitats and exacerbates the threat of commercial fishing by dragging nets weighted down by metal girders across the sea bed. Such practices can lead to large-scale food web and ecosystem changes, and further reduce fisheries catches.

China recently experienced fishery management challenges associated with electrical beam trawls, a technology developed in the early 1990s. This technology resulted in an increase in shrimp catch rates, and at its height, more than 3,000 vessels used electrical beam trawls in Zheijiang Province, and an even greater number along the Chinese coast. However, lack of regulation enabled fishers to cause damage to juvenile shrimps and other benthic species. In 2001, China banned this fishing method in waters off Zheijiang Province and parts of the East China Sea (Yu, Chen et al. 2007).

Destructive fishing prevails elsewhere in the North West Pacific. In Japan, driftnet fishing, which catches everything that enters its path, is believed to have reduced the populations of such commercially viable fish as tuna, marlin, swordfish, and salmon. Driftnet fishing, the most destructive pelagic fishing method, entails drifting nets—usually a gill net with floats—attached to a rope, ranging in length from 25 meters to four kilometers. In the mid 1980s, Japan operated about 900 driftnet vessels earning approximately USD $300 million per year. However, concern over this practice led to a ban on driftnet fishing in the high seas in 1992 (Lee 1997). One study showed that the Japanese land-based driftnet fishery for salmon also produced significant by-catch, including thousands of seabirds from more than a dozen species (DeGange and Day 1991).

In Russian waters, driftnet fishing is a transboundary issue. Not only does it affect targeted fish populations and catch non-target species as by-catch, but because Russia sells the right to fish inside the Russian EEZ, this type of fishing has also incited international controversy for the indiscriminate destruction of marine life.

Climate Change: Sea Surface Temperature Increase

Global climate change affects all aspects of an ecosystem, including increasing sea surface temperatures. Climate change has generally not been well researched throughout the North West Pacific, particularly the threats and socioeconomic impacts in Russia and North and South Korea. However, sea surface temperature increase has been identified in all four countries, three with severe impact and one with moderate impact. Other aspects of climate change, including sea level rise (a moderate impact threat) and acidification, are even less well documented. But now as in the future, the levels of these climate change-induced threats are expected to increase and compound all other threats, such as overfishing and pollution.

The impact of climate change on marine biogeochemical parameters and ecosystems is one of the most important issues in the North West Pacific. Studies suggest that sea surface temperature is rising faster in the North West Pacific than in other parts of the world's oceans. In terms of annual mean, the warming rate of surface air temperature and sea surface temperature ranged from 0.15 to 0.21 °C per decade in and around the main stream of the Kuroshio in the East China Sea, which exceeded the global mean warming rate of 0.128 ± 0.026 °C per decade between 1956 and 2005, as reported in IPCC 2007. Direct evidence of marine pelagic ecosystem change has been found with the warming of seawater and sea level rise in the main stream of the Kuroshio in the East China Sea and the North West Pacific during the last three decades. Overall, increasing sea surface temperature correlates with the biological productivity of the region, and can lead to biological and economic loss.

Within the region, climate change and sea warming impacts are well documented in North and South Korea. Climatic regime shifts over the North Pacific in 1976 and 1988 changed the dynamics of the marine ecosystem by altering patterns of biological primary production—and thus fisheries resources—in Korean waters. Primary production increased again after 1988, with the biomass and production of sardine collapsing and mackerel increasing (Zhang, Lee et al. 2000).

In and around Japan and the East Sea, climatic and oceanic regime shifts strongly affect the structure of fish communities, and may pose a larger threat than commercial fishing. No evidence shows "fishing down food webs" (i.e. at lower trophic levels) in this region, although, in addition to the impacts of abrupt shifts occurring in the late 1980s, the large predatory and demersal fishes seem to be facing stronger fishing pressures with the collapse of the Japanese sardine (Tian, Kidokoro et al. 2006). Sea warming in this region in the late 1980s also caused serious coral bleaching. Since 1998, the year of the worst coral reef bleaching around the globe ever recorded, most of the reefs have recovered in Japan, Taiwan, and possibly China. However, in summer 2001, with increasing sea surface temperatures, more bleaching occurred in Japan; the Southern Ryukyu Islands experienced the most severe coral mortality in the region, with 46-69% death (Dai, Gang et al. 2002). The total estimated cost of severe bleaching for Japan approaches USD $7 billion in net present value, according to a 50-year time horizon with a 3% discount (Cesar, Burke et al. 2003).

During the last decade, the waters around Russia have also experienced sea surface temperature increases. The southeastern Bering Sea shelf underwent a warming of 3 °C that is closely associated with a marked decrease of sea ice over the area. The warming of the eastern Bering Sea shelf could profoundly influence the ecosystem of the Bering Sea—from modifying the timing of the spring phytoplankton blooms to the northward advance of subarctic species and the northward retreat of arctic species (Stabeno, Bond et al. 2007). Although recent decades of ocean observation suggest possible links between climate change and species fluctuations, mechanisms linking climate and population fluctuations are only starting to be understood. Research suggests strong links between sea warming and the long-term viability of populations in the southeastern Bering Sea; the deaths of hundreds of thousands of short-tailed shearwaters in 1997 offer evidence of this connection (Baduini, Hyrenbach et al. 2001). Furthermore, sea ice associated phytoplankton blooms 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. Melting sea ice, a result of warming temperatures, has increased the geographic extent of sea ice-associated phytoplankton blooms in the southeastern Bering Sea, which can critically affect the entire food web structure, from lower trophic level production to marine fisheries. Indeed, changes in sea ice thickness, snow depths, and the timing of break-up all influence pupping and foraging success for ice-associated mammals (Hunt, Stabeno et al. 2002). Ice-associated blooms, superimposed on a gradual ecosystem shift attributed to global climate change and increasing sea surface temperatures, can dramatically alter the Bering Sea ecosystem (Jin, Deal et al. 2007).

Despite these trends, and though climate variability has altered the rich Bering Sea ecosystem in the past, its relative importance to fisheries' impact on shaping the current ecosystem remains uncertain (Aydin and Mueter 2007). Recently, major declines of marine mammal and bird populations have raised the question about causes: were the declines from fishing pressure, or driven by climate change effects? (Schell 2000). Commercial fishing is further discussed on page 48.

Sea level rise is also a future threat (presently a moderate impact threat) to the region. Data shows that in the last decade, the rise in sea level has been higher than global averages and predictions. Patterns of recent sea level rise in the East/Japan Sea over nine years reveal average trends of 5.4 ± 0.3 mm yr(-1) for the entire sea and 6.6 ± 0.4 mm yr(-1) for the southern part of the sea. These levels are much larger than the global rates of 3.1 ± 0.4 mm yr(-1) reported by Cabanes et al. (2001) and 2.8 ± 0.4 mm yr(-1) (Kang, Cherniawsky et al. 2005). As an island country, Japan is particularly vulnerable to sea level rise. Many people will be affected, with great potential for the loss of land, wetlands, and capital (Nicholls and Mimura 1998). Around the Korean Peninsula, the sea level has risen by 0.28 centimeters per year over the past two decades. Again, this rise is about two times higher than that of the global increase (Youn, Oh et al. 2004). In China, sea level rise had great impacts on China's coast in the past century, including increased coastal erosion, degraded coastal ecosystems, exacerbated saltwater intrusion, and enhanced storm surges (Li, Fan et al. 2004). The impacts of climate change and the adjustments of coastal systems throughout the region are highly localized, resulting from local differences in climate change, coastal physiographic and ecological conditions, and the resilience of coastal systems. Societal vulnerabilities to climate change are greatly influenced by their adaptive capacities and selective adjustment, which are heavily determined by local socioeconomic conditions (Li, Fan et al. 2004).

Pollution: Land-Based Chemicals

Land-based chemical pollution is an extremely serious form of pollution throughout the North West, with documented impacts in all countries (three with severe impacts). Much research still needs to be done, however, on land-based pollution, particularly the threats and socioeconomic impacts in Russia and in North and South Korea. Land-based chemicals deposit heavy metals and persistent organic pollutants into the North West Pacific Ocean. Not surprisingly, higher levels of chemical pollution are found in urban, densely populated areas, like the large, rapidly

growing cities in China, where industrial growth is proceeding at an unprecedented pace. 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, they affect all parts of the marine ecosystem, from the fish on down. Studies show that chemicals can endanger fishes' reproductive capacities, DNA, and very existence. Such changes have great potential to alter the entire food web. Chemicals can also jeopardize 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 throughout the North West region. As agriculture, mining, and industrial activities intensify and new synthetic compounds are developed, chemical pollution has proceeded unregulated and unmonitored. Many of the impacts on marine ecosystems and humans are unknown.

Southern China's and Hong Kong's waters show vast evidence of chemical pollution, which derives from a variety of sources, including industrial wastewater and agriculture fertilizer. Persistent organic pollutants are rampant in the Pearl River Delta (Fu, Mai et al. 2003). Heavy metals, chemicals, PCBs, DDT, and sewage have been identified in fish and marine mammals such as humpback dolphins, which can lead to mortality, though more studies need to be conducted (Fang, Cheung et al. 2003; Jefferson and Hung 2004; Cheung, Leung et al. 2008). Chemical pollution threatens human health as well. DDTs and chlordane compounds (CHLs) in fish expose humans to potential cancer risks (Qiu, Guo et al. 2008), and elevated mercury levels of children in Hong Kong were correlated with the frequency of fish consumption (Ip, Wong et al. 2004).

Waters around Okinawa Island, Japan, also show evidence of organochlorine pesticides, organo-tin compounds, and PCBs with possible toxicological effects on marine life, including corals. Levels of these contaminants on some of the study sites exceeded the Japanese Environmental Quality Target for water pollutants. Surface sediments in Tokyo Bay—one of the most heavily polluted marine embayments in the world—recently revealed high concentrations of steroid estrogens and their conjugates, the result of highly polluted discharges from tributary rivers containing municipal and industrial wastewater (Isobe, Serizawa et al. 2006). In South Korea, red meat from toothed whales, dolphins, and porpoises sold for human consumption contain high levels of mercury that exceeds the safety limit of 0.5Â [mu]g/wet g for T-Hg set by the South Korean health authorities for the fishery industry. (Endo, Yong-Un et al. 2007). Finally, in Russia, recreation, railways, industry, and agriculture negatively affect the coastal zone with pollutants including oil, surfactants, heavy metals, and radionuclides, among others (Vashchenko 2000).

Pollution: Nutrients

Like land-based chemical pollution, land-based nutrient pollution is documented in all countries in this region (three with severe impacts). Again, this is an understudied threat, with gaps in research on threats and socioeconomic impacts notably in Russia, Japan, and North Korea and South Korea. It is clear, however, that increased nutrient pollution threatens both environmental and socioeconomic systems throughout the North West Pacific. Nutrients come from a variety of sources, but throughout the region, sewage is a formidable problem, as is pollution caused by increased discharges of industrial, agricultural, and aquaculture wastewater. Nutrient inputs can lead to eutrophication, which increases the ecosystem's primary productivity, restricts oxygen and water quality, and affects fish and other marine populations (Sien 2001). As human populations and industrial cities in the region have grown and exerted more pressure on resources, particularly in China, wastewater and sewage discharges have also increased, affecting fisheries and aquaculture operations, creating health problems, and reducing marine biodiversity (Qu, Xu et al. 2005).

While some of the nutrient-based threats are site specific, many have transboundary impacts. The massive discharge from the Yangtze River during a summer monsoon, for example, can extend as far as the southern end of the Korean peninsula (Teng, Yu et al. 2005). HABs, a result of eutrophication due to organic pollution, have been increasing in frequency and intensity in the region since the 1970s, and HAB organisms are easily transported to other seas via shipping traffic and ballast water (Teng, Yu et al. 2005). In 2002, 51 HAB cases were identified in the East China Sea and 17 in the Yellow Sea and Bohai Sea. In 2003, this increased to 86 in the East China Sea, many stemming from pollution from the Yangtze River Estuary (Qu, Xu et al. 2005). HABs have also been observed in the waters of the Far Eastern seas of Russia (Konovalova 1999). These blooms have measurable impacts on fish stocks and other ecosystem services, although their socioeconomic impact remains undocumented.

In China, nutrient pollution derives from a variety of sources, including domestic sewage, industrial wastewater, agriculture fertilizer, and mariculture. In the Yangtze River Estuary and adjacent sea areas, since the 1980s, chlorophyll concentrations have increased by a factor of four, and HABs have increased rapidly since 1985. The macrozoobenthic biomass also decreased sharply from the mid-1980s to the present, suggesting that the estuary is in a high, and worsening, eutrophication state (Wang

2006). Overall, nutrient inputs and associated HABs result in tremendous economic losses, from fish or shellfish stock declines, and poisoned seafood, for example. The bloom that occurred in May 2000 in the Yangtze River Estuary and the coastal waters of the Zhejiang, for example, covered more than 7,000 square kilometers and seriously threatened the region's aquaculture. As a result of this event, the Zhoushan Islands experienced a loss of about USD $3 million (Qu, Xu et al. 2005).

Hong Kong's and Southern China waters show ample evidence of land-based pollution as well. Much of the nutrient pollution comes from the region's rapid economic, urban, and industrial growth. One result is eutrophication. Tolo Harbor, an almost land-locked, semi-enclosed sea inlet with a narrow outlet to the South China Sea, shows increasing evidence of eutrophication, evidenced by a significant increase in the severity and frequency of algal blooms, which correlate with excessive nutrient loading (Chau 2007).

Korea's surrounding waters reveal similar effects of nutrient pollution. HABs throughout Korean waters have a serious economic impact on the mariculture (shellfish and finfish) industry (Park 1991). HABs in South Korea's Jinhae (Chinhae) Bay, the site of a large chemical fertilizer plant, caused mass mortality of shellfish in the 1970s and early 1980s. The high level of eutrophication resulting from both waste discharge from an industrial complex and organic deposits from aquaculture led to a decrease in shellfish production (Cho 1991). Enriched environments in Jinhae Bay and the Youngsan River estuarine bay have altered community dynamics overall and reduced the abundance and biomass of macrofauna (Lim, Diaz et al. 2006).

In Japan, long-lasting, noxious blooms of the dinoflagellate Cochlodinium polykrikoides, observed along the western coast of Japan and southern coast of Korea, have caused mass mortalities of cultured and natural fish and invertebrates. These blooms and eutrophication have increased in frequency and scale throughout the region, particularly in the Seto Inland Sea (Imai, Yamaguchi et al. 2006; Imai and Kimura 2008).

Habitat Destruction: Land-Based Sedimentation

In the North West Pacific, land-based sedimentation has been documented in all countries, three with severe impacts. Little research is available on China and Japan, and still less on Russia, North Korea, and South Korea. Sedimentation into coastal waters has increased as human populations have modified the nearshore marine environment, from building large cities 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, poor agricultural practices, coastal erosion, mining, and the construction of roads all contribute to increased sedimentation in coastal and nearshore habitats.

Increased sedimentation in coastal waters produces turbidity (Victor, Neth et al. 2006), reduces available light, and can suffocate coral reefs and kill fish. Overall, sedimentation from soil erosion has been shown to be a major stress to coral reef health (Maragos and Cook 1995). Sedimentation can thus negatively affect ecosystem services, fisheries, and tourism (Cesar and van Beukering 2004).

The Yalujiang, Shuangtaizihe, Luanhe, Jiaojiang, and Zhujiang estuaries in China suffer from suspended sediments that contain trace metals (Zhang and Liu 2002). Environmental pollution of the Yangtze River basin directly affects the marine environment in the East China Sea. The ecosystem's stability is maintained by a steady freshwater discharge from the river that mixes with the saline marine water in the estuary, and the sediment loads from the river that balance ocean erosion in the delta and its adjacent coastal areas (Li and Daler, 2004). The large-scale water transfer and dam construction in the Yangtze River basin will change this balance (Li, Fan et al. 2004). In Japan, sedimentation from terrestrial runoff threatens coral. In 2001, soil runoff caused the mass mortality of Porites corals (Dai, Gang et al. 2002).

Pollution: Solid Waste Disposal

Solid waste disposal—in particular marine debris, which includes derelict fishing gear, bottles, plastics, and Styrofoam—remains in the sea almost in perpetuity. Industrialization, population growth, and dense activity in coastal areas all contribute to the problem, which can harm marine life and fisheries resources as well as cause maritime accidents (Cho 2005). Studies in the East China Sea and South Sea of Korea between 1996 and 2005 reported the different types, quantities, and distribution of marine litter on the sea bed; results showed the highest densities in coastal areas. Fishing gear accounted for about half of the debris, whereas rubber, vinyl, metal, plastic, glass, and wood were below 30% (Lee, Cho et al. 2006). Because much of it is transboundary, marine debris is a controversial issue on an international scale. A comprehensive joint approach by Korea, China, and Japan is needed to monitor discharge sources in the East China Sea (Lee, Cho et al. 2006).

Despite the prevalence of marine debris in the North West Pacific, its impact is not well studied; nor is the effect of other activities, including dumping, known. However, new studies are being conducted to evaluate this threat. In Russia, the accidental and purposeful dumping of large amounts of high-level radioactive waste, weapons, and reactors into marine waters has prompted

> Ocean acidification is an area for future research throughout the entire region.

new studies on their environmental impact, as well as a renewed search for international solutions and cooperation for the management of radioactive waste (Vartanov and Hollister 1997).

Pollution: Oil Spills and Antifouling Chemicals, Ocean Waste, and Toxic Dumping

Other forms of pollution—particularly two sub-categories, oil spills and antifouling chemicals, ocean waste, and toxic dumping—pose threats to the North West Pacific as well. Both sub-categories have been identified in all North West Pacific countries, with about half of them exhibiting severe impacts. Because the seas in this region cross national boundaries, much of this pollution is transboundary in nature, thus creating a complex, international web of ecological and socioeconomic issues (Sien 2001). However, as with chemical and nutrient pollution, more research needs to be conducted on threats and socioeconomic impacts in all of the countries.

Oil pollution results from offshore drilling, shipping, increasing numbers of harbors and ports, and the transport of oil in tankers. It can be chronic and acute, as well as infrequent but nonetheless still acute. Shipping and industrial activities contribute to oil pollution, especially in densely trafficked seas. Crude oil is highly toxic to marine organisms (Law and Hii 2006). Severe oil spills and oil pollution can also decrease local income and revenue derived from marine resources and tourism. Antifouling chemicals are also toxic to marine systems. One of the most noxious 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 (Basheer, Tan et al. 2002).

These forms of pollution are prevalent throughout the North West Pacific. In Hong Kong, sediments are often seriously polluted with petroleum hydrocarbons, particularly in heavily urbanized and industrialized areas such as Kowloon Bay, Tsing Yi North, and Tolo Harbor (Zheng and Richardson 1999). In Japan, research shows that commercial ship-bottom paints containing Diuron and Irgarol 1051 are used extensively and adversely affect marine health (Okamura, Aoyama et al. 2003).

Toxic dumping also occurs frequently. Russia has dumped large quantities of radioactive waste in the Far Eastern Seas (encompassing the East Siberian Sea, the Okhotsk Sea, parts of the Bering Sea and the Sea of Japan); smaller amounts of radioactive waste have been dumped by Japan and South Korea (Ikeuchi, Amano et al. 1999). One joint Japanese-Korean-Russian assessment of contamination of radionuclides from past dumping of radioactive waste in areas of the Okhotsk Sea in the mid-1990s, however, generally showed levels of contaminants comparable with those found in reference sites outside the dumping areas. There was no clear effect of contamination due to radioactive waste dumping (Pettersson, Amano et al. 1999). But new research is coming to light about Russian accidental as well as purposeful dumping of substantial quantities of high-level radioactive waste, weapons, and reactors into the marine environment. Such research could better characterize the environmental impacts of these activities and could prompt a renewed search for international solutions and cooperation for the management of radioactive waste (Vartanov and Hollister 1997).

Other Regional Threats

The moderate and low impact threats discussed briefly below are worth mentioning for the prevalent impacts they have now as well as the impacts they could have in the future. Some of these threats, notably invasive species, still require more research.

Pollution: Aquaculture: Wastewater

Throughout the entire region, wastewater generated by aquaculture has negatively affected the marine ecosystem. It is identified as a severe impact threat in one country and moderate impact threat in two countries, with no studies found on Russia. It is a growing threat, however, region-wide and especially in China. Fish waste creates nutrient pollution, leading to the growth of phytoplankton and algae and possible deaths of fish and other marine life. Aquaculture can also facilitate the introduction of non-native species from one area to another, which can lead to the loss of food, native habitat, or spawning areas for native species.

In China, aquaculture has expanded under by national policies promoting food self-sufficiency and economic growth, including employment generation, especially for rural communities. In 1989, aquaculture produced 571,000 tons and represented the fastest growing sector of total production. China now boasts the highest mariculture production in the world, especially of kelp, mollusks, shrimp, and finfish. In 2001, total mariculture production reached 11,315,000 tons from a production area of 1,286,000 hectares (Biao and Yu 2007). The FAO reported that development of aquaculture in the open market economy regime after 1978 has—and will continue to be—sustainable and economically productive, both domestically and internationally (Hishamunda and Subasinghe 2003). Chinese aquaculture has, however, suffered disease outbreaks and environmental problems; it also pollutes the coastal environment (Biao and Yu 2007). Thus mariculture may be sustainable only with the adoption of sustainable culture systems (controlling the density of stocking fish, restricting the total number of net-cages in

mariculture zones, etc.) (Feng, Hou et al. 2004). In North Korea, marine cage farming is, as in China, expanding, producing more than 40,000 tons of fish (Kim and Taeyon-dong 2000). Overall, interest in offshore aquaculture is growing as a means of overcoming environmental concerns that plague nearshore and coastal aquaculture production (Lipton and Kim 2007).

Invasive Species

Marine invasive species have not been studied uniformly throughout the North West Pacific. Only in China have invasives been identified as a severe threat. About 30 species of exotic marine organisms—10 fish, two shrimp, nine mollusk, one echinoderm, four alga, and two halophytic weeds—have been introduced into China for mariculture. Ship hull fouling, boring, dry and semi-dry ballast, and water ballast have transported hundreds of exotic species to China (Liang and Wang 2001). Between 2001 and 2003, total economic losses caused by terrestrial and marine invasive species in China were estimated to be USD $14.45 billion, with direct and indirect economic losses accounting for 16.59% and 83.41% of total economic losses, respectively (Xu, Ding et al. 2006). While marine invasive species are not well documented, studies indicate that ballast water is a major source of exotic species introduction to Hong Kong waters. Invasives, in turn, can transport disease, threaten native marine life, and lead to economic loss (Chu, Tam et al. 1997).

Overfishing and Exploitation: Aquaria Trade

The aquaria trade, a form of overfishing and exploitation documented in China and Japan, is a low impact threat with potential for greater impact. For example, Taiwan supplies aquarium and marine/ornamental fish to the United States, with 95% of curios obtained from wild populations. Sharks, seahorses, and porcupine fishes are the three main fish groups most traded, adding to the conservation concerns for some of these species (Grey, Blais et al. 2005). Hong Kong also has an active aquaria trade (Cheong 1996; Cheung and Chang 2003). However, the exact impacts of the aquaria trade are unknown.

Highlighting Regional Solutions

This section highlights regional solutions to the threats facing the North West Pacific. There is limited documentation in the literature for regional solutions in this region; below are some highlights gleaned from the research.

Integrated Coastal and Ocean Zone Management

Integrated coastal zone and ocean management, or ICOZM, is an approach for coastal management taking into account regarding all aspects of the coastal and ocean zone, including geographical and political boundaries. Since the early 1990s, countries in the North West Pacific have embraced aspects of this concept. In China, sectoral conflicts involving coral and sand mining, aquaculture, fisheries, coastal construction, offshore oil drilling, and environmental projection have given rise to the need for this holistic form of management. In response, the Chinese government has made a significant effort in developing legislation for the coastal zone. The China Ocean Agenda 21 (1996) aims to develop its marine economy while enhancing the role of a healthy, productive coastal marine environment. It is also a framework for the exploration and protection of maritime resources, improvement of the polluted marine environment, and implementation of sustainable development. Key coastal management legislation relating to the evolving coastal management framework includes the Fisheries Law, Mineral Resources Law, Law on Exclusive Economic Zone and Continental Shelf, and others. 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 (The Global Forum on Oceans, Coasts, and Islands website 2008). Like China, Korea and Japan established decision-making bodies responsible for issues related to integrated coastal zone management and sustainable development. Despite this progress in the overall North West Pacific, comprehensive coastal and ocean management remains a daunting challenge.

Regional Governance, Agreements, and Approaches

Because the waters of the North West Pacific cross political borders, regional cooperation, based on the 1982 UN Convention, is key to sustainable use of ocean resources. Most fish stocks in the region migrate beyond the jurisdiction of any one country; similarly, the semi-enclosed seas, such as the Yellow Sea and the East Sea, cannot be effectively managed without cooperation from bordering coastal states (Kang 2006). Regional and international cooperation is required to effectively protect and preserve the marine ecosystem and resources in the sea, and avoid conflicts that could further deteriorate ecological and socioeconomic conditions.

Although regional regulatory agencies, bilateral fishing agreements with other countries, and some joint research efforts exist, these structures need to be strengthened throughout the region (Large Marine Ecosystems (LME) undated). In the Oyashio Current region, for example, Japan and Russia disagree on sovereignty over the Kuril Islands and associated fishing rights. In the East China Sea, China, Japan, and South Korea exhibit a similar lack of regional coordination; an intergovernmental initiative could establish measures to recover depleted fisheries

resources, enact appropriate laws and regulations to protect fishing resources, further international coordination among these countries, and undertake joint scientific studies (Large Marine Ecosystems (LME) undated). In the Yellow Sea, China and Korea have made progress with regional initiatives such as the Asia-Pacific Economic Cooperation forum and other structures.

The transboundary issues that need to be addressed throughout the North West Pacific include the management of marine resources, industrial pollution, and ecosystem health. Currently, a lack of formal infrastructure hinders international collaboration in monitoring and research activities in the ocean (Large Marine Ecosystems (LME) undated). Overall, 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).

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

Despite the North West Pacific's vast coastal and marine resources, relatively few of the coasts are protected, with total protected areas varying by country. MPAs in Russia comprise only 1.8% of the Russian shelf, although many land reserves protect marine areas as part of their total area. However, federal protection of marine mammal habitats is only as stringent as the most protected MPAs afford (WWF website 2008). In 2005, key ministers from China's resource sectors for the first time developed a common strategy to protect the entire Yangtze River basin; China has also designated more than 20 wetland sites as Ramsar sites (WWF China website 2008). As a result of wetlands and salt marsh protection, not more than 30% of these areas have been lost in the last 30 years (Teng, Yu et al. 2005). In the Amur River Basin, China and Russia have given various levels of protection to one million hectares of wetlands (Alekseev, Baklanov et al. 2006).

In Korea, MPAs contain fishery resource conservation areas, managed nursery areas for fishery resources, salt marshes, and entire ecosystems near Busan and around Daeijak Island (Yeon undated). However, the conversion of tidal flats in South Korea into agricultural land still occurs at a rapid pace, despite research that illustrates public preference for environmental conservation over more economic development (Bae 2002). There is also acknowledgement that the marine tourism resources of Korea have been underutilized, and that the resources on which such tourism depends must be preserved (Tyrrell, Kim et al. 1999).

In the Yellow Sea ecoregion (China, South Korea, Bohai Sea), WWF is spearheading an effort to develop a regionally coordinated MPA network to help address the transboundary nature of the ecoregion (WWF China website 2008). Although protected areas are increasing throughout the entire North West Pacific, differences in regulations across locations and weak enforcement have led to uncoordinated, sometimes ineffective approaches to the management of these protected areas (Alekseev, Baklanov et al. 2006).

Regulatory Frameworks

Each country in the North West Pacific faces challenges related to sustainable development. For the East China Sea, the goal is to reverse the negative processes taking place and restore ecosystem balance by integrating socioeconomic and environmental decision-making that promotes sustainable development. A better understanding of the driving forces in society that cause these environmental pressures is required in order to overcome such obstacles. Korea has already 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 been adequately addressed, leading to a suggestion that Korea move away from CFMR to a new paradigm that emphasizes resource sustainability and responsible fishing activities (Park and Ryu 1999). In China, a recognized need also exists to create national development strategies and legal frameworks to protect its marine environment and economy (Zhang, Que et al. 2004).

V. Pacific Ocean and East Asian Seas Regional Analysis: Threats, Impacts, and Solutions

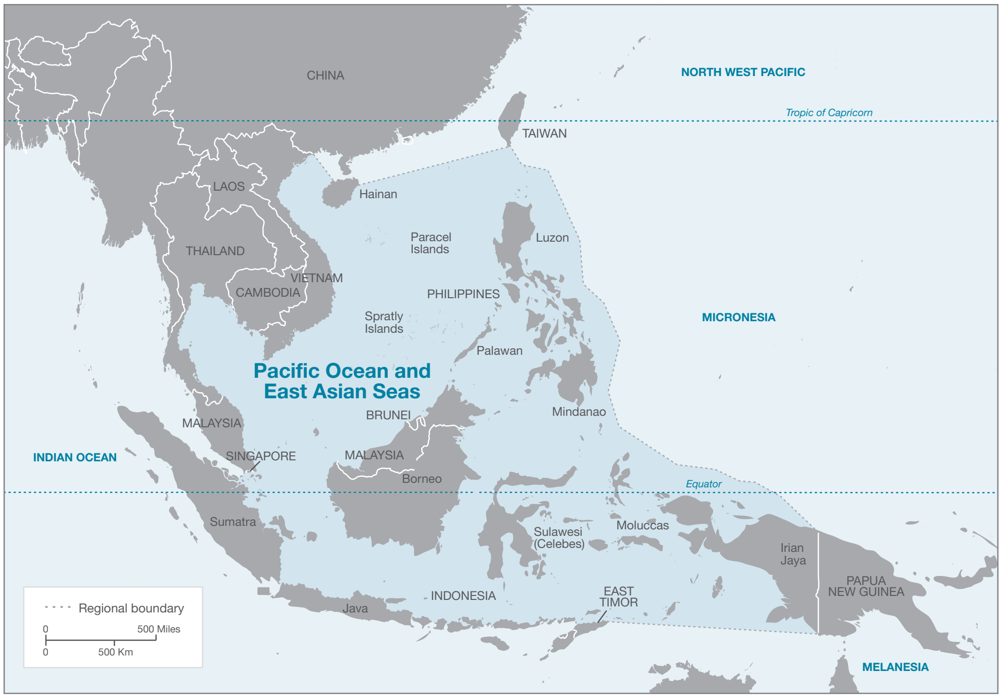
Photo: Fishermen in Northern Sulawesi, Indonesia. (©Wolcott Henry 2005/ Marine Photobank)

The East Asian Seas encompass the countries of Brunei Darussalam, Cambodia, East Timor (north coast), Indonesia, Malaysia, the Philippines, Singapore, Thailand, and Vietnam.

The South China Sea, a marginal sea largely surrounded by land, covers an area of about 3.3 million square kilometers and experiences a monsoonal climate. Its coastal fringes (China, Malaysia, the Philippines, Vietnam, Thailand, and Indonesia; some of the island groups are disputed) support a population of more than 270 million people and some of the fastest growing industries in the world (Morton and Blackmore 2001). Millions of people in the region live near or below the poverty line, depend on subsistence fishing, and compete for marine resources for their livelihoods. Resources in the East Asian Seas include valuable mangrove forests, coral reefs, seagrass beds, and wetlands, which are all threatened to various degrees (Wilkinson, DeVantier et al. 2005). Parts of this region—East Timor, Indonesia, Malaysia, and the Philippines—fall within the Indo-Pacific Coral Triangle, which contains the world's richest marine life and about 75% of all reef-building, hard coral species known. The center of hard coral diversity lies in eastern Indonesia, the Philippines, and the South China Sea's Spratly Islands, where more than 70 hard coral genera have been documented. These reefs support high diversity of plant and animal species, including 16 species of seagrass in the Philippines, more than 2,000 species of nearshore fish, and many endemic species. Based on estimates, Indonesia contains 18% of the world's coral reefs. The coral reefs of Indonesia and the Philippines provide annual economic benefits estimated at USD $1.6 billion and USD $1.1 billion per year, respectively (Burke, Selig et al. 2002). However, the majority of these reefs are at moderate to severe risk.

Here, as in most of the other Pacific regions, all four broad threats (overfishing and exploitation, climate change, habitat destruction, and pollution) impose severe to moderate impacts across the region, with information on invasive species throughout these countries severely lacking. Land-based chemical and nutrient pollution were identified in seven countries (each with severe impacts in five countries). Such pollution can create dead zones and algal blooms, alter ecosystem

Map 4: Pacific Ocean and East Asian Seas



Source: International Ocean Commission and The United Nations (www.unep-wcmc.org/gramed) 2008 Lucidity Information Design, LLC

structure, and jeopardize human systems. Other forms of pollution—wastewater from aquaculture, oil spills, and antifouling chemicals—have moderate impacts. Commercial fishing, which can cause ecological shifts, reduce fish stocks, and thereby threaten food supply, also threatens seven countries (with severe impacts in three).

Artisanal/recreational/subsistence fishing is a moderate impact threat. Similarly, habitat destruction (coastal development and land reclamation foremost, and then sedimentation and destructive fishing), which leads to the degradation of critical ecosystems that produce invaluable services and products for society, is widespread in many countries. Finally, climate change—sea level rise specifically—not only destroys marine ecosystems, but can create uninhabitable areas. It is important to note that these various threats do not operate in isolation, but rather function as multiple, compounded stressors that together can devastate marine and human systems.

The Pacific Ocean and East Asian Seas discussion that follows first presents overall regional trends of severe and moderate impact threats, including a table listing the levels of threats and impacts in each country. Then, the literature review section offers a more in-depth discussion of the most severe documented impact threats. Documented moderate impact threats are also presented if they are prevalent or notable throughout the region. Finally, the last section provides a brief overview of potential solutions to the threats facing this region as a whole.

Natural events such as typhoons, cyclones, hurricanes, and storm surges pose another important area for study throughout the entire region.

Pacific Ocean and East Asian Seas Regional Trends: Primary Threats and Associated Environmental and Socioeconomic Impacts

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

Based on this assessment, the threats with overall severe impacts across the entire Pacific Ocean and East Asian Seas region are:

- land-based chemicals identified in seven countries, with a majority of high impact ratings.
- nutrient pollution identified in seven countries, with a majority of high impact ratings.
- commercial overfishing identified in seven countries, with a majority of high impact ratings.
- coastal development/land reclamation identified in seven countries, with a majority of high impact ratings.

The threats with overall moderate impacts across the region are:

- sea level rise identified in seven countries.
- land-based sedimentation identified in six countries.
- artisanal/recreational/subsistence fishing and destructive fishing identified in six countries.
- wastewater from aquaculture identified in six countries.
- oil spills and antifouling chemicals identified in six countries.
- coastal modification from aquaculture identified in six countries.
- sea surface temperature increase resulting from climate change identified in six countries.
- aquaria trade identified in four countries (in three countries with a severe impact).
- by-catch identified in four countries.
- discharge identified in four countries.

Key observations regarding research gaps and identified impacts:

- This region is densely populated, with coastal communities that are highly dependent on marine resources.
- Indonesia and Vietnam contain the greatest number of severe impacts (eight and 10, respectively).
- Vietnam contains mostly threats with severe impacts (10), one with moderate impact, and none with low impacts.
- There are large research gaps in Brunei, Cambodia, and East Timor. These countries also have the least number of documented threat categories as well as the lowest number of threats with impacts within the region, all of which are moderate impacts.

The region's vast mangrove loss—up to 83.7% in Thailand—imposes formidable ecological and economic costs. More studies are needed, however, to examine the exact impacts.

The following table distills the findings from the literature, documenting by country, threats and environmental and socioeconomic impacts. There is considerable variation in availability of scientific literature in this region. The Pacific Ocean and East Asian Seas face mounting threats, but many of these threats and their impacts are poorly understood and/or researched (Morton and Blackmore 2001). Large gaps in the research include studies on most of the broad threats (pollution, habitat destruction, overfishing and exploitation, climate change, and invasives) in Brunei and Cambodia; the socioeconomic impacts of various threats to individual countries and the region; and the causes and impacts of land-based pollution throughout the region.

TABLE 3: Pacific Ocean and East Asian Seas Threats Based on Scientific Literature and Impact Assessment

✓ Identified as Threat

● Severe Impact ● Moderate Impact ● Low Impact

It was documented when an article identified an issue as a present or future threat. If no scientific literature was found on the topic, then no check was assigned. This does not necessarily mean the topic is not a threat; rather, it suggests that no scientific literature was found on the topic.

	BRUNEI DARUSSALAM		CAMBODIA		EAST TIMOR*		INDONESIA		MALAYSIA		PHILIPPINES		SINGAPORE		THAILAND		VIETNAM	
	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts
POLLUTION																		
Aquaculture: Wastewater							✓	Moderate	✓	Moderate	✓	Moderate	✓	Low	✓	Severe	✓	Severe
Land-based Chemicals			✓	Moderate			✓	Severe	✓	Severe	✓	Severe	✓	Moderate	✓	Severe	✓	Severe
Fishing Lines/Nets							✓	Moderate	✓	Moderate					✓	Low		
Nutrients			✓	Moderate			✓	Severe	✓	Severe	✓	Severe	✓	Moderate	✓	Severe	✓	Severe
Offshore Oil/Mining	✓	Moderate					✓	Moderate	✓	Moderate								
Oil Spills & Antifouling Chemicals	✓	Moderate					✓	Moderate	✓	Moderate	✓	Moderate	✓	Moderate	✓	Moderate		
Radionuclide																		
Solid Waste Disposal									✓	Moderate					✓	Moderate		
Thermal							✓	Moderate					✓	Moderate				
Ocean Waste & Toxic Dumping																		
HABITAT DESTRUCTION																		
Anchor Damage																		
Aquaculture: Coastal Modification							✓	Moderate	✓	Moderate	✓	Moderate	✓	Low	✓	Moderate	✓	Severe
Coastal Development/Land Reclamation			✓	Moderate			✓	Severe	✓	Severe	✓	Moderate	✓	Severe	✓	Severe	✓	Severe
Destructive Fishing	✓	Moderate					✓	Severe	✓	Moderate	✓	Severe			✓	Moderate	✓	Severe
Dredging																		
Marine Recreation									✓	Low	✓	Low			✓	Low		
Land-based Sedimentation	✓	Moderate					✓	Severe	✓	Severe	✓	Severe			✓	Moderate	✓	Severe
Ship Groundings																		
Tsunamis							✓	Low										
Typhoons/Cyclones/Hurricanes & Storm Surge																		
Wrecks/Military Equipment																		
OVERFISHING & EXPLOITATION																		
Aquaria Trade							✓	Severe	✓	Moderate	✓	Severe	✓	Severe				
Artisanal/Recreational/Subsistence Fishing			✓	Moderate			✓	Severe	✓	Moderate	✓	Severe			✓	Moderate	✓	Severe
By-Catch & Discharge	✓	Moderate					✓	Moderate							✓	Severe	✓	Severe
Commercial Fishing	✓	Moderate					✓	Severe	✓	Moderate	✓	Moderate	✓	Moderate	✓	Severe	✓	Severe
CLIMATE CHANGE																		
Acidification																		
Sea Level Rise			✓	Moderate	✓	Moderate	✓	Moderate			✓	Moderate	✓	Moderate	✓	Moderate	✓	Moderate
Sea Surface Temperature**					✓	Moderate	✓	Moderate	✓	Moderate	✓	Moderate	✓	Moderate	✓	Moderate		
INVASIVES																		
Invasive Species (Different Vectors)													✓	Moderate				

*Due to the recent independence of East Timor, the limited research conducted in East timor and Timor Sea prior to 2002 is integrated in Indonesia.

**Changes in SST is strongly associated with El Niño Southern Oscillation (ENSO) events, which are predicted to increase in frequency and intensity over time due to climate change.

For a complete list of references used for the literature review and synthesis to create this table see Appendix C, Table 3 p.135.

Pacific Ocean and East Asian Seas Literature Review of Severe and Moderate Impact Threats

The discussion that follows highlights the greatest threats to the Pacific Ocean and East Asian Seas. The most severe threats are discussed (see bullets and table above), and each threat category includes country-specific details on threats as well 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.

Pollution: Nutrients

Studies have identified land-based nutrient pollution in seven countries (five with severe impacts). Even with research still needed to document threats and determine more precise threat-impact relationships across countries, it is clear that nutrient pollution poses a severe threat to the East Asian Seas. Most of the nutrients enter waters from domestic and industrial wastewater, including agriculture and untreated sewage. Although they can support productivity of the region's coastal areas, nutrients have significant environmental, health, and economic impacts. While nutrients "enrich" the waters, they can cause phytoplankton blooms, eutrophication, hypoxia, and red tides, which affect marine life. A reduction in the number and abundance of species, in turn, threatens marine life, economic livelihood, and food security.

Throughout the region, the lack of adequate sewage plants and treatment facilities exacerbates the East Asian Seas' land-based pollution problem. Raw sewage effluent, particularly from several densely populated cities, deposits heavy loads of untreated sewage (Isobe, Zakaria et al. 2004). Such pollution has caused major economic and public health concerns. The dinoflagellate Pyrodinium bahamense, which causes algal blooms, produces saxitoxin, which in turn causes PSP. Extreme cases of PSP, which can paralyze the human respiratory system within 24 hours of ingestion of toxic shellfish, often lead to death. Blooms of this organism have been reported in Malaysia, Brunei, the Philippines, and Indonesia. The ASEAN-Canada Red Tide Network has recorded 31 blooms of the organism in 26 areas since 1976 when it first occurred in Sabah, Malaysia. As of 1999, the most hard-hit country has been the Philippines, which has the greatest number of areas affected (18) and greatest number of PSP cases (about 1995). Malaysia has reported a total of 609 PSP cases and 44 deaths. While these blooms can seriously jeopardize human health, more studies on their ecological impacts need to be conducted. Regional collaborative research and monitoring can aid such efforts (Azanza and Taylor 2001).

In Brunei, red tide occurrences have plagued the coastal waters, with severe implications for fisheries. The red tides have made it necessary to impose bans on the import, sale, and consumption of certain species of fish and shellfish (Selvanathan, Mahali et al. 1994). Indonesian waters similarly show the negative impacts of land-based nutrient pollution (Evans, Dawson et al. 1995). In Malaysia, nutrient pollution has led to HABs; at Palawan, Philippines, algal blooms persisted for two months in 2005 and are recurring (Anton, Teoh et al. 2008; Azanza, David et al. 2008; Wang, Tang et al. 2008). Vietnam also suffers from nutrient pollution that can cause HABs. In southeastern Vietnamese coastal waters in 2002, HABs caused large economic losses in aquaculture and wild fisheries. However, more studies of HABs—in particular, their relationship to offshore upwelling and winds—need to be conducted for the region as a whole (Tang, Kawamura et al. 2004).

Pollution: Land-Based Chemicals

Land-based chemicals are somewhat better documented in the East Asian Seas than nutrient pollution, though gaps in the research still make for an incomplete picture. Research identified land-based chemicals in seven countries, five with severe threats. Not surprisingly, higher levels of chemical pollution are found in urban, densely populated areas, with toxic industrial activities like mining expected to increase in the future (Glover and Smith 2003). When chemicals accumulate through the food chain or pollute the sediment, they affect all parts of the marine ecosystem, from the fish on down. Studies show that chemicals can endanger fishes' reproductive capacities, DNA, and very existence. Such changes not only endanger the fish, but have great potential to alter the entire food web. Chemicals can also jeopardize 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 throughout the East Asian Seas. Many of the impacts on marine ecosystems and humans, however, are unknown.

Regionally, contaminants including persistent organochlorines (OCs) such as PCBs, DDTs, HCHs, CHLs, and HCB are prevalent. Mussels collected from coastal waters surrounding Cambodia, China, Indonesia, Malaysia, the Philippines, Singapore, and Vietnam at regular intervals between 1994 and 2001 revealed higher levels of DDTs and HCHs in developing countries than in Asia's developed countries, which suggests unsustainable use of DDTs and HCHs—products of industrial activity—along the coastal waters of Asian developing countries (Monirith, Ueno et al. 2003).

In Cambodia, chemical pollution from mercury has greatly affected certain marine fish, making human consumption of fish

hazardous. Mercury levels exceeding the guidelines by the U.S. Environmental Protection Agency (U.S. EPA) and by a Joint FAO/WHO Expert Committee on Food Additives (JECFA) were found in sharp-tooth snapper, for example (Agusa, Kunito et al. 2005). Concentrations of 20 trace elements were also found in the muscle and liver of 34 marine fish species collected from coastal areas in Cambodia, further posing a human health danger from their ingestion (Agusa, Kunito et al. 2007). While mercury contamination threatens both marine life and human health, Cambodian waters are generally thought to be less contaminated than other waters in the region (Monirith, Nakata et al. 1999).

Indonesian waters similarly show the negative impacts of chemical pollution, including mercury released from gold mining (Blackwood and Edinger 2007; Edinger, Siregar et al. 2007). Mercury contamination has affected fish and human health in two gold mining areas: Tatelu (North Sulawesi Province) and Galangan (Katingan District, Central Kalimatan Province) (Castilhos, Rodrigues et al. 2006). Other pollutants are hazardous as well. Organophosphate concentrates (diazinon, chlorpyrifos, profenofos, parathion, etc.) have been found in dead coral tissues in Java, Bali, Sulawesi, and Komodo; levels were highest in those collected from Java coastal waters, medium in Bali and Sulawesi coastal waters, and nonexistent in Komodo (Sabdono, Kang et al. 2007). Other contaminants seem to be more widespread. For example, concentrations of 20 trace elements were found in the muscle and liver of 34 species of marine fish collected from coastal areas in Indonesia (Agusa, Kunito et al. 2007).

In Malaysia, chemical pollution also appears to be widespread. Heavy metals have been identified in coastal waters, and trace elements were determined in the muscles and liver of marine fishes collected there (David, Moosa et al. 2002; Agusa, Kunito et al. 2007). Harmful chemicals such as methylmercury, generated in Palawan mine-waste calcines and Honda Bay in the Philippines, enter the water, marine fish, and then seafood, threatening human health (Gray, Greaves et al. 2003). Endocrine-disrupting phenols affect marine life as well (Santiago and Kwan 2007). The concentrations of zinc and lead in coastal sediments off Juru in Penang, and in the Johor Strait, measured two to three times higher than global shale values; the source of the lead pollution may be leaded petrol (Shazili, Yunus et al. 2006).

As in Malaysia, endocrine disruptors pose a major threat to marine life in Singapore (Basheer, Tan et al. 2002; Basheer, Lee et al. 2004). Samples taken from locations near the main shipyards and shipping lanes demonstrated high levels of heavy metals and pesticides in mussel tissues (Bayen, Thomas et al. 2004). However, metal contamination is considered moderate when compared to Thailand and China (Cuong, Karuppiah et al. 2008). Levels of PCB contamination are also considered moderate, but are high enough to induce toxicological impacts that are unacceptable according to the U.S. EPA (Wurl and Obbard 2006).

Different types of chemical pollution threaten Thailand, with some debate as to the exact impacts. Heavy metals have been identified in the Gulf of Thailand (Censi, Spoto et al. 2006), and toxic compounds including organochlorine pesticides such as DDTs, CHLs, HCHs, and HCB, have been found in mussels and oysters collected in coastal Thai waters (Agusa, Kunito et al. 2007). One study, however, identified much lower residue levels of pollutants than those found elsewhere in the tropical coastal waters of Asia. PCBs were present in high concentrations in urban and industrial areas, but contamination from these pollutants did not seem to pose a serious threat to human health or ecosystems (Cheevaporn, Duangkaew et al. 2005). Thermal pollution, however, seems to be a serious issue (Charubhan, Charubhan et al. 2003).

Much of Vietnam's pollution results from the country's rapid industrial growth. Organochlorine pesticides like DDT and PCB residues were found in soils and surface sediments collected from Hanoi City, Viettri City, and Halong Bay, representative of industrial and agricultural areas in northern Vietnam. Mining activities contributed to higher concentrations of pollution in Halong Bay. But organo-chlorine pollution is widespread; the high accumulation of DDTs in soils, sediments, and biota from north to south Vietnam indicates that input of DDT still occurs (Viet, Hoai et al. 2000) (Minh, Kunisue et al. 2002). Studies also show that PCDD and PCDF (dioxins) in bottom sediments resemble those of the toxic defoliant "Agent Orange" (Pavlov, Smurov et al. 2004).

Overfishing and Exploitation: Commercial Fishing and Artisanal/Recreational/Subsistence Fishing

Asia, an important region in terms of fish trade, supplies nearly 60% of global fish production. Yet commercial, industrial fishing and recreational, artisanal, and subsistence fishing pose severe threats to the East Asian Seas and illustrate the negative impact of overexploitation and unsustainable use of ocean resources on marine life and human livelihood. Both types of fishing have been identified in seven countries, with a majority of severe impacts. Regionally, commercial fishing is a severe impact threat, while artisanal/recreational/subsistence fishing is an overall moderate impact threat. More research needs to be conducted on countries including Brunei, Cambodia, the Philippines, and Singapore to evaluate these impacts. Although not discussed in depth here, by-catch, a moderate impact threat regionally, is also a concern, especially in Indonesia (Evans and Wahju 1996; White, Giles et

al. 2006; White and Cavanagh 2007). However, this threat is generally not well documented.

The region's coastal fisheries play a critical role in ensuring food security and providing livelihoods, particularly for poorer communities. Coastal fisheries resources are being severely depleted, however, which suggests overfishing and the lack of effective management of fishing capacity in the region. In parts of this region, artisanal fishing in coral reefs may be more destructive than commercial fishing, though it has a lesser impact in the overall region. Both types of overfishing can lead to species reduction or loss, habitat destruction, and the loss of economic livelihood. (Stobutzki, Silvestre et al. 2006). In Indonesia, for example, more than 32,000 square kilometers of reefs were overfished in 2002, which resulted in massive societal losses estimated at USD $1.9 billion over 20 years (Burke, Selig et al. 2002).

Little is known about Brunei's fishing practices. Because 25 species were lightly fished in 1989–1990, they provide baseline data that can be incorporated into wider reference systems relevant to current fisheries assessment and management in the country, and the region (Silvestre and Garces 2004). The trawl fishery of Brunei has been profitable in many areas, though trawling operations offshore are deemed financially unfeasible (Cruz-Trinidad, Silvestre et al. 1997).

In Malaysia, the live reef fish trade has greatly affected marine life (Johnston 2007). In 2001, at least 565,000 seahorses—a far greater number than previously assumed—were caught as trawl by-catch and traded as traditional Chinese medicines, mostly overseas. One species, H. kuda, which lives in shallow mangrove estuaries, was targeted by artisanal fishers. However, for all four species caught, the populations are rapidly declining, revealing the need for the conservation, monitoring, and regulating of the trade (Squires, Omar et al. 2003; Choo and Liew 2005). Other marine species are also overfished. Current statistics indicate that leatherback and olive ridley turtles are on the verge of extinction due to commercial fishing, while other sea turtle species are in steady decline. Coordinated efforts to protect these endangered animals, such as sanctuaries, need to be improved (Chan 2006).

Like Malaysia, the Philippines has a robust live fish trade industry, with an estimated annual value of at least USD $30 million. Palawan Province, the trade's center, accounts for about 55% of the commodity's total export (Pomeroy, Pido et al. 2008). Concern about the trade has led to government regulation to ensure its sustainability and reduce threats associated with overfishing and destructive fishing, which often go hand-in-hand. The "Palawan Live Reef Fish Ordinance of 2006" requires sustainable regulation of the live reef fish food industry (Pomeroy, Pido et al. 2008). Yet, as the trade continues, overfishing still impairs coral reefs—and the economy. Only 4–5% of coral reefs in this region remain in excellent condition (Gozun, van der Heijden et al. 2005). In 2002, the financial damage from overfishing of more than 21,000 square kilometers of reef was estimated at USD $1.2 billion over 20 years (Burke, Selig et al. 2002). Yet coral reefs in their current degraded condition contribute at least USD $1.4 billion to the economy each year (White, Vogt et al. 2000).

In Thailand, commercial fishing poses a major threat. Fish stocks are overexploited, with major fluctuations in total catch (1.7 million tons in 1985, to 2.7 million tons in 1988, to 1.8 million tons in 1991, to 1.1 million tons in 2003) (Pauly, Chuenpagdee et al. 2003). Data from the Department of Fisheries between 1971 and 2000 revealed that 35% of marine production is "trash fish," most used as raw materials for fish meal production. Otter board trawlers contribute about 80% of the total trash fish production. Trash fish production decreased, however, when the number of fishing vessels was reduced (Kaewnern and Wangvoralak 2005). Small-scale fisheries also pose a problem. While they provide food and income to millions of people worldwide, they are generally poorly documented and their impacts not well understood. The small-scale fisheries in the Ko Chang archipelago, however, may be illustrative. Although a "no-take" marine national park has been established, some fisheries—mostly shrimp trammel net, squid trap, crab trap, fish gill net, hook-and-line, and reef fish trap fisheries—have continued unabated and irregularly monitored within the park's boundaries. Small-scale fishing boats operating out of villages on Ko Chang and Ko Maisi Yai worked for an estimated 38,000 person days per year and caught 333,000 kg/year of target fish and invertebrates (Lunn and Dearden 2006).

In Vietnam, overfishing and exploitation of many species pose serious threats. Studies found that juvenile fish are now an important economic component of the total catch, and that fishers operating larger boats were more willing to use juvenile and trash fish excluder devices (JTED) to exclude these fish than fishers operating smaller boats. A study found that 73% of juvenile fish, 16% of valuable fish, and 8% of shrimp were excluded by the JTED, although most valuable fish and shrimp were smaller than the minimum legal landing size. Overall, this loss represents a 9% reduction in revenue, which could be offset by not catching fish less than the minimum legal landing size (Eayrs, Hai et al. 2007). Another severe threat in Vietnam is the illegal and domestic and international trade in sea turtles and their products, as well as their accidental capture in fishing gear and the loss of nesting and foraging habitats. Because sea turtles have dramatically declined over the last 50 years, with only a few nesting locations remaining, a new national sea turtle conservation action plan was created (Cox 2004).

Habitat Destruction: Coastal Development and Land Reclamation

Reclamation/conversion of mangrove forest and mudflats for aquaculture, agriculture, industry, housing, and recreational purposes is the major threat to fragile ecosystems that provide important habitats and ecosystem services. The literature identifies seven countries where coastal development and land reclamation is a threat (five with severe impacts), and it is considered regionally a severe impact threat. While more studies are needed on specific countries, it is clear that the coastal zone throughout the East Asian Seas is under considerable stress as a result of continuing population growth, large-scale infrastructure developments, and extensive land reclamation projects.

Mangrove, seagrass, and coastal wetlands have been destroyed region-wide. Coastal wetland and peat swamp loss is estimated to be 46% in Indonesia, 59% in Malaysia, and 98% Vietnam (Burke, Kura et al. 2001). Mangrove loss is estimated to be 54.9% in Indonesia, 74.1% in Malaysia, 66.7% in Philippines, 83.7% in Thailand, and 36.9% in Vietnam (Spalding, Blasco et al. 1997). The World Resources Institute estimates that 88% of the reefs are threatened in Indonesia—with only about 6% in "excellent" condition (Burke, Selig et al. 2002). In Singapore, coastal and marine ecosystems have been severely modified by development and the port industry; reclamation has transformed almost the entire southern and northeastern coasts of the main island (World Resources Institute website 2007).

Coastal modification imposes substantial ecological and socio-economic costs (discussed in Section II). Coastal ecosystems in this region provide many important ecosystem services, including gas regulation, disturbance regulation, water regulation, water supply, erosion control, nutrient cycling, waste treatment, pollination, biological control, habitat/refugia, production, raw material, genetic resources, recreation, cultural value, and storm protection (Costanza 1997; Costanza 1999). The ecosystem services products of natural coastal ecosystems per year by country are estimated at USD $1.4 billion in Brunei, $123.2 billion in Indonesia, $8.1 billion in Malaysia, $18.4 billion in the Philippines, $3.9 billion in Thailand, and $4.2 billion in Vietnam (Martinez, Intralawan et al. 2007). The coral reefs, seagrass, mangroves, and mudflats around Olango Island in the Philippines alone provide an estimated annual net revenue of USD $38,300 to $63,400 per square kilometer along the entire 40 square kilometer reef area (and another $38,900 if wetlands are considered) from fisheries, seaweed farming, bird habitats, tourism, and wood harvesting (White, Ross et al. 2000).

The loss of these ecosystems will greatly affect society. Hotels in Bali and Lombok spend an estimated USD $100,000 per year to mitigate beach erosion (Abdullah, Agustina et al. 2005). Similarly, the estimated annual losses of mangrove deforestation in Thailand (about 30 square kilometers annually) range from USD $12,000 to $408,000 (Barbier, Strand et al. 2002).

Habitat Destruction: Destructive Fishing

Destructive fishing, closely associated with commercial fishing and artisanal, recreational, and subsistence fishing, threatens many parts of Asia and the East Asian Seas. It is documented as a threat in six countries, three with severe impacts and an overall moderate rating. But much of the impact of overfishing and destructive fishing in the East Asian Seas is understudied (there is little known about Brunei, for example). It is known that Indonesia fishers use cyanide and dynamite to stun fish, which destroy coral reefs, and Cambodian and Vietnamese fishers use destructive fishing methods to kill dugong, but large research gaps remain (Hines, Adulyanukosol et al. 2008). What is known, however, is that destructive fishing—from blast fishing to poison fishing—can indiscriminately kill fish and lead to species reduction or loss, habitat destruction, and the decline of economic livelihoods.

Indonesia is currently experiencing the deleterious effects of destructive fishing, including poison fishing, blast fishing, and coral mining. Often, artisanal fishers employ these methods to compete with larger fishers in a declining, exploited market. Destructive fishing prevails; a single blast 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%. Cyanide fishing is also prevalent. Yet the social costs of overexploitation may far outweigh the short-term economic gains (Cesar, Lundin et al. 1997). Research on the benefits of blast fishing to individual fishing households and Indonesian society as a whole showed it to be unsustainable. One study that calculated a cost-benefit balance at the society level showed a net loss after 20 years of blast fishing of USD $306,800 per square kilometer of coral reef where there is a high potential value of tourism and coastal protection, and USD $33,900 per square kilometers of coral reef where there is a low potential value. The study concluded that the economic costs to society are four times higher than the total net private benefits from blast fishing in areas with high potential value of tourism and coastal protection (Pet-Soede, Cesar et al. 1999).

In the Philippines, the benthic status of 28 nearshore, artisanal coral reef fishing grounds in the central Philippines was assessed in 2000–2002, together with surveys of the seahorse. Results showed some of the most degraded coral reefs in the world; abiotic structure dominated the fishing grounds, with 69%

of the benthos comprising rubble. Rubble cover coincided with substantial blast fishing, poor benthic quality, and low seahorse densities (Marcus, Samoilys et al. 2007). Seventy percent of the Philippines' mangrove forests have been converted to aquaculture, logged, or reclaimed for other uses, and half of all seagrass beds have either been lost or severely degraded. Land clearing (discussed above) together with destructive fishing has led to the decline in fisheries catch per unit effort (Gozun, van der Heijden et al. 2005). Indeed, the Philippines' fishing industry now suffers from destructive fishing as well as overfishing. Although NGO and government efforts have worked to ban some destructive fishing practices, such as cyanide fishing, they have not fully disappeared. Nor have existing laws and regulations for coastal management accomplished their expressed goals. For example, Palawan Province adopted a live reef fish ordinance of 2006 to reduce threats associated with destructive fishing and overfishing. However, the key challenge is how to translate the ordinance provisions into effective actions (Pomeroy, Pido et al. 2008).

Pollution: Aquaculture: Wastewater

Aquaculture, one of the East Asian Seas' most important industries, brings important socioeconomic benefits. The wastewater it generates, however, can be considered a threat. Although understudied in many countries, pollution from aquaculture has been identified as a threat in six countries, most with moderate or severe impact.

Regionally, aquaculture provides a third of total fisheries production. Since the 1980s, aquaculture throughout the region has increased, particularly mariculture (shrimp) in coastal ponds (Wilkinson, DeVantier et al. 2005). Half of the total aquaculture yield comes from land-based ponds and water-based pens, cages, longlines, and stakes in brackish water and marine habitats. While aquaculture produces important economic gains related to employment, income generation, and foreign trade, the environmental impacts may overshadow the socioeconomic opportunities. Environmental impacts resulting from aquaculture operations include mangrove loss and coastal modification, by-catch during the collection of wild seed, introductions of non-native species, the spread of parasites and diseases, the overuse of chemicals, and, significantly, the release of wastewater, which discharges nutrient loads into the ocean. Such pollution, in turn, can cause HABs and affect the entire marine ecosystem. The socioeconomic impacts of aquaculture include privatization of public lands and waterways, loss of fisheries livelihoods, food insecurity, and urban migration (Primavera 2006).

In 2004, Indonesia exported a total of USD $2.072 billion worth of fishery commodities, with aquaculture accounting for 26% of that amount (Food and Agriculture Organization of the United Nations (FAO) 2006). In Indonesia, prawn aquaculture has led to salinization of the groundwater and severe surface water pollution. Water pollution extreme enough to cause massive fish and coral mortality, harvest failure in aquaculture, and threats to human health has been found in all of Indonesia's populated areas (Abdullah, Agustina et al. 2005). Indeed, while coastal aquaculture projects are increasing rapidly (with little or no regulation), the industry poses a threat to itself. By 2001, operators abandoned about 70% of shrimp farms because of the high concentrations of chemicals in the waters (Abdullah, Agustina et al. 2005).

Like Indonesia, Malaysia has also established prawn aquaculture, as well as the culture of sea bass and other fish. One study examined the impact of floating net-cages for sea bass on planktonic processes and water chemistry in two heavily used mangrove estuaries. Results showed that concentrations of dissolved inorganic and particulate nutrients were usually greater in cage versus adjacent, non-cage waters, thereby suggesting wastewater pollution (Alongi, Chong et al. 2003).

In the Philippines, aquaculture involves many species and farming practices. Most of the production derives from farming seaweed, tilapia, shrimp, carp, oysters, and mussels. It contributes significantly to the country's food security, employment, and foreign exchange earnings. However, the FAO reported that the future growth of Philippine aquaculture may not be sustainable due to practices that can impose vast ecological and socioeconomic damage. Much of the wastewater is generated by imported feeds that, when expired, contain toxins that cause high shrimp mortality (Kongkeo 1997). Organic pollution has also altered marine coastal environments in both metropolitan and rural regions alike, including Manila Bay and rural Lingayen Gulf, with mariculture zones in Bolinao Bay, Pangasinan. In 2002 in Pangasinan, after less than a decade of intensive milkfish farming, organic feed and waste discharges triggered a negative feedback response that resulted in the deaths of thousands of pounds of milkfish from oxygen depletion, eutrophication, and red tide HABs, imposing economic loss to operators and coastal fishers (Food and Agriculture Organization of the United Nations (FAO) 2006–2008; Reichardt, McGlone et al. 2007).

Marine aquaculture plays an increasingly important role in Thailand's food security and economy, particularly for exports, but associated threats produce many environmental and socioeconomic impacts (Lin 2003). In 2001, aquaculture provided employment to more than 80,000 households; in 2002, it accounted for 2.07% of total GDP (Food and Agriculture Organization of the United Nations (FAO) 2006-2008). The main brackish

water cultured species include the giant tiger prawn, shrimp, green mussel, blood cockle, and oyster. The black tiger shrimp dominates Thai production, and about 90% of the cultivated shrimps are exported to industrialized countries (Lindberg and Nylander 2001). Rising demand for shrimp in the developed countries has, not surprisingly, fostered a dramatic growth in shrimp aquaculture (Flaherty and Karnjanakesorn 1995). Despite its economic vitality, shrimp farming (the semi-closed system in particular) has major environmental impacts due to chemical use, mangrove destruction, salinization, eutrophication, sedimentation, and spread of disease; resulting socioeconomic impacts range from health problems to loss of livelihood and freshwater resources (Lindberg and Nylander 2001). Intensive shrimp farming in particular discharges large quantities of effluents (Flaherty and Karnjanakesorn 1995). The use of antibiotics in shrimp aquaculture is also becoming more widespread. While antibiotics may treat or prevent disease outbreaks, if not used efficiently and safely, they have negative environmental impacts (Holmstrom, Graslund et al. 2003).

In the last two decades, Vietnam has also experienced a rapid growth in the aquaculture industry. The country is dominated by rice-cum-fish (paddy fields used for the culture of rice and aquatic organisms), mangrove-cum-aquaculture (mangrove areas used for aquaculture), and marine cage culture for giant tiger prawn, finfish, lobster, and other species. In 2004, aquaculture contributed over 60% of the USD $2.397 billion in export earned from Vietnam's fisheries. Giant tiger prawn farming is the most developed type of marine aquaculture in the 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%. However, in the 1990s, it became unsustainable due to unplanned development of the industry and the resulting self-pollution of the farms, destruction of mangrove forests, and outbreak of diseases (de Graaf and Xuan 1999). As in other countries in the region, aquaculture waste has caused serious environmental problems. Antibiotics, which are found in water and mud in mangrove area shrimp ponds in southern Vietnam, contaminate the water (Le and Munekage 2004). Yet despite studies investigating bacteria in four shrimp farming locations in mangrove areas in Vietnam, the concentration of antibiotic residues and incidence of antibiotic resistance is not clearly defined (Le and Munekage 2004).

Photo: Nudibranch, Bunaken Indonesia. (Neil Atterbury/Marine Photobank)

Habitat Destruction: Aquaculture: Coastal Modification

A major threat caused by aquaculture is also coastal modification, which has been identified in six countries and is considered a moderate impact threat region-wide.

Throughout the region, the clearing of land—often mangrove forests and seagrass beds—for aquaculture has serious repercussions for coastal and nearshore ecosystem health. Coastal modification leaves areas exposed to erosion, flooding, and storm damage, alters natural drainage patterns, increases salinization, and destroys critical habitat for many marine species. Such habitat loss has serious implications for local food production and biodiversity, including the fish, bird, and invertebrate species that depend on mangroves. Coastal development threatens resource-dependent industries such as tourism.

Intensive aquaculture for prawns has led to the conversion and clearance of Indonesia's mangrove forests, whose removal in turn threatens coral reefs and seagrass beds (Abdullah, Agustina et al. 2005). Recent estimates indicate that by the early 1990s, Malaysia had lost 74% of its original mangrove cover (Burke 2003). In Thailand, although the government restricts the use of mangroves to designated areas, and farms larger than eight hectares must construct wastewater oxidation ponds, the loss of mangroves continue (Barbier, Strand et al. 2002). The estimated annual losses of mangrove deforestation in Thailand (about 30 square kilometers annually) range from USD $12,000 to $408,000 (Barbier, Strand et al. 2002).

Other Regional Threats

The moderate impact threats discussed briefly below are worth mentioning for the prevalent impacts they have now as well as the impacts they could have in the future. Many of these threats, like the aquaria trade and climate change, require further research.

Overfishing and Exploitation: Aquaria Trade

The marine aquarium trade is a serious issue throughout the region, documented in four countries (three with severe impacts); tropical marine ornamentals comprise an increasingly important fishery worldwide. While captive breeding occasionally takes place, almost all marine aquarium species are taken from the wild, with tropical coral reefs the most important source of specimens for the trade. These mostly originate from Southeast Asia, particularly Indonesia. There, millions of coral reef fishes are collected each year for sale. The industry is unmonitored, with some species (such as Banggai cardinalfish) unsuitable for large-scale exploitation (Lunn and Moreau 2004). The Philippines also has a serious aquarium/marine ornamental trade issue. The country supplies fish to the United States, with 95% of curios obtained from wild populations. Sharks, seahorses, and porcupine fishes are the three main fish groups most traded (Grey, Blais et al. 2005). Anemonefish and anemones are also a highly traded species, with measurable declines caused by the trade. Although the potential for the overexploitation of marine ornamentals is great and the industry remains largely unregulated, few studies have addressed the population-level impacts of ornamental exploitation in the Philippines (Shuman, Hodgson et al. 2005).

Pollution: Oil Spills and Antifouling Chemicals

Ocean-based pollution is prevalent throughout the region. Oil spills and antifouling chemicals, documented in six countries, are considered an overall moderate impact threat region-wide. Much research remains to be done to gain a clearer picture of ocean-based pollution in the East Asian Seas. What known pollution exists, however, damages marine life, alters the food web, threatens human health, and leads to biodiversity and economic loss.

Shipping and industrial activities contribute to oil pollution, especially in the high traffic area of the Indonesian shipping pathways of Malacca and Lombok Straits. The former is the main conduit for cargo between the Indo-European region and the rest of Asia and Australia, as well as the coast (Chiu, Ho et al. 2006). Crude oil is highly toxic to marine organisms, and present levels of oil pollution in the seawater have chronic effects on the growth and hatching rate of marine organisms. Currently, technologies and management regimes are being developed to reduce oil contamination in water three to six times current levels in sediment (Law and Hii 2006).

Countries reveal varying levels of oil pollution. In Malaysia, the use of leaded petrol is thought to 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). Such pollution threatens both marine life and human health. 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 (Basheer, Tan et al. 2002).

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). Antifouling chemicals, found in paint additives on ship and boat hulls, docks, fishnets, and buoys to discourage the growth of marine organisms, 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. Finally, the waters surrounding Indonesia contain extensive reserves of oil and natural gas. The region is thus a potential candidate for new energy and oil exploration company operations.

Climate Change: Sea Surface Temperature Increase and Sea Level Rise

Global climate change poses another major threat to the East Asian Seas, both now and in the future (Hoegh-Guldberg 2004). While documented as a moderate impact threat overall, studies on acidification are largely nonexistent, and research on sea level rise (identified in seven countries) and sea surface temperature increase (identified in six countries) are also incomplete.

Research has shown, however, that along with moderate sea surface temperature increases, ENSO events enhanced the western North Pacific summer monsoon inside the South China Sea (Chang, Hsu et al. 2008). Sea temperature-induced coral bleaching and mortality have impaired this region's coral reefs with increasing frequency since the late 1970s; mass bleaching events, which often cover thousands of square kilometers of coral reefs, are triggered 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. In the Philippines, studies have been conducted on the mechanisms by which coral reefs recover from bleaching events, in order to understand them in the context of global climate change, and predict future increases in both the frequency and severity of such events. While elevated sea surface temperatures were thought to cause an estimated 90% of coral bleached in the 1998 ENSO event, the effect of anthropogenic disturbances cannot be ignored (Arceo, Quibilan et al. 2001; Raymundo and Maypa 2003). The loss of coral populations affect those who depend on coral reefs for their daily survival (Hoegh-Guldberg 2004). The total cost of severe bleaching for Southeast Asia, for example, approximates USD $38.3 billion in net present value (a 50 year time horizon with 3% discount) (Cesar, Burke et al. 2003).

Sea level rise is another byproduct of climate change. The mean sea level over the South China Sea had a rise rate of 11.3 mm/yr during 1993–2000 and a fall rate of 11.8 mm/yr during 2001–2005. The thermal change of the upper layer of the South China Sea may contribute significantly to these sea level variations (Cheng and Qi 2007). Regardless, sea level rise has the potential to irreparably alter coastal areas. In Indonesia, the coastal area of Semarang is already subject to coastal hazard due to tidal inundation and land subsidence. Sea level rise can heighten the impact of inundation, leading to destruction of the coastal areas and great economic loss (Marfai and King 2008). East Timor is vulnerable to climate change and especially to sea level rise (Barnett 2007). Barnett predicts that changes in the abundance and distribution of coastal resources is likely to cause a reduction in food security, and sea level rise is likely to damage coastal areas, including Dili, the capital city. In the Philippines, sea level rise has been observed since 1965 and continues today. Parts of Cavite and Manila Bay are especially vulnerable to accelerated sea level rise. The Manila Bay shoreline has changed greatly in the last 5–10 years due to reclamation for housing, ports, coastal roads, buildings, and other urbanized developments, adding to the threat of inundation (Perez, Feir et al. 1996).

Highlighting Regional Solutions

This section highlights regional solutions to the threats facing the East Asian Seas. Large gaps exist in the literature for this region; below are some highlights gleaned from the research.

Market-Based Solutions and Alternate Livelihoods

Throughout the region, the tension between development and conservation continues. Millions of people, many very poor, depend on marine resources for subsistence. But in order to reduce overfishing, there needs to be a focus on reducing fishing efforts and impacts, as well as developing alternative livelihoods for fishers. Economic incentives that replace overfishing and destructive fishing practices could greatly aid the region. More sustainable methods (i.e. changing equipment) could be one sustainable solution. Currently, IGOs like the FAO have focused alternative livelihood training on mariculture, seaweed, and other marine resources, even though those industries also present tradeoffs. Tourism is another source of potential income. The creation of MPAs on Apo Island, Philippines, for example, has created new livelihoods strategies mostly related to tourism. The two new resorts on the island, bed-and-breakfasts, t-shirt vendors, fishing boat charters, dive masters, and guards for the MPA all provide alternative livelihoods. It has been so successful, in fact, that tourism now generates more cash income than fishing for the island, and just over half of Apo households are involved in the island's tourist trade (Craig, van Beukering et al. 2008).

Integrated Coastal and Ocean Zone Management

As explained in the Pacific Ocean (section II), ICOZM is an EBM approach to a location that 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. In the East Asian Seas, ICOZM is one solution to the region's threats and competing coastal and ocean activities, and some aspects of this concept have been implemented. In the aquaculture industry, for example, there have been calls for a new approach to management based on stakeholder needs, mechanisms for conflict resolution, assimilative capacity of the environment, protection of community resources, and rehabilitation of degraded habitats, to improvements in the aquaculture sector pertaining to management of feed, water, and effluents (Primavera 2006). Also, in the South China Sea Region, the UN Environment Programme is working on a regional plan for sustainable development at priority transboundary sites in the region (Wilkinson, DeVantier et al. 2005).

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

Throughout the region, there has been acknowledgement of the crucial importance of MPAs and MPA network strategies as tools for sustainable fisheries management resource protection. Development of an effective, integrated network of MPAs, with substantial no-take zones and effective policy and legal frameworks, is an urgent priority. Indonesia already has 102 gazetted MPAs, five biosphere reserves, three World Heritage sites, and two wetlands of international importance (Abdullah, Agustina et al. 2005). Between 30 and 50 of these sites contain coral reefs. In the South China Sea area, about 125 MPAs have been gazetted (Wilkinson, DeVantier et al. 2005). Individual MPAs like Tubbataha Reef World Heritage (Philippines), Bunaken National Park (Indonesia), and Komodo National Park (Indonesia), are leaders in park management. Palawan, the fifth largest island in the Philippines, is so biologically important that in 1990, UNESCO declared the entire area as a Biosphere Reserve and a mangrove preserve (World Resources Institute website 2007). Such MPAs and reserves offer models of both effective marine management and grassroots involvement. Studies conducted on Philippine MPAs have shown their effectiveness. More than 90% of the people on Apo Island depend on fishing as their primarily livelihood strategy; studies found that the MPA there had increased local fish catches, with the spillover effect of the MPA held responsible for the increase (Russ and Alcala 2003; Craig, van Beukering et al. 2008). On a site in Indonesia, MPAs allowed fish stocks and yields to recover and led to the halting of destructive fishing practices (Cesar 2002).

Given the increase in local fish stocks near MPAs, there is little doubt about the potential for economic benefits of these MPAs. The quantifiable net benefit of managing Taka Bone Tate MPA, Indonesia, was estimated to be between USD $3.5 and $5 million in net present value at a 10% discount over 25 years (Cesar 2002). In the Apo Island case study, an investment of USD $75,000 to protect one square kilometer of coral reefs was found to return between USD $31,900 and $113,000 annually in increased fish production and local dive tourism (White, Vogt et al. 2000). MPAs' recreational values also increase economic benefits. In Palau Payar MPA in Malaysia, the potential estimated recreational value of reefs approximates USD $390,000 per year (Yeo 2004), with the reefs at Paulau Redang MPA in Malaysia between USD $373,900 to $545,100 per year (Mohd Parid, Lim et al. 2005 in (Conservation International 2008)). In the Hon Mun MPA in Vietnam, the recreation benefits from the reef-related recreation industry was estimated at USD $4.2 million, and the total value added from the support function of coral reefs was estimated at $2 million for local fishing and aquaculture industries (Nam and Herman 2005). Reef ecotourism generates many of these sources of revenue (Hargreaves-Allen 2004 in (Conservation International 2008)).

In other places, successes are not as certain. In Indonesia and the South China Sea, MPA effectiveness is limited by insufficient resources for management and proper enforcement of regulations (Abdullah, Agustina et al. 2005). And throughout Southeast Asia, concerns are being raised about high failure rates of community-based, small-scale, no-take marine reserves, due to many variables (Crawford, Kasmidi et al. 2006). Although progress has been made, MPAs still have a long way to go. In the Philippines, for example, only 4% of coral reefs are listed as being protected, even while destructive fishing, sedimentation, pollution, and a lack of enforcement occur in some of the protected areas (Wilkinson, DeVantier et al. 2005).

Regional Governance, Agreements, and Approaches

Regional policy mechanisms are important for marine conservation in the East Asian Seas. One example of a regional policy structure is the Association of Southeast Asian Nations (ASEAN) (Glover and Earle 2004). The association has funded projects in the region supporting marine conservation, as well as adopted criteria to ensure that national action is coordinated across the regions, particularly in shared waters. It has also adopted Marine Water Quality Criteria for the region, as well as national marine protected and marine heritage areas. The association has also developed a plan of action to improve regional coordination of integrated coastal zone management.

Some countries, such as Indonesia, also participate in international treaties and regulations (ASEAN, 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.). 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. Local policies may, in the short term, better provide frameworks for sustainable resource management. Indeed, several smaller, community-based management initiatives have proven successful at protecting coral reefs and replenishing reef-based fisheries (Abdullah, Agustina et al. 2005). Vietnam, for example, has regulations for wetland conservation (Wilkinson, DeVantier et al. 2005).

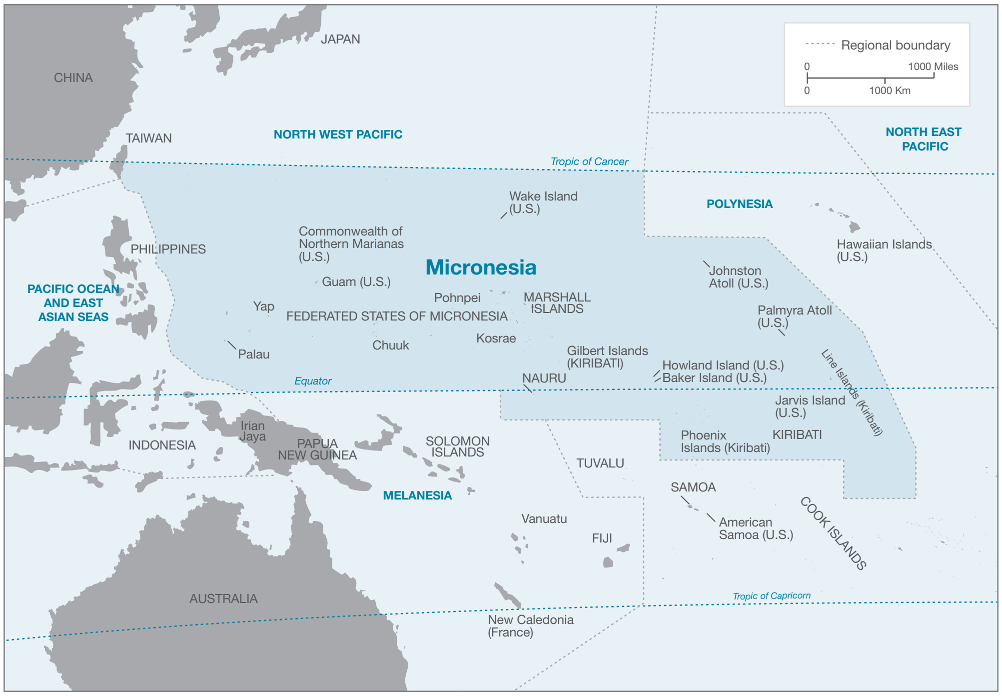
VI. Micronesia Regional Analysis: Threats, Impacts, and Solutions

Photo: Bubble coral *(Plerogyra sinuosa)* on the Sankisan Maru wreck at Chuuk Lagoon, Federated States of Micronesia. (David Burdick)

Micronesia, a subregion of Oceania, comprises hundreds of small islands spread over a large area of the western Pacific. The region includes the Northern Mariana Islands (a U.S. Commonwealth), Guam (a U.S. territory), Kiribati, the Marshall Islands, the Federated States of Micronesia (FSM), Nauru, Palau, and other U.S. remote islands (including Wake Island).

Compared to other regions of the world, Micronesia's marine systems are in good condition, with some areas in excellent condition (South, Skelton et al. 2004). Marine biodiversity in Micronesia remains among the highest in the world; the waters of this region are home to 1,300 species of reef fish and 483 coral species—60% of all known corals—and its high endemism harbors endangered and vulnerable species like saltwater crocodiles, sea turtles, giant clams, and the world's most isolated population of dugong, which is related to the manatee (The Nature Conservancy (TNC) 2008). Micronesia also supports a variety of marine habitats: seagrass beds, fringing coral reefs, active volcanoes, and marine lakes. Because they cover such a vast region, the islands vary considerably in geography, culture, and population—from high atolls to single, low-lying coral islands, and highly populated islands like Guam to less populated ones like Nauru, a single island country. Many are charting a new path from subsistence and traditional management systems to market-based economies. Marine resources, especially the highly valued tuna fisheries and other commercial and artisanal fisheries, are critical for the economic well-being of Micronesia, particularly given limited agricultural opportunities on some islands, such as Kiribati. Tourism is also a major industry for some islands; Guam's reefs are valued at USD $127.3 million per year, with tourism accounting for 75% of this value. Diving and snorkeling are valued at USD $8.7 million, fisheries at $4 million, biodiversity at $2 million, and coastal protection at $8.4 million (van Beukering, Haider et al. 2007).

Map 5: Micronesia



Source: International Ocean Commission and The United Nations (www.unep-wcmc.org/gramed) 2008 Lucidity Information Design, LLC

In Micronesia, all four broad threats (overfishing and exploitation, climate change, habitat destruction, and pollution) have severe to moderate impacts across the region, with invasive species noted as a generally understudied and low impact threat in four countries or territories. One of the most severe threats—commercial fishing (identified in six countries or territories, with a severe impact in five)—causes ecological shifts and reduces fish stocks and food supply, thereby endangering human economies and livelihoods. Artisanal/recreational/subsistence fishing, a moderate impact threat, further exacerbates the problem. Climate-induced sea surface temperature increase (identified in six countries or territories, with a severe impact in five) poses another dire threat to Micronesia. Compounded with sea level rise, a moderate impact threat in Micronesia, sea surface temperature warming can destroy marine ecosystems, jeopardize human economies and livelihoods, and create uninhabitable areas. Widespread pollution from various sources—including nutrients and oil spills and antifouling chemicals—as well as habitat destruction from coastal development and land reclamation, land-based sedimentation, and typhoons and storm surges—are less studied, but still significant, threats. Pollution and habitat destruction lead to the degradation of critical ecosystems that produce invaluable services for society. Significantly, these threats do not operate in isolation, but rather function as multiple, compounded stressors that together can devastate marine and human systems.

The discussion on Micronesia that follows first presents overall regional trends of severe and moderate impact threats, including a table listing the levels of threats and impacts in each country or territory. Then, the literature review section offers a more in-depth discussion of the most severe impact threats. Moderate impact threats are also presented if they are prevalent or notable throughout the region. Finally, the last section provides a brief overview of potential solutions to the threats facing this region as a whole.

Micronesia Regional Trends: Primary Threats and Associated Environmental and Socioeconomic Impacts

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

Based on this assessment, the threats with overall severe impacts across the entire Micronesia region are:

- commercial overfishing, identified in six countries or territories.
- sea surface temperature increase resulting from climate change, identified in six countries or territories.

The threats with overall moderate impacts across the region are:

- oil spills and antifouling chemicals identified across the region as low and moderate impact in seven countries or territories.
- artisanal/recreational/subsistence fishing identified in five countries or territories.
- typhoons and storm surges identified in four out of eight countries or territories.
- sea level rise identified in four countries or territories
- coastal development/land reclamation identified in four countries or territories.
- land-based sedimentation in three countries or territories with high impact.

Key observations regarding research gaps and identified impacts:

- This region is remote, with low population densities compared to other regions.
- The countries and territories in this region have large EEZs to manage.
- Many island people depend on marine resources for food and income and are thus vulnerable to environmental change.
- Research gaps exist throughout the region on climate change and land-based chemicals and nutrient pollution.
- Nauru, Kiribati, and other remote islands have both the least number of moderate to severe impacts as well as the least number of threat types identified. Sea level rise, however, is a major threat to many low-lying islands and atolls.
- Countries and territories such as Nauru and Kiribati have scant research on threats and only a few documented number of identified threat categories.

> Sea level rise has been documented as so severe a threat in parts of the region (such as Kiribati) that it will inhibit the long-term ability of people to inhabit some of the region's island countries and territories. However, more research on this threat needs to be done throughout Micronesia.

The following table distills the findings from the literature, documenting by country or territory, threats and environmental and socioeconomic impacts. There is considerable variation in availability of scientific literature in this region. In the past few years, increasing studies on Palau have strongly linked threats with socioeconomic impacts. Gaps exist throughout the region, however. For example, pollution and climate change are not well documented, and the Marshall Islands, Nauru, and Kiribati have very little information on threats and impacts to their coastal and ocean resources.

TABLE 4: Micronesia Threats Based on Scientific Literature and Impact Assessment

✓ Identified as Threat

● Severe Impact ● Moderate Impact ● Low Impact

It was documented when an article identified an issue as a present or future threat. If no scientific literature was found on the topic, then no check was assigned. This does not necessarily mean the topic is not a threat; rather, it suggests that no scientific literature was found on the topic.

	COMMON-WEALTH OF THE NORTHERN MARIANAS		FEDERATED STATES OF MICRONESIA		GUAM		NAURU		KIRIBATI		MARSHALL ISLANDS		OTHER US REMOTE ISLANDS		PALAU	
	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts
POLLUTION																
Aquaculture: Wastewater																
Land-based Chemicals					✓	Moderate										
Fishing Lines/Nets					✓	Moderate										
Nutrients			✓	Severe					✓	Moderate					✓	Severe
Offshore Oil/Mining																
Oil Spills & Antifouling Chemicals	✓	Low	✓	Moderate	✓	Moderate	✓	Low	✓	Low	✓	Low			✓	Low
Radionuclide											✓	Severe				
Solid Waste Disposal			✓	Severe	✓	Severe									✓	Moderate
Thermal																
Ocean Waste & Toxic Dumping			✓	Moderate							✓	Moderate	✓	Severe		
HABITAT DESTRUCTION																
Anchor Damage	✓	Moderate			✓	Severe									✓	Low
Aquaculture: Coastal Modification																
Coastal Development/Land Reclamation	✓	Moderate	✓	Moderate	✓	Severe									✓	Moderate
Destructive Fishing			✓	Moderate											✓	Moderate
Dredging			✓	Moderate	✓	Severe	✓	Moderate							✓	Low
Marine Recreation					✓	Moderate							✓	Low		
Land-based Sedimentation			✓	Severe	✓	Severe									✓	Severe
Ship Groundings			✓	Low											✓	Low
Tsunamis																
Typhoons/Cyclones/Hurricanes & Storm Surge	✓	Severe	✓	Severe	✓	Severe									✓	Severe
Wrecks/Military Equipment	✓	Moderate	✓	Low									✓	Moderate		
OVERFISHING & EXPLOITATION																
Aquaria Trade											✓	Moderate			✓	Low
Artisanal/Recreational/Subsistence Fishing			✓	Severe					✓	Moderate	✓	Moderate	✓	Low	✓	Severe
By-Catch & Discharge																
Commercial Fishing	✓	Severe	✓	Severe	✓	Severe			✓	Moderate	✓	Severe			✓	Severe
CLIMATE CHANGE																
Acidification																
Sea Level Rise	✓	Moderate	✓	Severe					✓	Severe	✓	Severe				
Sea Surface Temperature**	✓	Severe					✓	Moderate	✓	Severe	✓	Severe	✓	Severe	✓	Severe
INVASIVES																
Invasive Species (Different Vectors)	✓	Moderate			✓	Low							✓	Low	✓	Low

**Changes in SST is strongly associated with El Niño Southern Oscillation (ENSO) events, which are predicted to increase in frequency and intensity over time due to climate change.
For a complete list of references used for the literature review and synthesis to create this table see Appendix C, Table 4 p.138.

Micronesia Literature Review of Severe and Moderate Impact Threats

The discussion that follows highlights the greatest documented threats to Micronesia. The most severe threats are discussed (see bullets and table above), and each threat category includes country/territory-specific details on threats as well 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.

Overfishing and Exploitation: Commercial Fishing and Artisanal/Recreational/Subsistence Fishing

Commercial, industrial fishing, as well as artisanal, recreational, and subsistence fishing, pose two important threats to Micronesia and illustrate the negative impact of overexploitation and unsustainable use of ocean resources on marine life and human livelihoods. Commercial fishing, identified in six countries or territories, is a severe impact in five and an overall severe impact threat in the region (with incomplete information on other countries or territories). Artisanal/recreational/subsistence fishing, considered a moderate threat region-wide, is documented in five countries or territories, with further studies needed in countries or territories including the Northern Marianas, Guam, and Nauru. Both types of fishing reduce fish stocks and biodiversity, thus leading to economic loss and threatened food security.

The limited resources of many of these islands mean that their inhabitants exploit marine and fish resources, often unsustainably (Fleming and Blowes 2003). Many commercial fisheries have been in decline for many years. While the commercial yield of tunas in the Central Pacific, for example, increased several-fold between 1952 and 1998, tuna stocks remain 40% of 1950s levels. Blue marlin declined 21% and swordfish 56% (Cox, Martell et al. 2002). Such overexploitation can lead to species reduction or loss, habitat destruction, and the loss of economic livelihoods. Artisanal fishing (small-scale commercial and subsistence fishing), as well as recreational fishing, can be just as destructive as larger-scale commercial fishing to marine life, especially to coral reef fisheries. On the Marshall Islands, for example, subsistence and artisanal fishing plays an important role in daily life. However, the export of live coral and other reef products, as well as illegal shark fishing, lead to exploitation and unsustainability (Pinca, Berger et al. 2005). In Guam, bottom fishing charters harvested 2.1 metric tons of fish in 2003, affecting coral reef productivity (Flores 2003). And in Palau, studies cite subsistence overfishing as a major stress to the coral reef fisheries (Maragos and Cook 1995).

In FSM, overfishing has been identified as an urgent and critical threat. Both population growth and a shift from subsistence to commercial harvesting, compounded with the breakdown of traditional management systems, have increased pressure on FSM's coral reefs over the last three decades, even though the number of people employed in the fishing industry has declined. In 2006, the Conservation Society of Pohnpei conducted a market-based analysis in conjunction with ongoing ecosystem assessments in order to determine the condition of Pohnpei's reef fisheries. Both concluded that the reef fish populations in Pohnpei are being overfished and that present harvest levels are unsustainable. Without an overarching policy that combines habitat protection and fishery management practices, Pohnpei's fishery resources are likely to continue to decline dramatically (George, Luckymis et al. 2008). In FSM, destructive fishing practices, including the use of explosives in reef flats and lagoons, indiscriminately kill large numbers of fish and other nearby marine organisms while destroying habitats (George, Luckymis et al. 2008).

Commercial, or industrial, fishing also poses a severe threat to the Commonwealth of Northern Marianas. In 1997, the Northern Marianas' cucumber fishery closed due to declining catch (Trianni, Moosa et al. 2002; Trianni and Bryan 2004). Commercial fishing gear, from bottom trawls to dredges, gillnets, and longlines, while designed to catch the most fish possible, can be highly destructive to other species and to habitats. Overfishing thus magnifies habitat destruction. On the Marshall Islands, longline fishing entangles other marine animals as by-catch (Pinca, Berger et al. 2005).

Intensive fishing has also put pressure on Kiribati's marine resources; in the late 1990s, the economic value of Kiribati's fisheries approached USD $146 million (Dalzell, Adams et al. 1996). In recent decades, intensive harvesting as well as population pressures have increased around the productive lagoon fisheries of Tarawa atoll. The situation represents the increasingly common condition of resource depletion and marine community structure change wrought by human activities. With more landings in the 1990s than in the 1970s, important finfish species have declined in catch-per-unit effort, with severe depletion of some preferred species. These results suggest declining abundance of locally important fish species and changes in species composition in Tarawa Lagoon (Beets 2001; Thomas 2007).

Climate Change: Sea Surface Temperature Increase

Global climate change affects all aspects of an ecosystem, including increasing ocean temperatures. More research needs to be done in this region on other aspects of climate change—notably acidification (with no documented studies) and sea level rise (considered a moderate impact threat regionally, and discussed

below). However, sea surface temperature increase has been documented in six countries or territories, five with severe impacts. No information on sea surface temperature is available for FSM or Guam.

An area-averaged annual mean warming of about 2 °C or higher for the 2050s and about 3 °C or higher for the 2080s are projected for small island developing states—including those in the Pacific—as a consequence of increases in atmospheric concentrations of greenhouse gases. In general, however, seasonal variations of the projected sea surface warming are minimal (Lal, Harasawa et al. 2002). On a region-wide scale, sea surface temperature increase threatens human populations and the marine ecosystem. In Micronesia, elevated sea surface temperatures may create the potential for more frequent and intense storms and typhoons, which negatively affect coastal areas, particularly atolls and low-lying coastal regions with wetlands, seagrass beds, and mangroves, as well as shallow reefs (Hoegh-Guldberg, Hoegh-Guldberg et al. 2000). Sea temperature increases also alter the ocean environment, which may, in turn, lead to coral bleaching episodes and other biological shifts. Projected future climate change could lead to shifts in species composition as well (Gaffin and Oneill 1997; Intergovernmental Panel on Climate Change (IPCC) 2007). When combined with more localized stresses like overfishing, tourism, coastal development, and pollution, climate change and increasing sea surface temperatures can negatively affect not only the ocean ecosystem, but the economic viability of islands.

The link between increased greenhouse gases, climate change, and regional coral bleaching events—strongly associated with elevated sea surface temperatures during recurrent ENSO events—is widely accepted in the scientific community (Hoegh-Guldberg 1999; Hughes, Baird et al. 2003). Palau experienced an ENSO event, sea surface temperature increase, and severe coral bleaching event in 1997–98 (Bruno, Siddon et al. 2001). Nauru also experienced coral bleaching and mass fish kills in 2003, possibly a result of unusually high sea surface temperatures (Lovell, Sykes et al. 2004). In Kiribati, surveys in 2004 revealed almost 100% coral mortality in the lagoon of Kanton Atoll, and 62% mortality on the outer leeward reef slopes of Kiribati, as well as elsewhere throughout the Phoenix Island group. The mortality corresponded to a record high of 16 °C heating around the Phoenix Islands between August 2002 and March 2003. At the time of the study, invertebrates seemed reduced inside the Kanton Atoll lagoon, though fish populations did not appear reduced to the same levels, and apex predators and key indicator fish species were present. Because of the lack of evidence of overfishing or land-based pollution, the study concluded that the exposure to excessively high water temperatures killed the coral reef community and caused the excessive loss of coral species and cover throughout the Phoenix Island group (Alling, Doherty et al. 2007).

Increasing sea surface temperatures can also alter biochemical dynamics and ocean chemistry, which, in turn, can harm fish communities and fisheries. Planktonic communities contribute to oceanic productivity, fishery yields, and net marine sequestration of atmospheric greenhouse gases. However, elevated sea surface temperature could create a “domain shift” toward an ecosystem dominated by prokaryotes, which would alter nutrient flux pathways and affect food web structures, export production structures, and fishery yields (Karl, Bidigare et al. 2001). While tuna catch and its associated revenues fluctuate with natural events such as ENSO, the Marshall Islands fisheries have, in the last decade, started to capitalize on some of the positive effects brought by the warmer waters of ENSO on tuna populations. Still, climate change and increased sea surface temperature are expected to exert a significant—and generally negative—impact on fisheries and the marine environment in this region (Moss 2007). While elevated sea surface temperature affects fisheries, it also impairs other industries, such as tourism. In the two years following the 1998 bleaching event in Palau, the combined effects of lost visitation and reduced satisfaction caused a reduction of total producer surplus by as much as 10%, and to total consumer surplus by as much as 20% (roughly USD $350,000/year) (Graham, Idechong et al. 2001). In the Northern Marianas, reefs are valued at an estimated USD $61.2 million per year, with tourism valued at $42.3 million, fisheries at $1.3 million, coastal protection at $8 million, and diving and snorkeling at $5.8 million (van Beukering, Haider et al. 2007).

Habitat Destruction: Typhoons and Storm Surges

A storm or tidal surge resulting from an intense storm, tropical cyclone, or Pacific typhoon, as well as the typhoons themselves, can be particularly damaging to marine ecosystems and fishery resources in Micronesia, where they have been documented in four locations, all with severe impacts. Although large gaps in the research on specific countries or territories exist, studies show that storm surges create a rise in water level, wave run-ups, and flooding of low-lying coastal areas that greatly affect the region. Typhoons as a whole produce these damaging storm surges along with strong winds, torrential rains, and coastal flooding.

Typhoons and storm surges threaten marine habitats in various ways. Major storm waves have damaged marine benthic communities in Guam, which in the last decade experienced four

large typhoons (Porter, Leberer et al. 2005). In Palau, typhoons and their associated waves caused major stress to coral reefs (Maragos and Cook 1995; Golbuu, Bauman et al. 2005). Besides harming coral reefs, typhoons can be destructive to essential fish habitat, which, in turn, can lead to economic loss for fisheries (Brock 1996). Storm surges and typhoons exacerbate marine debris and pollution. Increased precipitation causes land-based erosion, sedimentation, and increased nutrient inputs from runoff (Starmer 2005). As storms create turbidity at river mouths, pollution runoff from waste oil, fire retardant, and other contaminants entering the water increases (Porter, Leberer et al. 2005).

Climate Change: Sea Level Rise

As climate change impacts increase in the future, sea level rise is predicted to be an extremely serious threat in Micronesia (Hasurmai, Joseph et al. 2005; Porter, Leberer et al. 2005). Sea level rise and its impacts are not yet well documented in small island developing states. In the literature on Micronesia, for example, sea level rise has been identified in only four locations (Northern Marianas, FSM, Kiribati, and Marshall Islands, most with severe impacts). However, sea level rise will certainly limit the long-term ability of humans to inhabit island states such as Kiribati, a coral-rubble atoll with land rising rarely more than three meters above present sea level (Roy and Connell 1991; South, Skelton et al. 2004). In 1999, small uninhabited islets of Kiribati disappeared. Salt water intrusion into fresh water supplies also threatens the vast archipelago. It is predicted that an 80 centimeter sea level rise could inundate two-thirds of Kiribati, thereby threatening its entire human population (Intergovernmental Panel on Climate Change (IPCC) 2007).

Kiribati is not alone in its vulnerability to sea level rise. The Marshall Islands, for example, have an elevation of 0.6 meter. Sea level rise could change (or submerge) the coastline, threaten the water supply, destroy coastal development, decrease tourism income, and reduce agriculture and vegetation (Gaffin and Oneill 1997; Intergovernmental Panel on Climate Change (IPCC) 2007). Sea level rise could, in fact, affect many parts of Micronesia and further threaten social and economic infrastructure, which is often located along the coastline. Sea level rise may, in the end, produce major population upheavals, migrations, and greater pressure on those countries or territories that will need to accommodate these refugees (Barnett and Adger 2003; Hunt 2003).

The Australian government is supporting data collection in territories across the Pacific on sea level rise. The first two phases (July 1991 to December 2000) established sea level and meteorological monitoring stations at 11 sites, one each in the Cook Islands, Fiji, Kiribati, the Marshall Islands, Nauru, Papua New Guinea, the Solomon Islands, Tonga, Tuvalu, Vanuatu, and Samoa. During the third stage (2001–2005), another station was established in FSM and continuous global positioning systems (CGPS) were installed at many of these locations to monitor the islands' vertical movements. During the fourth, five-year phase (2006–2010), data will continue to be collected, analyzed, stored and disseminated, and personnel will be trained to assist with the interpretation of the data.

It is important to note that one other climate change-related threat, ocean acidification, will compound problems generated by sea surface warming and sea level rise. Ocean acidification will affect reef-building organisms with calcium carbonate structures and thereby impair the reef ecosystem, alter the entire food web, and threaten fishers' livelihoods. Although the ocean acidification scenarios have been modeled, the overall impact is unknown.

Habitat Destruction: Land-Based Sedimentation

Land-based sedimentation results from poor land use practices, including agriculture, deforestation, and coastal development, which can increase erosion and sedimentation. Three Micronesian countries and territories (FSM, Guam, and Palau) suffer the effects of sedimentation, all with severe impacts.

In light of the gaps in the research (very little literature discussed this threat), more studies need to be conducted to gain a clearer picture of land-based sedimentation in the region.

A few case studies, however, have been documented. Runoff from coastal development in Babeldaob, Palau, has been shown to increase sedimentation (Golbuu, Bauman et al. 2005). Mangroves in Palau trap 30% of sediments from land-based sources; if these mangroves disappear, the sedimentation will worsen in coastal areas (Victor, Golbuu et al. 2004). In Guam, wildfires, clearing and grading forested lands, recreational off-road vehicle use, and wild populations of introduced mammals have accelerated the rates of upland erosion (Porter, Leberer et al. 2005).

Increased sedimentation in coastal waters produces turbidity (Victor, Neth et al. 2006), reduces available light, and can suffocate coral reefs and kill fish. Overall, sedimentation from soil erosion has been shown to be a major stress to coral reef health (Maragos and Cook 1995). In Palau, sediments smother seagrass and coral reefs, and hinder coral recovery by blocking recruitment (Victor, Golbuu et al. 2004). In FSM, coastal development—increased dredging, road construction, and land

The studies on nutrient-based pollution that exist suggest that it poses a severe threat to some Micronesian islands; however, it is documented only in three countries or territories.

clearing—has been the leading cause of sedimentation and one of the largest stressors to Pohnpei's coral reefs, with dozens of dredge sites and mangrove clearings surrounding the coast (George, Luckymis et al. 2008). Accelerated siltation, sedimentation, and turbidity due to erosion-related land-practices have been shown to be the most serious cause of damage in Guam's waters (Gawel 1999). Finally, sedimentation negatively affects ecosystem services, fisheries, and tourism (Cesar and van Beukering 2004).

Other Regional Threats

The impact threats discussed briefly below are worth mentioning for the prevalent impacts they have now as well as the impacts they could have in the future. All of these threats, however, require further research, as they are not uniformly documented in the literature.

Pollution: Nutrients

Nutrients from land-based pollution, documented in only three locations (no other literature was found), threaten both environmental and socioeconomic systems in Micronesia. Studies are not widespread, but where they have been conducted, they suggest that impacts are generally moderate to severe. Increased nutrients come from a variety of sources, but fertilizers used for agriculture and sewage effluent are among the worst offenders. Sewage effluent derives from deficient or ineffective sewage and waste disposal facilities in the region. Palau, for example, either lacks facilities altogether, or uses septic tanks and plants that cannot effectively handle waste (Golbuu, Bauman et al. 2005). FSM similarly lack proper sewage and waste disposal facilities (Hasurmai, Joseph et al. 2005). In Guam, discharges of sewage and stormwater also lead to increased nutrient inputs (Gawel 1999). However, nonpoint sources of fecal contamination are by far the worst source of sewage contamination in Guam's coastal waters (Matson 1993).

Increased nutrients threaten both marine and human systems. Nutrients from sewage can lead to disease and outbreaks that impair coral reef health. Algal outbreaks, which thrive on nutrients from sewage, and coral diseases such as coralline lethal orange disease, tumors, and black band disease, can cause coral mortality (Starmer 2005; Sussman, Bourne et al. 2006). The loss of corals to crown-of-thorns starfish predation is a major problem (Gawel 1999). In FSM, the construction of pigpens and placement of sewage outfalls in coastal areas, compounded by other poor land use practices, affect coral reef health (George, Luckymis et al. 2008). In Guam, increased nutrient inputs pose a threat to humans; they have been shown to produce high numbers of indicator bacteria (46% frequency) in sediments that underlie otherwise indicator-free recreational waters. Largely, however, the presence of indicator bacteria in recreational waters is unacknowledged and unmonitored, posing potential health risks to recreational users (Matson 1993).

Pollution: Solid Waste Disposal

Micronesia also suffers from different kinds of marine debris, garbage, solid waste, and toxic dumping, which can deposit nutrients and toxic chemicals into the ocean. Solid waste disposal, identified only in three countries or territories (FSM, Guam, and Palau), nonetheless exerts an overall severe impact on the environment. Solid waste on small islands is challenging to manage; as a result, much of the waste ends up in the sea. Marine debris accumulation in the nearshore marine habitat can also entangle mammals and seabirds and threaten endangered species (Henderson 2001; Boland and Donohue 2003).

Photo: Striped puffer *(Arothron manilensis)* in Guam, Mariana Islands. (David Burdick)

Highlighting Regional Solutions

This section highlights regional solutions to the threats facing Micronesia. Gaps exist in the literature for this region; below are some highlights gleaned from the research.

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

Various governments and intergovernmental parties have started to address the growing threat of global climate change. In 1987, the UNEP South Pacific Task Team evaluated the impacts of and solutions to climate change on Pacific island countries and territories. Between 1997 and 2000, the Secretariat of the Pacific Regional Environment Program's (SPREP) Pacific Islands Climate Change Assistance Programme was implemented to assist 10 Pacific island countries or territories that signed and ratified the UN Framework Convention on Climate Change (UNFCCC) with their reporting, training, and capacity building responsibilities under the convention, including the assessment of their vulnerability to climate change. In 1998, participants from 12 countries or territories received training on assessing climate change vulnerability and adaptation requirements. Yet despite regional coordination, success was limited. With regard to mangrove rehabilitation efforts in Micronesia, for example, the only successful projects were recorded in Kiribati, Northern Mariana Islands, and Palau (Gilman, Ellison et al. 2006). But because many Pacific islands (such as Kiribati) are overwhelmed by the possibility that global climate change may result in a total loss of their territories, they have become effective global advocates of the importance of mitigating against those factors that are causing climate change (South, Skelton et al. 2004).

The Pacific Islands Framework for Action on Climate Change, Climate Variability, and Sea Level Rise 2000-2004 offers a framework for addressing climate change. Building on this document, PICTs (Pacific Island Countries and Territories—including American Samoa, Cook Islands, Fiji, French Polynesia, Guam, Kiribati, Commonwealth of the Northern Marianas, Marshall Islands, FSM, Nauru, New Caledonia, Niue, Palau, Papua Guinea, Samoa, Solomon Islands, Tokelau, Tonga, Tuvalu, Vanuatu, Wallis, and Futuna) developed another framework for action, Pacific Islands Framework for Action on Climate Change, 2006–2015. Such a strategic platform for policy and decision makers takes into account climate change (as a result of both human activity and natural variability) on national and regional levels (South Pacific Regional Environment Programme (SPREP) 2005).

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

Community-based MPAs and marine reserves offer a solution to the pressing problems faced by Micronesia and are also being used as a fisheries resource management tool. Protected areas—from national parks to monuments, managed resource protected areas, protected seascapes, and habitat management areas—exist throughout the region and can provide ecological and socioeconomic benefits. Fish "spilling over" from no-fishing zones, for example, leads to improved fish catches for fishers, thus improving livelihood, food security, and nutrition and health (Craig, van Beukering et al. 2008).

Financing effective management of both small and large MPAs, however, is challenging. There are some innovative examples throughout this region. In Kiribati, the government established the remote Phoenix Islands protected area (PIPA), covering 410,500 square kilometers and nominated it for a World Heritage site. Kiribati's Phoenix Islands (one of the planet's last intact coral archipelagos) represents—after Australia's Great Barrier Reef and the United States' Northwestern Hawaiian Islands—the single largest protected marine area in the world (Wood, Fish et al. 2008). To support management costs, the government has established a trust fund for the PIPA that is a conservation concession. The trust will purchase from the government conservation rights, replacing former access rights and payments from commercial fishing. However, more surveillance against illegal fishing—resulting from lost income from retired commercial fishing licenses—is needed.

Regional Governance, Agreements, and Approaches: The Micronesia Challenge

The Micronesia Challenge, a regional intergovernmental initiative, recognizes the need across Micronesia to focus on awareness and communication, compliance and enforcement, marine habitat and natural processes restoration, problematic invasive species control, policies and regulations, and site/area management. It strives to conserve 30% of nearshore coastal waters by 2020. However, the challenge has limited capacity to address socioeconomic issues (Golbuu, Bauman et al. 2005).

The government of Palau is a key driver behind the Micronesia Challenge, which began in 2005 with President Tommy E. Remengesau, Jr. One of the biggest steps that Palau's government has taken towards long-term protection of its natural resources was the creation of a comprehensive Protected Areas Network (PAN). The Nature Conservancy worked closely with government and community stakeholders to ensure that the

PAN has a collaborative conservation approach that will benefit local communities and protect the island's great biodiversity. The PAN will serve as the foundation for Palau's natural resource conservation efforts.

Ecosystem-Based Management

An EBM approach to the region considers multiple external influences, is adaptive, and strives to balance diverse environmental and socioeconomic objectives. Pilots for EBM are being tested in Palau, and scientists have posited EBM as one solution to the threats facing Micronesia. A few studies recommend a "white water to blue water" integrated watershed approach to the management of coral reefs (Merlin and Raynor 2005; Golbuu, Fabricius et al. 2008). Other research suggests that the linkages between global warming and its effects on the tuna fisheries sector must be better understood and uncertainties accounted for so that impacts are appropriately addressed and integrated into sustainable fisheries development policies. This study concludes that new fisheries development strategies that emphasize ecosystem-based planning are required as a start, as are the various international initiatives that further understanding of the links between climate and ocean systems (Moss 2007).

Regulation and Enforcement

There is a great need to develop, implement, and use legislation, regulations, permit systems, and policies to alleviate threats in this region, both to the open oceans and nearshore areas. These laws and regulations need to be aligned with global conventions and agreements. Compliance and enforcement is particularly important for fisheries management as well as land-based pollution. For example, a recent report calculated the economic value of coral reefs in Saipan (Northern Marianas) to be USD $61.16 million per year, with tourism comprising about 70% of this value (Waddell 2008). Findings from the report supported three main recommendations: 1) establish measures to address the issue of nonpoint and point source pollution; 2) make use of the cultural importance residents place on marine ecosystems to improve coral reef management; and 3) develop a comprehensive system of user fees for visitors of MPAs on Saipan.

Strengthening Institutions and Building Capacity

A great opportunity exists to strengthen coastal and ocean local, national, and regional management institutions as well as build capacity and knowledge regarding coastal and ocean resources. For example, institutions and the Western and Central Pacific Tuna Convention could be directed to support reduction of harvests, allow for transferability of harvesting rights across countries/territories and vessels, manage financial risk, and build governance capacity and effectiveness. At this time, however, limited capacity exists to address the socioeconomic impacts of the threats listed above (Golbuu, Bauman et al. 2005).

Progress is being made, however, via the efforts of NGOs such as The Nature Conservancy, which implemented a Micronesia Leaders in Conservation Model. Still, 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 needs to be made a high priority. This will entail great effort on the part of national, regional, and international education and training institutions, and require significant funding.

VII. Melanesia Regional Analysis: Threats, Impacts, and Solutions

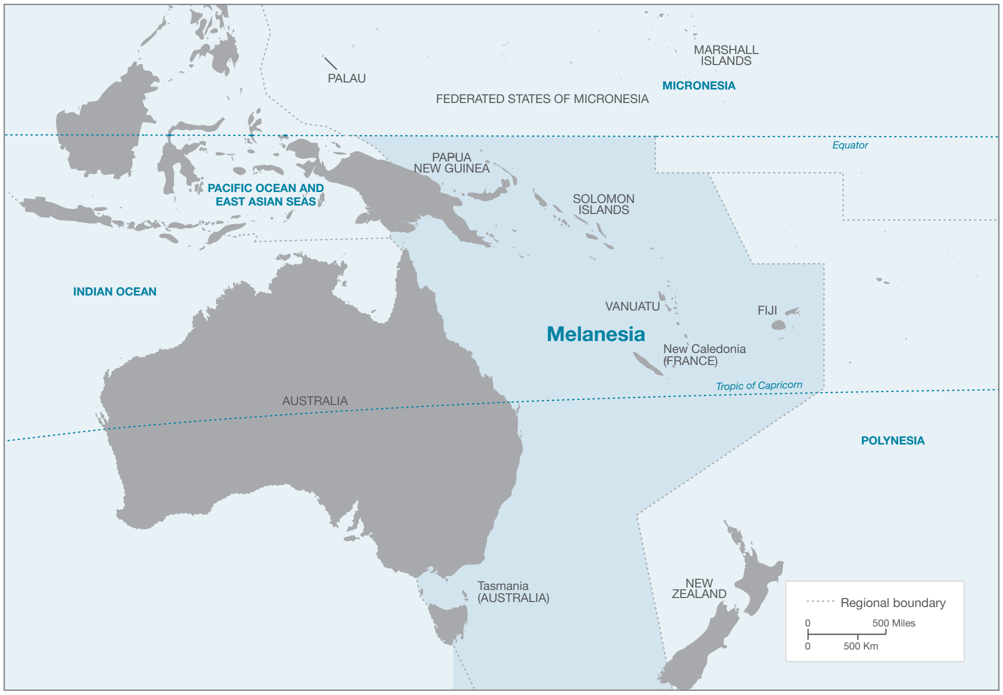
Photo: Tenure of reefs by indigenous peoples is particularly important in the Melanesian region. Solomon Islands. (Joshua Cinner/ARC Centre of Excellence for Coral Reef Studies /Marine Photobank)

Melanesia, a subregion of Oceania, includes the island countries and territories of Australia (the world's largest island and smallest continent), Fiji, New Caledonia (France), Papua New Guinea, Solomon Islands, and Vanuatu.

Melanesia is an extremely diverse region, with both rural, sparsely populated islands, and densely populated urban areas. Although Australia contains significant cities and natural resources, many of the other Pacific islands are much poorer and less developed, lack ample natural resources, and depend on the sustainable use of their local resources for survival (South, Skelton et al. 2004). One of the outstanding characteristics of Melanesia is its coral reefs, though many places lack sufficient data to assess their health. Australia's Great Barrier Reef, located in the Coral Sea, is the world's largest coral reef system. Containing more than 2,900 individual reefs, it harbors a wide diversity of marine life. Fiji is a major tourist destination whose reefs, which attracted 430,800 tourists in 2004, provide a major source of food for local people. The value of Fiji's marine ecosystem services has been estimated at USD $578 million per year, and tourism generates about USD $115 million annually (Fiji Islands Bureau of Statistics website 2008). New Caledonia's archipelagos, hotspots for endangered species, support high levels of endemism and are surrounded by a relatively pristine barrier reef, second only in size to Australia's Great Barrier Reef. Delimiting the northeast boundary of the Coral Sea, the Solomon Islands boast 6,000 square kilometers of reef, abundant seagrass, and 22 species of mangroves, but, like Papua New Guinea and other Melanesian countries and territories, contain many yet undocumented areas (Huber 1994; Bryant, Burke et al. 1998). Throughout Melanesia, specifically Papua New Guinea, the Solomon Islands, and Fiji, tenure and ownership of reefs by indigenous peoples are particularly important, though this form of stewardship is slowly breaking down (Oreihaka and Ramohia 1994).

All four broad threats (overfishing and exploitation, climate change, habitat destruction, and pollution) have severe to moderate impacts across Melanesia, with invasive species noted as a generally understudied and identified as a low impact threat in two countries or territories. One of the most severe threats

Map 6: Melanesia



Source: International Ocean Commission and The United Nations (www.unep-wcmc.org/gramed) 2008 Lucidity Information Design, LLC

facing the region is land-based sedimentation, identified in six countries or territories; such habitat destruction removes critically important resources for both people and sea life. Overfishing and exploitation also jeopardize Melanesian waters, with commercial fishing identified as a threat in six countries or territories (with mostly moderate and severe impacts) and artisanal/recreational/subsistence fishing a major threat in five countries or territories. Overfishing causes ecological shifts and reduces fish stocks and food supply, thereby endangering human economies and livelihoods. Climate change not only destroys marine ecosystems and can create uninhabitable areas, but can exacerbate all of the threats above. It is important to note that these threats do not operate in isolation, but rather function as multiple, compounded stressors that together can devastate marine and human systems.

The discussion on Melanesia that follows first presents overall regional trends of severe and moderate impact threats, including a table listing the levels of threats and impacts in each country or territory. Then, the literature review section offers a more in-depth discussion of the most severe impact threats. Moderate impact threats are also presented if they are prevalent or notable throughout the region. Finally, the last section provides a brief overview of potential solutions to the threats facing this region as a whole.

Melanesia Regional Trends: Primary Threats and Associated Environmental and Socioeconomic Impacts

The bullets below highlight significant severe and moderate impact threats in Melanesia based on the impact assessment methodology described in the Introduction (section I).

Based on this assessment, the threats with with overall severe impacts across the entire region are:

- land-based sedimentation identified in six countries or territories.
- commercial overfishing identified in six countries or territories.
- artisanal/recreational/subsistence fishing identified in five countries or territories.

The threats with overall moderate impacts across the region are:

- oil spills and antifouling chemicals identified across the region as low and moderate impact in six countries or territories.
- sea surface temperature increase resulting from climate change identified in five countries or territories.
- nutrients identified in four countries or territories.
- sea level rise identified in four countries or territories.

- land-based chemical pollution in four countries or territories.
- coastal development/land reclamation identified in three countries or territories.

Key observations regarding research gaps and identified impacts:

- Papua New Guinea and Fiji have recently conducted more studies on threats, but few link these threats to impacts or prioritize the threats.
- Australia has the most comprehensive research, the greatest total number of impacts, as well as the greatest documented number of impacts associated with identified threat categories.

The following table distills the findings from the literature, documenting by country or territory, threats and environmental and socioeconomic impacts. Because boundaries of the region largely adjoin other large ocean spaces, documented trans-boundary effects (excluding global climate change) are relatively small (South, Skelton et al. 2004). Scientists have not, however, conducted research on many of these threats and impacts for all of this region's countries and territories. While Australia has research on threats and impacts, it still has gaps (documented in the table). Other countries and territories such as Papua New Guinea and Fiji have enjoyed more study recently, but few studies link threats to impacts or prioritize the threats.

TABLE 5: Melanesia Threats Based on Scientific Literature and Impact Assessment

✓ Identified as Threat 🔴 Severe Impact 🟠 Moderate Impact 🟡 Low Impact It was documented when an article identified an issue as a present or future threat. If no scientific literature was found on the topic, then no check was assigned. This does not necessarily mean the topic is not a threat; rather, it suggests that no scientific literature was found on the topic.	AUSTRALIA		FIJI		NEW CALEDONIA		PAPUA NEW GUINEA		SOLOMON ISLANDS		VANUATU	
	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts
POLLUTION												
Aquaculture: Wastewater	✓	🟠	✓	🟡	✓	🟠						
Land-based Chemicals	✓	🟠	✓	🟠	✓	🟠	✓	🟠				
Fishing Lines/Nets	✓	🟡										
Nutrients	✓	🟠	✓	🟠	✓	🔴	✓	🟠				
Offshore Oil/Mining	✓	🟠					✓	🟡				
Oil Spills & Antifouling Chemicals	✓	🟡	✓	🟠	✓	🟠	✓	🟠	✓	🟠	✓	🟡
Radionuclide												
Solid Waste Disposal			✓	🟠			✓	🔴				
Thermal												
Ocean Waste & Toxic Dumping	✓	🟡	✓	🟠	✓	🟠					✓	🟡
HABITAT DESTRUCTION												
Anchor Damage	✓	🟡										
Aquaculture: Coastal Modification	✓	🟠			✓	🟠						
Coastal Development/Land Reclamation	✓	🔴	✓	🔴	✓	🔴						
Destructive Fishing			✓	🟡			✓	🟠	✓	🟠		
Dredging	✓	🔴										
Marine Recreation	✓	🟡	✓	🟡								
Land-based Sedimentation	✓	🟠	✓	🟠	✓	🟠	✓	🔴	✓	🔴	✓	🟠
Ship Groundings												
Tsunamis					✓	🔴	✓	🟠				
Typhoons/Cyclones/Hurricanes & Storm Surge					✓	🔴					✓	🟠
Wrecks/Military Equipment							✓	🟠				
OVERFISHING & EXPLOITATION												
Aquaria Trade	✓	🟡	✓	🟠					✓	🟠	✓	🟡
Artisanal/Recreational/Subsistence Fishing			✓	🔴	✓	🟠	✓	🔴	✓	🔴	✓	🟠
By-Catch & Discharge	✓	🟡										
Commercial Fishing	✓	🟡	✓	🔴	✓	🟠	✓	🔴	✓	🟠	✓	🟠
CLIMATE CHANGE												
Acidification	✓	🔴										
Sea Level Rise	✓	🟠	✓	🟠					✓	🟠	✓	🟠
Sea Surface Temperature**	✓	🔴	✓	🔴	✓	🔴	✓	🟡			✓	🟠
INVASIVES												
Invasive Species (Different Vectors)	✓	🟠									✓	🟡

**Changes in SST is strongly associated with El Niño Southern Oscillation (ENSO) events, which are predicted to increase in frequency and intensity over time due to climate change.
For a complete list of references used for the literature review and synthesis to create this table see Appendix C, Table 5 p.140.

Melanesia Literature Review of Severe and Moderate Impact Threats

The discussion that follows highlights the greatest documented threats to Melanesia. The most severe threats are discussed (see bullets and table above), and each threat category includes country/territory-specific details on threats as well 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.

Habitat Destruction: Land-Based Sedimentation

Land-based sedimentation, a serious form of habitat destruction, is a prevalent problem throughout Melanesia. The literature documents it in all six countries or territories, each with severe and moderate impacts. Increased sedimentation in coastal waters produces turbidity (Victor, Neth et al. 2006), reduces available light, and can suffocate coral reefs and kill fish. Overall, sedimentation from soil erosion has been shown to be a major stress to coral reef health (Maragos and Cook 1995). Finally, both increased nutrients and sedimentation negatively affect ecosystem services, fisheries, and tourism (Cesar and van Beukering 2004).

Elevated sedimentation, combined with nutrient inputs, have long been thought to be the major water quality threats to Australia's Great Barrier Reef (GBR). Increased sedimentation can inhibit growth of shallow seagrass beds and inshore reefs in deposition areas and increase eutrophication. Sedimentation results primarily from intensive crop agriculture, cattle grazing, and land clearing, and is exacerbated by high erosion rates (Haynes and Michalek-Wagner 2000). The combined impact of runoff and sedimentation, crown-of-thorns starfish outbreaks, and sea surface temperature increases may cause devastating changes to the GBR ecosystem (McKergow, Prosser et al. 2005)

Fiji suffers from major sedimentation caused by runoff from logging and deforestation as well. Modification of coastal areas has also caused greater changes in erosion rates and more runoff (South, Skelton et al. 2004). Leeward reefs in Northern Viti Levu and some other areas have probably been degraded by increased sedimentation from agricultural areas. Sedimentation also affects the Solomon Islands. Deforestation has promoted heavy runoff during major rainfall events which has, in turn, increased turbidity (South, Skelton et al. 2004). When the diversity and abundance of benthic organisms were examined in relation to the long-term logging impacts in Kolombangara and Vangunu, Western Province, they were found to be more abundant in areas with less sedimentation (Morrissey, Turner et al. 2003).

Overfishing and Exploitation: Commercial Fishing

In Melanesia, commercial, industrial fishing has been documented in all six countries and territories, most with moderate and severe impacts. Throughout the region, reef fish and coastal pelagic fish are the most commonly fished, with marine resources fished in both coastal/inshore areas and in the offshore zone. Despite some knowledge of commercial fishing, more research needs to be done (South, Skelton et al. 2004). What is certain, however, is that severe overfishing can cause ecological shifts, reduce fish stocks, and, to these islands that depend on marine resources for food and livelihood, endanger the islands' human existence.

Commercial fishing is an important part of the region's economies, but may be on an unsustainable path. In the late 1990s, the economic values of some of the largest Melanesian fisheries approached USD $161 million (Papua New Guinea). After commercial reef fisheries in Melanesia followed the arrival of Europeans, unregulated fishing of various marine organisms, such as pearl oysters, trochus, and sea cucumbers, ensued, with many stocks severely reduced (Dalzell and Adams 1996). Extinct species include giant clams, and endangered species include sea turtles, giant tritons, mangrove crabs, bêche-de-mer, trochus and turban shells, and highly targeted reef fishes (South and Skelton 2000). Increasing fishing efforts and new technology appear to be depleting a major offshore tuna species (Hunt 2003). The growing aquarium and ornamental coral trade in Fiji, the Solomon Islands, and Vanuatu, which mainly targets American, European, and Japanese markets, has exacerbated a decline in reef life (Guillaume 2004). Despite these trends and projections, it must be noted that fisheries catches from Melanesia's coral reefs are rarely recorded in official statistics, so reconstruction of catch estimates with limited hard data requires assumptions and results in some uncertainties (Zeller, Booth et al. 2007).

Coastal development/land reclamation has been documented as a severe threat in Australia, Fiji, and New Caledonia, but no studies exist for the rest of the region.

In Australia, commercial fishing is a relatively low threat. The country is a major supplier of dried pipehorses (at least one endemic), which are caught via trawl by-catch, a highly destructive practice, and also the sole supplier of two sea dragon species (Martin-Smith and Vincent 2006). Other levels of fish catch (including swordfish, yellowfin tuna, big eye tuna, and striped marlin) have declined since the early 2000s, however, because of high operating costs and fewer vessels, reduced catch rates in inshore areas, and new management policies. The Eastern Tuna and Billfish Fishery Statutory Management Plan (2005), for example, allocates fishing rights in the form of hook limits, introduces trigger catch limits, and aims to mitigate seabird by-catch, among other precautions (Epe, Phillips et al. 2007). Fiji's reef populations show some signs of commercial overexploitation. The depletion of important consumer species has negative impacts on coral reef ecosystem structure as well as islanders' livelihood (Dulvy, Polunin et al. 2004). In areas of high fishing intensity, the benthic community structures varied significantly; hard coral cover was lower, and turf-algal cover was higher (Dulvy, Mitchell et al. 2002). Surveys indicate that the region has also been overfished primarily through the widespread local and commercial use of gillnets and reliance on fishing as a sole source of some villages' income. The surveys suggest that the expansion of the current resource exploitation patterns would further damage marine life, but that balancing the traditional social and community-based marine management structures of semi-subsistent villages with market-driven demands would be challenging (Matthews, Veitayaki et al. 1998). Further studies on the impact of fishing in Fiji, however, need to be done, since conclusions are not always consistent. One study, for example, found that the indirect effects of fishing did not have an important bearing on fish diversity or biomass, and that predation by target species did not greatly affect the structuring of Fijian reef communities. This suggests that the overall health of reef fish communities depends on a range of processes that operate on difference scales in different circumstances (Jennings and Polunin 1997).

In areas of Papua New Guinea, such as the Lihir Island group's deepwater fish stock, overfishing occurs at relatively moderate levels of fishing pressures. Studies recommend, however, that accurate long-term monitoring of catches be undertaken if these stocks are to be commercially exploited (Fry, Brewer et al. 2006).

Overfishing and Exploitation: Artisanal/Recreational/Subsistence Fishing

Artisanal, recreational, and subsistence fishing, identified in five countries or territories (three with severe impacts, two with moderate, and no studies found on Australia) also threaten Melanesia's marine environment. Subsistence (coastal and offshore) fishing is conducted in about equal measure as commercial fishing, and poses as severe an overall threat to the region (Gillett 2007). Many of the fisheries in the inshore areas of the islands of the region, which are subsistence or small-scale commercial fisheries, show signs of overexploitation (Dalzell and Adams 1996). Despite some knowledge of artisanal/subsistence fishing, more research needs to be done, especially on the reproduction and ecology of the most important target species of subsistence and artisanal fisheries (South, Skelton et al. 2004). Yet as case studies in Melanesia reveal, subsistence overfishing can cause ecological shifts, reduce fish stocks, and endanger the islanders' livelihoods.

In Australia, artisanal and recreational fishing poses a relatively low threat to the marine environment, though in Tasmania, recreational fishing abounds. Although one in three of Tasmania's residents fishes for recreation, little information is known about the stock of popular recreational fishes like the sand flathead. More research needs to be conducted on the population and distribution of these fish, especially since Tasmania's recent shift to ecosystem-based fisheries management (Morton, Lyle et al. 2005).

Fiji's reef populations suffer mainly from artisanal and subsistence fishing. As noted above, depletion of important consumer species by exploitation has negative impacts on coral reef ecosystem structure as well as subsistence and livelihoods (Dulvy, Polunin et al. 2004). In areas of high fishing intensity, the benthic community structures varied significantly; hard coral cover was lower, and turf-algal cover was higher (Dulvy, Mitchell et al. 2002). Surveys also indicate that the region has been overfished through reliance on fishing as a sole source of some villages' income (Matthews, Veitayaki et al. 1998). Women comprise a high proportion of such fishers; they fish for subsistence and increasingly for income generation. Forty-four percent of respondents to a survey said that they sold marine products at least once a week, in addition to fulfilling their traditional household roles (Fay-Sauni, Vuki et al. 2008).

New Caledonia's reefs are in overall healthy condition, and the islands' fishery resources—mainly fish, spiny lobsters, mud crabs, and sea cucumbers fished from the reefs and mangrove areas—do not appear to be seriously overfished. However, human population growth has increased subsistence fishing pressure, especially by those who engage in traditional fishing methods (Lovell, Sykes et al. 2004).

Overexploitation of fish resources in the Solomon Islands has led to some conservation measures. Since the mid-1980s, rapid

population growth and increased dependence on inshore marine resources, particularly finfish, for subsistence has put renewed pressures on the islands' relatively limited coral reef. Bêche-de-mer, trochus shell, pearl oyster shell, green snail shell, turtle shell, and crocodile shell all increased in export value, although measures were taken in the early 1990s to conserve some of these species. For example, in 1993, the export of turtle shell and crocodile skin was banned. Still, relatively little information exists on coral reef species exploitation and sustainability, and on the ecological consequences of reef fisheries. Conducting baseline studies is fundamental to assessing changes to the reefs (Sulu, Hay et al. 2000).

In Vanuatu, the Fisheries Department emphasizes the fundamental role of traditional management practices, which generally focus on nearshore reefs. Their management strategy is based on traditional marine tenure, which prohibits or restricts the harvest of some marine resources. However, the slow erosion of community tradition has negatively affected fish populations. Other fisheries target sea turtles, dugongs, the palolo seaworm, as well as offshore fisheries for deepwater snapper, breams, grouper, and tuna (Hickey 2006).

Climate Change: Sea Surface Temperature Increase and Sea Level Rise

Global climate change, including sea level rise and sea surface temperature increase, is the dominant transboundary concern for Melanesia's inhabitants. Sea surface temperature increase, documented in all Melanesian countries and territories except for the Solomon Islands, is a moderate impact threat, as is sea level rise, identified in four locations. In all countries and territories, however, more research needs to be done to gain a clearer picture of climate change's present and future impacts on marine and human systems.

Many of the countries and territories in Melanesia are the most vulnerable among all Pacific countries and territories to sea level rise. An area-averaged annual mean warming of about 2 °C or higher for the 2050s and about 3 °C or higher for the 2080s are projected for the Pacific islands as a consequence of projected increases in atmospheric concentrations of greenhouse gases. In general, seasonal variations of the projected sea surface warming are minimal (Lal, Harasawa et al. 2002).

Elevated sea surface temperatures and sea level rise create the potential for more frequent and intense storms and cyclones, which can negatively affect atolls and low-lying coastal regions with wetlands, seagrass beds, mangroves, and shallow reefs. Sea warming causes coral bleaching events, and sea level rise can harm some of the 30% of known threatened plant species that are endemic to Melanesia (Nurse and Moore 2007). One study showed that the mangrove areas in Papua New Guinea, Fiji, New Caledonia, and the Solomon Islands are particularly vulnerable to disruption by sea level rise (Ellison 2003). Projected future climate change and sea level rise will also lead to shifts in species composition (Gaffin and Oneill 1997; Intergovernmental Panel on Climate Change (IPCC) 2007). As far as human systems go, sea level rise and sea surface temperature increase may limit the long-term ability of humans to inhabit these island countries and territories. Coastal erosion, saline intrusion, sea flooding, and land-based pollution already are serious problems on many of these islands. Further climate change will threaten infrastructure, because it is often located along the coastline. Other impacts include loss of income resulting from negative effects on tourism, increased vulnerability of human settlement due to decrease in land area, and loss of agriculture and vegetation (Gaffin and Oneill 1997; Intergovernmental Panel on Climate Change (IPCC) 2007). Climate change may in the end produce major population upheavals, migrations, and greater pressure on those countries and territories that will need to accommodate climate change refugees (Barnett and Adger 2003; Hunt 2003).

Studies have identified "hot spots" around Australia, the Tasman Sea and the Great Barrier Reef. These locations are especially vulnerable to climate change and severe cases of coral bleaching (Poloczanska, Babcock et al. 2007). In 1997–1998, increased sea surface temperatures resulting from ENSO caused widespread coral bleaching and mortality across the Great Barrier Reef, at One Tree Island lagoon (at the southern reef); a year later, some sites still showed a significant reduction of live coral cover and some fish abundance (Booth and Beretta 2002). In 2002, the Keppel Island group suffered moderate to severe mass bleaching—with more than 60% of corals bleached; severe (89%) bleaching occurred again in early 2006 (Berkelmans, De'ath et al 2004; Jones, Berkelmans et al. 2008). The total cost of severe coral bleaching in Australia is estimated at USD $28.4 billion in net present value, calculated over a 50 year time horizon with a 3% discount rate (Cesar, Burke et al. 2003).

Sea temperature warming and sea level rise also affect Fiji, a group of comparatively large and high islands. But because large portions of its populations and economic activities, as well as its capital, Suva, are concentrated on the narrow, low-lying areas fringing the coast, the possibility of inundation and flooding from climate change exists (Mimura 1999). One study showed that the rise in annual mean surface air temperature over Suva increased 0.25 °C per decade—1.5 times higher than the trends in global average temperature increases during the past century (Mataki, Koshy et al. 2006). The region is also increasingly susceptible to major storms (McInerney, Farlow et al. 2006).

Many Pacific islands, including the Solomon Islands and Vanuatu, have large research gaps in all major threat categories.

Some areas of the Solomon Islands are highly vulnerable to the effects of sea level rise, which may submerge low-lying islands and atolls (Sulu, Hay et al. 2000). In the island country of Vanuatu, an archipelago of steep islands surrounded by fringing reefs, sea level rise has already caused the submergence of three islands (South, Skelton et al. 2004). However, more research needs to be conducted to better evaluate present and future threats of sea rise to these islands.

As noted earlier, the Australian government is supporting data collection in countries across the Pacific on sea level rise. The first two phases (July 1991 to December 2000) established sea level and meteorological monitoring stations at 11 sites, one each in the Cook Islands, Fiji, Kiribati, the Marshall Islands, Nauru, Papua New Guinea, the Solomon Islands, Tonga, Tuvalu, Vanuatu, and Samoa. During the third stage (2001–2005), another station was established in FSM and continuous global positioning systems (CGPS) were installed at many of these locations to monitor the islands' vertical movements. During the fourth, five-year phase (2006–2010), data will continue to be collected, analyzed, stored, and disseminated, and personnel will be trained to assist with the interpretation of the data.

Pollution: Nutrients

Land-based pollution derives from many sources, including logging, agriculture, sewage, waste disposal, and industry. These activities, prevalent throughout Melanesia but documented in only four countries or territories, most with moderate impacts, produce runoff that deposits sediments, nutrients, and contaminants into the sea. While nutrients "enrich" the waters, they can cause phytoplankton blooms, eutrophication, hypoxia, and HABs. These events, in turn, can lead to a reduction in the number and abundance of species, and threaten human health and livelihood.

Growing populations, urbanization, and industry all contribute to pollution. In Fiji, development has placed new pressure on coastal and coral reef ecosystems. The high demand for coral sand for cement construction material has further stressed coastal systems. Other sources of pollution derive from sugar mills, agricultural industries, and sewage (Cripps 1992). The latter is a particularly potent problem; urban areas lack adequate wastewater disposal and treatment plants, and in Suva, fecal coliform levels have been found to endanger public health (Vuki, Naqasima et al. 2000).

As illustrated above, nutrient pollution affects human health. Ciguatera poisoning, common throughout tropical and subtropical countries and territories, is caused by the consumption of marine finfish that have accumulated naturally occurring toxins through their diet, originating from algae species. Nutrient inputs from fertilizer and sewage contribute to the growth of algae and algal blooms which, in turn, exacerbate the problem. In Vanuatu, the annual hospital admission rate for fish poisoning approximates 65 people (Goodman, Williams et al. 2003).

Habitat Destruction: Coastal Development and Land Reclamation

Coastal development is a threat in Melanesian island countries and territories, though it is extremely understudied on both a regional and a country/territory basis. However, the studies that do exist—the literature documents coastal development/land reclamation as a severe threat in three locations, Australia, Fiji, and New Caledonia—suggest the very serious nature of the problem. Development in popular tourist destinations such as Fiji destroys or harms critical habitat when, for example, bungalows are constructed over coral reefs. The Australian coastline is also developing rapidly. Modification of the shoreline alters currents and sediment delivery, often inducing erosion or receding beaches and modifying or removing critically important coastal habitats. Land-based pollution often accompanies such development. Throughout Melanesia, modified coasts are more vulnerable to increasing impacts of climate change; they become more prone to large storms, typhoons, and sea level rise.

Highlighting Regional Solutions

This section highlights regional solutions to the threats facing Melanesia. Large gaps exist in the literature for this region; below are some highlights gleaned from the research.

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

Global climate change—in particular sea surface temperature increase and sea level rise—threatens the viability of many Melanesian islands. Over the last two decades, governments and intergovernmental agencies like the UNEP South Pacific Task Team have begun to explore climate change-related threats, impacts, and solutions. Between 1997 and 2000, the Secretariat of the Pacific Regional Environmental Program's (SPREP) Pacific Islands Climate Change Assistance Program helped 10 Pacific island countries and territories, all signatories to the UN Framework Convention on Climate Change (UNFCC), address their vulnerability to climate change. In Vanuatu, SPREP, with funding from the Canadian government, moved 100 villagers living in the Lateu settlement to higher ground 600 meters from the coast and 15 meters above current sea level (The United Nations Framework Convention on Climate Change (UNFCCC) 2007).

Funding and implementing National Adaptation Program for Action (NAPAs), however, are limited to just six islands countries/territories within the Pacific. Progress is also slow, with much of the process focusing on just a few sectors and much-needed capacity building. (For further discussion on climate change adaptation strategies, see the Solutions in the Micronesia analysis on page 78 and 79.)

Ecosystem-Based Management and Integrated Coastal and Ocean Zone Management

Over the past decade, awareness and action on integrated and EBM in coastal and ocean environments have increased. In the Great Barrier Reef World Heritage Area, where land-based pollution from agriculture is considered the main threat to coastal water quality, efforts have been made to minimize vegetation clearing and encourage responsible pesticide/fertilizer use (Haynes and Michalek-Wagner 2000). The need to improve regional coordination of decision-making stakeholders on land management has been addressed, including the initiation of Integrated Catchment Management (ICM), but results to date have been less than optimal. Recent studies show that soil erosion and nutrient loss continue to deteriorate water quality of the Great Barrier Reef (Haynes and Michalek-Wagner 2000). However, integrated land management may become more successful through new research. A study shows that 70% of sediment from rivers comes from only 20% of the total catchment area, mostly from the coastal areas (McKergow, Prosser et al. 2005). This result indicates that sedimentation is relatively localized, and may aid future policy in targeting specific management areas. Many Pacific islands in Melanesia have well-established methods for catchment and EBM. For example, a study in Vanuatu confirms indigenous implementation of temporal separation of agricultural and fishing practices, as well as the creation of extensive areas to protect both freshwater and marine resources (Hickey 2006).

In addition to preserving traditional EBM, emerging technologies on fisheries modeling have been successfully implemented in this region. In Australia, scientific modeling tools that evaluate fishing impacts from a multi-species, ecological approach have been implemented in the southern and eastern parts of Australia (Smith, Fulton et al. 2007). The quantitative risk assessment method Sustainability Assessment for Fishing Effects (SAFE) has been used to successfully assess current fishing impacts and potentially at-risk species (Zhou and Griffiths 2008).

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

Marine management areas, which include community-based MPAs, marine reserves, national parks and monuments, protected seascapes, and habitat management areas, are increasingly being used as tools to protect Melanesia's marine habitats. These designated areas offer various benefits to both the marine environment and human populations. Not only do these areas protect marine life, they also benefit fishers by increasing fish populations that swim from MPAs to fishery areas, thereby improving food security and livelihood (Craig, van Beukering et al. 2008). An example of one large-scale MPA success is Australia's Great Barrier Reef World Heritage Area, where 33% has now been protected from extractive industries such as fishing and collecting (Lovell, Sykes et al. 2004). Land-based water quality impacts, however, remain a concern.

The current trend towards locally managed MPAs is engaging increasing numbers of communities throughout the region (South, Skelton et al. 2004). Local populations are participating more and reviving their traditions as a basis for sustainable reef management (Vieux, Aubanel et al. 2004). Research has shown that traditional MPAs, particularly those that consider traditional marine tenure, generally succeed. A study in Fiji found that community-based marine management offers many benefits: it establishes strong community leadership, increases people's knowledge, and delegates responsibility, among others (Muehlig-Hofmann 2007). Reefs with traditional systems of resources management are also healthier (Hoffmann 2002).

Local/community management has produced some impressive results. A study done at the Great Barrier Reef found that local stewardship of fishing efforts was linked to the conservation of reefs, and could provide some insurance against disturbances including mass bleaching (Hughes, Rodrigues et al. 2007). In the Solomon Islands, research suggests that the shift to customary management of sea cucumbers could reduce or halt current overfishing and chart an alternative path for artisanal communities in the Pacific (Ramofafia, Lane et al. 2004). One study of MPAs in Papua New Guinea showed that the average size and biomass of fishes were higher in all areas under traditional management when compared to nearby unmanaged areas. Socioeconomic assessments revealed that this "effective conservation" was positively related to compliance, visibility of the reserve, and length of time the management had been in place, but negatively related to market integration, wealth, and village population size. A model is also developing in Papua New Guinea for a decentralized, community-based system for reef resource management driven largely by NGOs, because there

are limited resources for national control. In Vanuatu, the Fisheries Department implemented village-based marine resource management measures in the 1990s, which prompted villagers to introduce controls over fishing for many species. Vanuatu and Australia are examples of where government-community collaboration on replenishing fish species resulted in the establishment of community-based MPAs (Lee 2003).

Locally managed marine area networks, however, often encounter obstacles. In Fiji, community-based marine management is important, but declining due to weakened traditional leadership and other factors (Muehlig-Hofmann 2007). Here and in other places, the trend from a primarily culturally motivated regime of marine resource management, with traditional practices, to a more commercially motivated system is apparent (Hickey 2006). Significantly, although the number of MPAs is increasing throughout Melanesia—there are more than a dozen in New Caledonia, for example—MPAs have as much potential for conflict as they do for convergence among competing groups. While governments, IGOs, and NGOs often press for the creation of MPAs, many local communities resist the concept, as their establishment could infringe on traditional fishing grounds. Similarly, the widely promoted and donor-supported MPA approach driven by the (largely Western) ideal of optimizing biological conservation may also arouse suspicion by rural communities who rely on marine resources for food security (Hickey 2006). Governments face many problems when attempting to introduce MPAs in reef areas that are already “owned” by islanders who claim traditional fishing rights (Sulu, Hay et al. 2000).

Resource use in the Marovo Lagoon in the Solomon Islands illustrates the traditional fishing rights issue. For three decades, Marovo’s reefs and rainforests have been exploited by foreign companies, while the lagoon has become recognized as an international hotspot for biodiversity. The tribal groups who own the lagoon and surrounding land through customary law have engaged with the fishing and logging companies and international conservation agencies with the intent of retaining their control over the lagoon’s resources. Encounters between local and non-local knowledge create potential for solutions as well as for conflict (Hviding 2006). Another example of conflict centers on the 2002 proposal for New Caledonia’s reef ecosystems to be listed as a UNESCO World Heritage Site; the efforts were blocked by international mining companies (Fried and Anex 2004).

Strengthening Institutions and Building Capacity

Throughout Melanesia, tremendous variation in capacity and extreme social, cultural, political, and environmental diversity exist. Parts of the region lack enough leaders and skilled people to implement and maintain projects, whether the projects are management, monitoring, or research-based. MPA managers, for example, need training, equipment, and staffing to make management more effective. One study showed that managers identified the need for training in creating alternative livelihood programs, coral reef conservation and management, and increasing community participation in conservation (Hoffmann 2006). These managers focused on reducing fishing pressures, improving their knowledge on coral reef management, and working with the local community on conservation (Hoffmann 2006). Yet knowledge is not enough; an aquarium trade “live rock” study from Fiji showed that creating awareness and moral responsibility was an effective tool in fisheries management (Kronen, Sauni et al. 2006). Nonetheless, 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 needs to be made a high priority. This will entail a great effort on the parts of national, regional, and international education and training institutions, and require significant funding.

Three Regional Governance, Agreements, and Approaches

Regional policy mechanisms, regulations, and enforcement are crucial aspects of marine conservation efforts in Melanesia. One example of a regional policy structure is the Pacific Islands Forum, which in 2002 endorsed the Pacific Islands Regional Ocean Policy. This policy envisions a healthy ocean that sustains the livelihoods of Pacific islanders. The Council of Regional Organizations of the Pacific approved a plan in 2004 and has started implementation of this Regional Ocean Policy (Glover and Earle 2004). In 2006-2008, the council maximized sustainable returns from fisheries by developing an ecosystem-based fisheries management planning framework and harmonizing legislation frameworks across the region. Smaller regional mechanisms exist as well. In 2005, the governments of Papua New Guinea, Indonesia, and the Solomon Islands committed to a tri-national partnership focused on conserving the western Pacific leatherback turtle within the Bismarck-Solomon Seas ecoregion. 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 signatory (South, Skelton et al. 2004).

Regulation and Enforcement

While many countries and territories are signatory to various regional policies, many lack their own regulations to implement those policies and fail to enforce them. Illegal fishing (such as with the use of explosives, poisons, and illegal nets) is a significant problem in some countries or territories, like Fiji. Fishing regulations are poorly enforced due to inadequate human resources and funds in the Fisheries Division (South, Skelton et al. 2004). Enforcement of marine resource laws and policies is a high priority that requires capacity building. A need exists to develop systems to patrol vast waters using new technologies and to prosecute offenders, for example. Sufficient community pressure and patrolling could stop illegal fishing.

Photo: Devil ray *(Mobula mobular)* in Fiji. Often mistaken as a manta due to their numbers in Kadavu, Fiji. (Richard Akhtar/Marine Photobank)

Alternative Livelihoods

Acute poverty exists throughout much of Melanesia—especially among the developing island countries and territories. The daily needs of these peoples often conflict with the need to protect valuable marine resources, upon which millions of people depend for subsistence. In order to reduce overfishing, one of the most pervasive threats in the region, fishing impacts could potentially be reduced and alternative livelihoods increased for fishers. Reducing fishing, which requires changing equipment to more sustainable methods, could result in less effort for higher value. No-take zones could be established as well. Another strategy involves tourism. In Fiji, for example, NOAA and the Marine Protected Areas Center are partnering with local groups to develop and market ecotourism, train locals on guiding tourists, and create snorkel trails. Fiji has also become a major exporter to the global aquarium trade of "live rock"—shipping 800,000 kg of live rock in 2001 to the United States alone. The live rock trade alleviates the pressure on fishing and provides a valuable alternate livelihood for coastal people. However, large-scale removal of live rock destroys habitats for fish and invertebrates and damages the reef structure, leading to increased coastal erosion and replacing one threat with another (Lovell, Sykes et al. 2004).

VIII. Polynesia Regional Analysis: Threats, Impacts, and Solutions

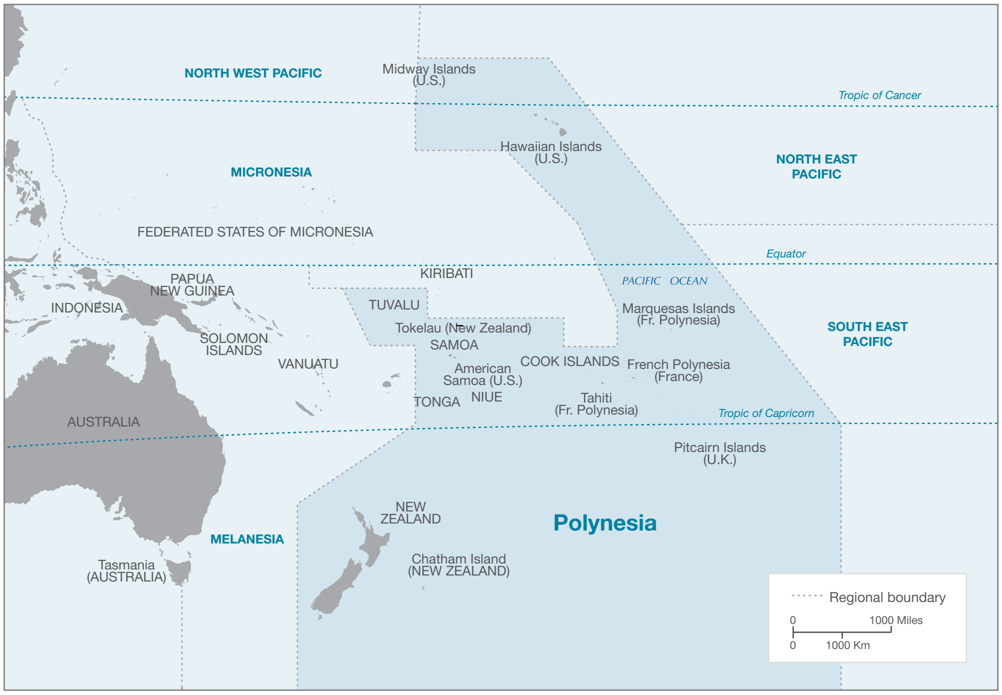
Photo: The Hawaiian monk seal *(Monachus schauinslandi)* is an endemic and endangered species protected by the Papahānaumokuākea Marine National Monument. (John Johnson/ Marine Photobank)

A subregion of Oceania, Polynesia comprises more than 1,000 island countries and territories scattered over a very large area: the Cook Islands, French Polynesia (France), Hawaiian Islands (United States), New Zealand, Niue, Pitcairn Islands (United Kingdom), Samoa (Western), Tokelau (New Zealand), Tonga, Tuvalu, and American Samoa.

The Polynesian islands range from very large, high continental islands, numerous offshore high islands, coral limestone islands, to numerous atolls. Some, such as Niue, consist of a single small coral island, while others, including Tonga and French Polynesia, comprise many large and small, highly dispersed islands. Although New Zealand and Hawaii contain significant urban areas and natural resources, many other Polynesian islands are less developed, have fewer natural resources, and depend on subsistence or small-scale agriculture and fishing. Many Polynesian societies, some of which have the highest poverty rates in the world, are undergoing difficult transitions from reciprocity exchange and direct sustenance systems into cash-based economies (Kronen 2004). Polynesia is, however, rich in coral reefs, which help support a robust tourist industry for parts of the region. Tahiti (the most populous island in French Polynesia) depends to a large extent on tourism and black pearl culture. The pearl industry, prevalent throughout eastern Polynesia, contributes exports worth USD $150 million annually (Adams, Bell et al. 2001; Berthe and Prou 2007). In the Hawaiian Islands—which have high marine endemism typical of many remote island ecosystems—the net benefits of Hawaii's coral reefs are estimated at USD $360 million a year for the islands' economy, and the overall asset value of the state of Hawaii's 1,660 square kilometers of reef area in the main islands is estimated at nearly USD $10 billion (Cesar and van Beukering 2004). Because of the stark contrasts in the socioeconomic environments of Polynesia, resources are used and managed differently throughout the region (Lovell, Sykes et al. 2004).

Polynesia is the only Pacific region with no threats documented as having severe impacts, though it does have moderate impact threats in all four broad categories (overfishing and exploitation, climate change, habitat destruction, and pollution). Invasive species is noted as an understudied, low

Map 7: Polynesia



Source: International Ocean Commission and The United Nations (www.unep-wcmc.org/gramed) 2008 Lucidity Information Design, LLC

impact threat. Coastal development and land reclamation, which lead to the degradation of critical ecosystems that produce invaluable services and products for society, is identified in eight countries or territories. Artisanal/recreational/subsistence is the main type of fishing threat in Polynesia, affecting seven countries or territories. Such overfishing can cause ecological shifts and reduce fish stocks and food supply, thereby endangering human economies and livelihoods. Climate change-related sea level rise, which can inundate some of the lower-lying islands, also affects eight countries or territories. Along with sea surface temperature increase (documented in six countries or territories), sea level rise not only destroys marine ecosystems, but can create uninhabitable areas. Climate change exacerbates all other threats in the region as well. Significantly, none of these threats operate in isolation, but rather function as multiple, compounded stressors that together can devastate marine and human systems. But because boundaries of the region largely adjoin other large ocean spaces, transboundary effects (aside from global climate change) are relatively small (South, Skelton et al. 2004).

The discussion on Polynesia that follows first presents overall regional trends of severe and moderate impact threats, including a table listing the levels of threats and impacts in each country/territory. Then, the literature review section offers a more in-depth discussion of the most severe impact threats. Moderate impact threats are also presented if they are prevalent or notable throughout the region. Finally, the last section provides a brief overview of potential solutions to the threats facing this region as a whole.

Polynesia Regional Trends: Primary Threats and Associated Environmental and Socioeconomic Impacts

The bullets below highlight significant severe and moderate impact threats in Polynesia, based on the impact assessment methodology described in the Introduction.

Based on this assessment, the threats with overall severe impacts across the entire Polynesia region are:

- no overall severe impact threats exist in this region.

The threats with overall moderate impacts across the region are:

- coastal development/land reclamation identified in eight countries or territories.
- sea level rise identified in eight countries or territories.
- artisanal/recreational/subsistence fishing identified in seven countries or territories.

- sea surface temperature increase resulting from climate change identified in six countries or territories.

- land-based sedimentation and nutrients identified in five countries or territories.

Key observations regarding research gaps and identified impacts:

- It is a vast region, made up of both large and small island nations and territories, some with extreme poverty and others with greater wealth.

- The more densely populated and wealthier islands such as Hawaii and New Zealand have more threats with greater impacts.

- Countries and territories such as Nauru such as Niue, Samoa, Tokelau, Tonga, and Tuvalu have just a few papers and reports on threats. Many small islands, namely the Pitcairn Islands, Niue, Tonga, and Tokelau, have few documented, identified threat categories.

The following table distills the findings from the literature, documenting by country or territory, threats and environmental and socioeconomic impacts, and showing the variation in availability of scientific research in Polynesia. Scientists have not conducted studies on many of the threats and impacts for all of this region's countries and territories. While New Zealand is the subject of much research on threats and impacts, it too still has gaps (documented in the table). Countries or territories such as Niue, Samoa, Tokelau, Tonga, and Tuvalu have just a few papers and reports on threats. In the past few years, studies on Hawaii have increased in number and have more strongly linked threats with socioeconomic impacts.

TABLE 6: Polynesia Threats Based on Scientific Literature and Impact Assessment

✓ Identified as Threat

● Severe Impact ● Moderate Impact ● Low Impact

It was documented when an article identified an issue as a present or future threat. If no scientific literature was found on the topic, then no check was assigned. This does not necessarily mean the topic is not a threat; rather, it suggests that no scientific literature was found on the topic.

	AMERICAN SAMOA		COOK ISLANDS		FRENCH POLYNESIA		HAWAIIAN ISLANDS		NEW ZEALAND		NIUE		PITCAIRN ISLANDS		SAMOA		TOKELAU		TONGA		TUVALU	
	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts
POLLUTION																						
Aquaculture: Wastewater			✓	Low	✓	Moderate	✓	Moderate	✓	Low												
Land-based Chemicals	✓	Severe			✓	Moderate			✓	Severe												
Fishing Lines/Nets							✓	Severe	✓	Moderate												
Nutrients	✓	Severe	✓	Low	✓	Severe	✓	Moderate	✓	Severe												
Offshore Oil/Mining																						
Oil Spills & Antifouling Chemicals	✓	Moderate	✓	Low	✓	Moderate					✓	Low					✓	Low	✓	Low		
Radionuclide					✓	Moderate																
Solid Waste Disposal			✓	Low			✓	Severe														
Thermal																						
Ocean Waste & Toxic Dumping	✓	Severe			✓	Moderate															✓	Low
HABITAT DESTRUCTION																						
Anchor Damage							✓	Moderate														
Aquaculture: Coastal Modification					✓	Moderate	✓	Moderate	✓	Low												
Coastal Development/Land Reclamation	✓	Severe	✓	Moderate	✓	Severe	✓	Severe	✓	Moderate							✓	Severe	✓	Severe	✓	Severe
Destructive Fishing															✓	Moderate						
Dredging									✓	Low									✓	Low		
Marine Recreation							✓	Moderate														
Land-based Sedimentation	✓	Severe	✓	Low	✓	Moderate	✓	Severe	✓	Severe												
Ship Groundings																						
Tsunamis					✓	Severe																
Typhoons/Cyclones/Hurricanes & Storm Surge	✓	Moderate			✓	Severe					✓	Moderate									✓	Severe
Wrecks/Military Equipment							✓	Moderate														
OVERFISHING & EXPLOITATION																						
Aquaria Trade							✓	Moderate											✓	Moderate		
Artisanal/Recreational/Subsistence Fishing	✓	Low	✓	Low	✓	Moderate	✓	Severe							✓	Severe			✓	Low	✓	Severe
By-Catch & Discharge	✓	Low					✓	Severe	✓	Moderate					✓	Low						
Commercial Fishing	✓	Moderate			✓	Moderate	✓	Severe	✓	Moderate									✓	Low		
CLIMATE CHANGE																						
Acidification	✓	Moderate					✓	Severe														
Sea Level Rise	✓	Low	✓	Severe			✓	Severe	✓	Moderate					✓	Moderate	✓	Severe	✓	Severe	✓	Severe
Sea Surface Temperature**	✓	Moderate	✓	Moderate	✓	Severe	✓	Severe	✓	Low					✓	Moderate						
INVASIVES																						
Invasive Species (Different Vectors)	✓	Low					✓	Moderate	✓	Moderate												

**Changes in SST is strongly associated with El Niño Southern Oscillation (ENSO) events, which are predicted to increase in frequency and intensity over time due to climate change.
For a complete list of references used for the literature review and synthesis to create this table see Appendix C, Table 6 p.142.

Polynesia Literature Review of Severe and Moderate Impact Threats

The discussion that follows highlights the greatest documented threats to Polynesia based on this synthetic analysis. The most severe threats are discussed (see bullets and table above), and each threat category includes country/territory-specific details on threats as well 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.

Habitat Destruction: Coastal Development and Land Reclamation

Coastal development is a threat in many Polynesian island countries and territories. Coastal modification is a threat identified in eight out of 11 countries or territories, with an average of moderate impacts. The impact of coastal development is severe for six countries or territories (American Samoa, French Polynesia, Hawaii, Tokelau, Tonga, and Tuvalu). However, more research needs to be conducted to gain a clearer picture of habitat destruction throughout other Polynesian islands.

Development in popular tourist destinations such as French Polynesia is destroying critical habitat or harming it when, for example, bungalows are constructed over coral reefs. Modification of the shoreline alters currents and sediment delivery, often inducing erosion and receding beaches in others. Increased development is often also coupled with increasing land-based pollution. Many important coastal habitats are modified or disappear as a result of coastal development. Land reclamation, (along with coral sand mining, sedimentation, and nutrient and chemical pollution) has degraded Samoa's coastal environment, for example (Taule'alo 1993). Coastal development (along with coral sand dredging) has also stressed French Polynesia's reefs (Harmelin-Vivien 1992). Throughout Polynesia, modified coasts are more vulnerable to increasing impacts of climate change; they become more prone to large storms, typhoons, and sea level rise. For example, in small island developing states such as Tonga and Tuvalu, coastal development is encroaching on limited, valuable habitat that not only is essential for livelihood and food security, but also protects society from increased risks associated with climate change.

Climate Change: Sea Surface Temperature Increase and Sea Level Rise

On a region-wide scale, climate change threatens human populations and the marine ecosystem. Sea surface temperature increase has been identified in six Polynesian countries or territories as a moderate impact threat, except in French Polynesia and the Hawaiian Islands, where it is severe. Sea level rise has been documented in eight countries or territories, where it is a severe impact threat for the Cook Islands, Hawaiian Islands, Tokelau, Tonga, and Tuvalu. Research has not been conducted for sea surface warming and sea level rise for many countries and territories in this region.

Marine ecosystems and human populations are increasingly vulnerable to climate change. An area-averaged annual mean warming of about 2 °C or higher for the 2050s and about 3 °C or higher for the 2080s are projected for small island countries and territories as a consequence of increases in atmospheric concentrations of greenhouse gases (Lal, Harasawa et al. 2002). Elevated sea surface temperatures and sea level rise create the potential for more frequent and intense storms and cyclones, which can negatively affect coastal areas, particularly atolls and low-lying coastal regions with wetlands, seagrass beds, mangroves, and shallow reefs. Polynesia is becoming increasingly susceptible to major storms. In Samoa, cyclones in 2004 damaged 13% of the coral reefs (Lovell, Sykes et al. 2004). Sea temperature and sea level rise also alter the ocean environment, which may increase coral bleaching episodes and lead to shifts in species composition (Gaffin and Oneill 1997; Intergovernmental Panel on Climate Change (IPCC) 2007).

Climate change-induced sea level rise and sea surface warming will also limit the long-term ability of humans to inhabit parts of Polynesia (Church, White et al. 2006). Climate change's impacts include increased coastal erosion; changes in aquifer volume and water quality with increased saline intrusion; loss of income resulting from negative effects on tourism; increased vulnerability of human settlement due to decrease in land area; and loss of agriculture and vegetation (Gaffin and Oneill 1997; Intergovernmental Panel on Climate Change (IPCC) 2007). Such events may in the end produce major population upheavals, migrations, and greater pressure on those countries that will need to accommodate these refugees (Barnett and Adger 2003; Hunt 2003).

Tuvalu, Tonga, and the Cook Islands are among the most vulnerable to sea level rise (Pernetta 1992). Sea level rise threatens Tokelau and Tuvalu, coral-rubble atolls with land rising rarely more than three meters above present sea level, with total inundation (Roy and Connell 1991; South, Skelton et al. 2004). Funafuti, Tuvalu, showed 2 ± 1 mm per year sea level increases between 1950 and 2001 (Church, White et al. 2006). In Tonga, human migration to coastal areas, such as the low-lying lagoon areas in Nuku'alofa, increases people's vulnerability to the effects of sea level rise (Mimura 1999).

Sea level rise also affects Samoa, a comparatively large and high island. However, because large portions of its population and economic activities, as well as its capital, are concentrated on the narrow, low-lying areas fringing the coast, the possibility of inundation and flooding from climate change remains a threat (Mimura 1999). In American Samoa, sea level rise affects fringe mangrove forests, which have been experiencing a rise in sea level relative to the mangrove surface. The relative sea level rise rate of +1.65 to 2.29 mm per year has been exceeding the rate of change in elevation of the mangrove surface, -2.6 to +1.4 mm per year (Gilman, Ellison et al. 2007; Craig 2008). It is unclear, however, if the basin mangrove has been experiencing a rise in sea level relative to the mangrove surface (Gilman, Ellison et al. 2007; Craig 2008).

As discussed above, the Australian government is supporting data collection in countries and territories across the Pacific on sea level rise. The first two phases (July 1991 to December 2000) established sea level and meteorological monitoring stations at 11 sites, one each in the Cook Islands, Fiji, Kiribati, the Marshall Islands, Nauru, Papua New Guinea, the Solomon Islands, Tonga, Tuvalu, Vanuatu, and Samoa. During the third stage (2001–2005), another station was established in FSM and continuous global positioning systems (CGPS) were installed at many of these locations to monitor the islands' vertical movements. During the fourth, five-year phase (2006–2010), data will continue to be collected, analyzed, stored, and disseminated, and personnel will be trained to assist with the interpretation of the data.

The link between increased greenhouse gases, climate change, and regional coral bleaching events, strongly associated with elevated sea surface temperatures during recurrent ENSO events, is widely accepted in the scientific community (Hoegh-Guldberg 1999; Hughes, Baird et al. 2003). In Polynesia, like other regions of the Pacific, sea surface temperature increases have coincided with severe coral bleaching events. In French Polynesia, coral bleaching and mortality have become more frequent over the last three decades, with major coral bleaching events in 1991, 1994, and 1998. Research on global climate change and sea surface temperature increase for the next century suggests that a complete collapse of coral reefs may be imminent if the corals and their symbiotic algae fail to adapt to changing conditions (Salvat and Aubanel 2002). In 2002, a severe bleaching event in Moorea caused about half of the coral reefs to suffer; with bleaching as high as 72% at some sites (Penin, Adjeroud et al. 2007). Over the past decade, Hawaiian waters have shown a warming trend both around the main islands and the Northwestern Hawaiian Islands (Coles and Brown 2003; Jokiel and Brown 2004). Increased sea surface temperatures resulted in severe coral reef bleaching in 1996 and 2002 (Jokiel and Brown 2004).

Overfishing and Exploitation: Artisanal/Recreational/Subsistence Fishing and Commercial Fishing

In Polynesia, artisanal, recreational, and subsistence fishing, as well as commercial fishing, threaten the marine environment. The limited resources of many of these islands mean that their inhabitants exploit marine and fish resources, often unsustainably (Fleming and Blowes 2003).

Artisanal/recreational/subsistence is the main type of fishing threat in Polynesia, affecting seven countries or territories. It has a moderate impact regionally and severe impacts in the Hawaiian Islands, Samoa, and Tuvalu. Commercial fishing, which is documented in five locations, has a severe impact in the Hawaiian Islands. Many locations, however, have yet to be researched and documented. Rapid population growth, increases in exports, and the use of destructive fishing gear/methods have all contributed to overexploitation of marine resources in the region.

Subsistence and commercial (coastal and offshore) fishing are conducted in about equal measure (Gillett 2007), and throughout the region, reef fish and coastal pelagic fish are the most commonly harvested. In general, the subsistence-based or small-scale commercial inshore fisheries are heavily fished and show signs of overexploitation; shallow fisheries are even more heavily overfished (Dalzell and Adams 1996; Malm 2001). Increasing fishing efforts and new technology appear to be depleting a major offshore tuna species (Hunt 2003). Although most Pacific island countries and territories have basic fisheries laws, many with management objectives, the emphasis is often on the development of fisheries, rather than on their sustainable management (Gillett 2007).

In Polynesia, arrival of Europeans engendered unregulated fishing of various marine organisms, such as pearl oysters, trochus, and sea cucumbers, with many stocks severely reduced (Dalzell and Adams 1996). Extinct species include giant clams, and endangered species include sea turtles, giant tritons, mangrove crabs, bêche-de-mer, trochus and turban shells, and highly targeted reef fishes (South and Skelton 2000). Indeed,

Natural events such as typhoons were documented as severe threats in French Polynesia and Tuvalu (and as moderate threats in American Samoa and Niue), suggesting that more research needs to be done on this threat category throughout the region.

more than half (55%) of the Pacific's island countries or territories exploit their coral reef fisheries in an unsustainable way; the total landings of coral reef fisheries are 64% higher than can be sustained, and the area of coral reef appropriated by fisheries exceeds the available effective area by 75,000 square kilometers, or 3.7 times the area of Australia's Great Barrier Reef. One study estimated that an extra 196,000 square kilometers would be required by 2050 to support the anticipated growth in human populations in the region (Newton, Cote et al. 2007). Despite these trends and projections, it must be noted that fisheries catches from Pacific island coral reefs are rarely recorded in official statistics, so reconstruction of catch estimates with limited hard data requires assumptions and results in some uncertainties (Zeller, Booth et al. 2007).

Most fishing in the Cook Islands operates on a subsistence and artisanal basis, particularly in the coral reefs and lagoons. The fisheries sector contributes substantially to exports, accounting for (in 2000) 27.5% of all agricultural exports. Although the offshore fishery is growing, reef/lagoon subsistence fishing remains the dominant activity (Thorpe, Reid et al. 2005). Presently, cultivation of pearl oysters is the only fishing activity of major economic significance in the Cook Islands.

Commercial, or industrial, fishing poses a severe threat to the Hawaiian Islands. Weak marine enforcement and compliance has produced overexploitation and overfishing in both the commercial and recreational sectors (Friedlander and Cesar 2004). Commercial fishing gear, from bottom trawls to dredges, gillnets, and longlines, while designed to catch the most fish possible, can be highly destructive to other species and habitats. Loggerhead sea turtle interactions with the longline swordfish fishery industry in Hawaii, for example, have become a serious concern in recent years, leading to shortened fishing seasons (Pradhan and Leung 2006; Pradhan and Leung 2006).

In New Zealand's deep-sea fisheries, the high-value orange roughy, oreos, and macrourid rattails—all of which have slow growth rates—are highly vulnerable to overfishing and have slow recovery rates. Rapid fishery development, followed by a decrease in stock and reductions in catch levels, has occurred periodically over the last 20 years. However, quota systems in a number of New Zealand fisheries were introduced in early 1986, suggesting that some of these fisheries may be sustainable in the long-term. A lack of good data on levels and patterns of recruitment continues to be a major source of uncertainty in current stock assessments, and a concern for the long-term sustainability of these fisheries (Clark 2001). Trawling has greatly affected New Zealand marine life and habitats as well. When benthic invertebrate by-catch from 73 trawl tows in Chatham Rise, New Zealand was collected during trawling for orange roughy in July 1994, the largest by-catch volumes comprised corals (Scleractinia and Antipatharia) from small seamounts—suggesting that trawling may depress local biodiversity (Probert, Mcknight et al. 1997). Research also shows trawling to be the predominant anthropogenic impact on sea lions—both through mortality as a result of by-catch, and resource competition effects. Despite legal protection and the imposition of new fisheries management measures, sea lions have experienced a 30% decline in pup production over the last decade (Chilvers 2007).

In Tonga, the rapid process of modernization, combined with population growth, urbanization, and the transition from subsistence to cash-based economies, has led to the slow breakdown of its traditional marine tenure systems and the overexploitation of marine resources, particularly with inshore and deepwater fisheries. Overfishing is now a serious threat. On Tongatapu, major collapses have occurred in mullet stocks, a traditionally important fish, and catches of most reef species have gradually declined. In the 1990s, the sea cucumber was depleted due to overfishing. Coral exploitation also occurs in Tonga, although the export of coral rock (not including black coral and other precious corals) is not permitted (Malm 2001). Inshore invertebrates such as bêche-de-mer, lobsters, and giant clams have undergone severe and recent declines (Food and Agriculture Organization of the United Nations (FAO) 2002). The live fish/curios trade is also a problem (Malm 2001). Offshore pelagic resources, however, remain relatively unexploited. Subsistence and artisanal coastal (reef and lagoon) fishing remains one of the most important sources of livelihood for Tongans despite market-based changes, but research indicates that maritime fisheries, agriculture, and other sectors are eroding the artisanal fishers' livelihoods, historic social status, and social networking values (Kronen 2004).

In Samoa, more than half of households engage in subsistence fishing, done on an artisanal basis at nearshore and lagoon waters. The maximum sustainable yield has been exceeded in many parts of the country due to overfishing, use of non-selective destructive fishing techniques such as poison and dynamite, and loss of fish habitat from coral sand mining and land-based runoff. Among other species, clam stocks have been so heavily fished that they are nearing extinction (Taule'alo 1993).

American Samoa, by contrast, shows relatively sustainable fish harvests, although more research needs to be conducted since fisheries catches are rarely recorded in official statistics and conclusions can vary. When village elders were interviewed, 85% felt that fishing was as good as when they were younger; indeed, the current composition of fish harvested resembled that previously found in a nearby archaeological excavation (Craig, Green et al. 2008). Other findings, however, showed some impacts of overfishing to the coral reef ecosystem, such as the current scarcity of large fish (Craig, DiDonato et al. 2005). Another study examined American Samoa's artisanal, small-boat sector, whose commercial catches are reported, and a shore-based, subsistence sector, with no regular reporting. Catch reconstruction (with large pelagic species removed) suggested a 79% decrease in catches between 1950 and 2002. Rapid human population growth on the main island may have contributed to reduced catches. Indeed, on the main island, the per capita catch rate may have declined from 36.3 kg/person/year in 1950 to 1.3 kg/person/year in 2002. The study concluded that between 1950 and 2002, a 17-fold difference between reconstructed estimates and reported statistics occurred (Zeller, Booth et al. 2007).

Pollution: Nutrients

Land-based nutrient pollution derives from many sources, including logging, agriculture, sewage, waste disposal, and industry. These activities are prevalent throughout Polynesia, where nutrients have been identified as a threat in five countries or territories, with an average of moderate impact. Severe impacts of land-based nutrient pollution are documented in American Samoa, French Polynesia, and New Zealand. About half of the Polynesian countries or territories, however, have little or no research documenting this threat.

Logging, agriculture, and other activities produce runoff that deposits sediments, nutrients, and contaminants into the sea. While nutrients "enrich" the waters, they can cause phytoplankton blooms, eutrophication, hypoxia, and HABs. Nutrient pollution can also threaten human health. Ciguatera poisoning, for example, common throughout tropical and subtropical countries and territories, is caused by the consumption of marine finfish that have accumulated naturally occurring toxins through their diet, originating from algae species. Nutrient inputs from fertilizer and sewage contribute to the growth of algae and algal blooms which, in turn, exacerbate the problem. In Tahiti, the largest and most populated island in French Polynesia, studies on ciguatera outbreaks indicate a temporal link between the ciguatera disease in humans and algal blooms (Chateau-Degat, Chinain et al. 2005).

Habitat Destruction: Land-Based Sedimentation

Land-based sedimentation is a threat identified in five out of 11 countries or territories in Polynesia, with severe impacts in American Samoa, the Hawaiian Islands, and New Zealand. Like nutrient pollution, sedimentation is poorly researched throughout the region. Land-based sedimentation comes from many sources, including logging, agriculture, and erosion. It produces turbidity, reduces available light, and can suffocate coral reefs and kill fish. These, in turn, can lead to a reduction in the number and abundance of species and increased threats to human health. Increased sedimentation also negatively affects ecosystem services, fisheries, and tourism (Cesar and van Beukering 2004). While sedimentation is not uniformly studied throughout Polynesia, studies suggest that it is a potentially serious threat. The Hawaiian Islands, for example, shows the deleterious effects of sedimentation on its reefs (Dollar and Grigg 2004). In Samoa, the current rates of forest depletion from logging and agriculture have led to runoff that enters the marine environment (Taule'alo 1993).

Other Regional Threats

The threats discussed briefly below are worth mentioning for the prevalent impacts they have now as well as the impacts they could have in the future. Most of these threats require far more research in order to gain better understanding of their ecological as well as socioeconomic impacts.

Pollution: Solid Waste

Polynesia also suffers from different kinds of marine debris, garbage, and solid waste, which can deposit nutrients and toxic chemicals into the ocean. Pollution has been documented in only two countries and territories in Polynesia—the Cook Islands, with a low impact, and the Hawaiian Islands, with a severe impact. Despite the dearth of research, it is a pressing problem throughout the region. Solid waste management on small islands is challenging to manage; as a result, much of it ends up in the sea. Marine debris is also a threat. The accumulation of marine debris in the nearshore marine habitat can entangle mammals and seabirds and threaten endangered species (Henderson 2001; Boland and Donohue 2003). Hawaii, besides generating large quantities of marine debris, also deposits PCBs into the ocean (Dameron, Parke et al. 2007; Pichel, Churnside et al. 2007; Rios, Moore et al. 2007). PCBs have a toxic effect on marine life and can affect the entire food web.

Natural Events/Disasters: Storm Surges and Typhoons

Storm surges and typhoons are identified on average as a low impact threat in Polynesia. But they are documented as having moderate to severe impacts in American Samoa, French Polynesia, Niue, and Tuvalu. A storm, or tidal surge, resulting from an intense storm, tropical cyclone, or Pacific typhoon, as well as the typhoons themselves, can be particularly damaging to marine ecosystems and fishery resources in Polynesia. Storm surges create a rise in water level, wave run-ups, and flooding of low-lying coastal areas. Typhoons as a whole produce these damaging storm surges along with strong winds, torrential rains, and coastal flooding. Typhoons and storm surges threaten marine habitats in various ways. Besides harming coral reefs, typhoons can be destructive to essential fish habitat, which, in turn, can lead to economic loss for fisheries (Brock 1996). In Hawaii, the fish catch and value declined after a typhoon (Brock 1996; Walsh, Cottong et al. 2004). Storm surges and typhoons exacerbate marine debris and pollution. Increased precipitation causes land-based erosion, sedimentation, and increased nutrient inputs from runoff (Starmer 2005). As storms create turbidity at river mouths, pollution runoff from waste oil, fire retardant, and other contaminants entering the water increases (Porter, Leberer et al. 2005).

Invasive Species

Invasive species, another understudied, low impact threat region-wide, is identified in the literature only in American Samoa, the Hawaiian Islands, and New Zealand. In other countries, they lack impact or have not yet been surveyed (Coles, DeFelice et al. 2002; Lambert 2002; Smith, Hunter et al. 2002; Coles, Reath et al. 2003; Coles, Eldredge et al. 2004; Fornwall and Loope 2004; Godwin, Eldredge et al. 2004; Ohtsuka, Horiguchi et al. 2004; Conklin and Smith 2005; Perkins and Xiang 2006; Coles and Bolick 2007; Paulay 2007; Zabin and Altieri 2007; Dunstan and Bax 2008).

Highlighting Regional Solutions

This section highlights regional solutions to the documented threats facing Polynesia. Large gaps in the literature exist for this region; below are some highlights gleaned from the research.

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

Because concern over climate change—including sea level rise and sea temperature increases—has become more widespread throughout Polynesia, different governments and intergovernmental parties like the UNEP South Pacific Task Team and others have initiated work on this topic. For example, between 1997 and 2000, the Secretariat of the Pacific Regional Environment Program's (SPREP) Pacific Islands Climate Change Assistance Programme assisted 10 Pacific island countries or territories in Polynesia, Micronesia, and Melanesia, with partially successful efforts at climate change adaptation and mitigation. (For further details, see the discussion of climate change solutions in Micronesia, pages 78 and 79.)

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

Protected areas, from community-based MPAs to marine reserves, national parks, managed resource protected areas, and other types of marine management areas, offer ecological benefits to the marine environment and socioeconomic benefits to surrounding human populations. Hawaii represents one promising example: the Northwestern Hawaiian Islands MPA protects more than 340,000 square kilometers and protects 7,000

species of birds, fish, and marine mammals—a quarter endemic to the islands. Most of the islands are, however, uninhabited, which removes many conventional challenges associated with MPA establishment (Papahānaumokuākea Marine National Monument website 2008).

The idea of locally managed MPAs, based on traditional marine tenure, has gained strength and acceptance throughout Polynesia (South, Skelton et al. 2004). Studies have shown that local communities are using their traditional cultures as a basis for sustainably managing their reefs, and that these traditionally managed MPAs are relatively successful (Hoffmann 2002; Vieux, Aubanel et al. 2004). Locally managed marine areas incorporating traditional management institutions have been implemented successfully in places like the Cook Islands using Ra'ui marine reserves (Hoffmann 2002). In Samoa, community owned fishery management was initiated in 65 villages within two years, with the majority producing Village Fisheries Management plans, and more than half establishing community-owned MPAs (King and Faasili 1999). American Samoa offers an example of how government-community collaboration on replenishing fish species resulted not only in the establishment of community-based MPAs, but in the banning of a scuba fishery that affected subsistence fishing, and a possible ban on fishing species of concern, including the bumphead parrotfish, humphead wrasse, and giant grouper (Green 2003; Lee 2003; Levine 2008).

Strengthening Institutions and Building Capacity

Because of Polynesia's extreme political and socioeconomic diversity, great differences exist in the experience and skills of its human inhabitants and their institutions. Hawaii and New Zealand have institutions and capacities for effective coastal and ocean management, but other countries and territories struggle to find the human and financial resources to manage their vast marine areas. Generally throughout Polynesia, some of the steps required to strengthen institutions and build capacity include training managers (of MPAs, for example), increasing community awareness and knowledge of, and participation in, conservation activities, and reducing stresses on marine resources. Building such capacity will help Polynesia address their concerns and strengthen activities, from management to monitoring (Hoffmann 2002; Hoffmann 2006).

Regional Governance, Agreements, and Approaches

Regulation and enforcement are key solutions to resource conservation. Although many Polynesian countries and territories have signed on to regional and even international agendas, they could benefit from strengthening their own. For example, illegal fishing remains a major problem throughout the islands, and this issue is only exacerbated by ineffective and poorly enforced fishing regulations. The enforcement of law and policy is a high priority that ties into capacity building. A need exists to develop systems to patrol vast waters using new technologies and prosecute offenders. For example, community pressure and patrolling could stop illegal fishing. The resurgence of some traditional institutions, such as the Ra'ui in the Cooks Island, has reduced nearshore illegal fishing activities (Hoffmann 2002).

Regulation and Enforcement

While many countries and territories are signatory to various regional policies, many lack their own regulations to implement those policies and fail to enforce them. Illegal fishing (such as with the use of explosives, poisons, and illegal nets) is a significant problem in some Pacific countries and territories. Fishing regulations are poorly enforced due to inadequate human resources and funds in the Fisheries Division (South, Skelton et al. 2004). As noted above, enforcement of marine laws and policies is a high priority that requires capacity building. Sufficient community pressure and patrolling could stop illegal fishing. American Samoa offers one example of this. When government and communities collaborated to reinforce a national scuba fishing ban in 2003, local authorities successfully monitored both fishery catches and reef fish populations (Green 2003). A recent study also cites using remote sensing of coral reefs as a cost-effective method to monitor coral reef biodiversity (Knudby, LeDrew et al. 2007).

Alternative Livelihoods

Many of the countries or territories within Polynesia—the less developed countries and territories in particular—are some of the poorest in the world. Because many suffer from poverty and lack of land-based economic infrastructure, they turn to the marine environment for subsistence and livelihood. However, these populations often outstrip their local resources, such as fish. Such reductions can threaten both sea life and human food supply, creating a vicious cycle. One solution to reduce overfishing—besides changing technologies or creating no-take zones—is to create alternative livelihoods for fishers, such as jobs associated with tourism.

Photo: Humpback whale mother and calf *(Megaptera novaeangliae)*, Vava'u, Tonga.
(Silke Stuckenbrock/Marine Photobank)

No research was found on the Pitcairn Islands, and more studies in all threat categories need to be done for Niue, Samoa, Tokelau, Tonga, and Tuvalu in particular.

IX. South East Pacific Ocean Regional Analysis: Threats, Impacts, and Solutions

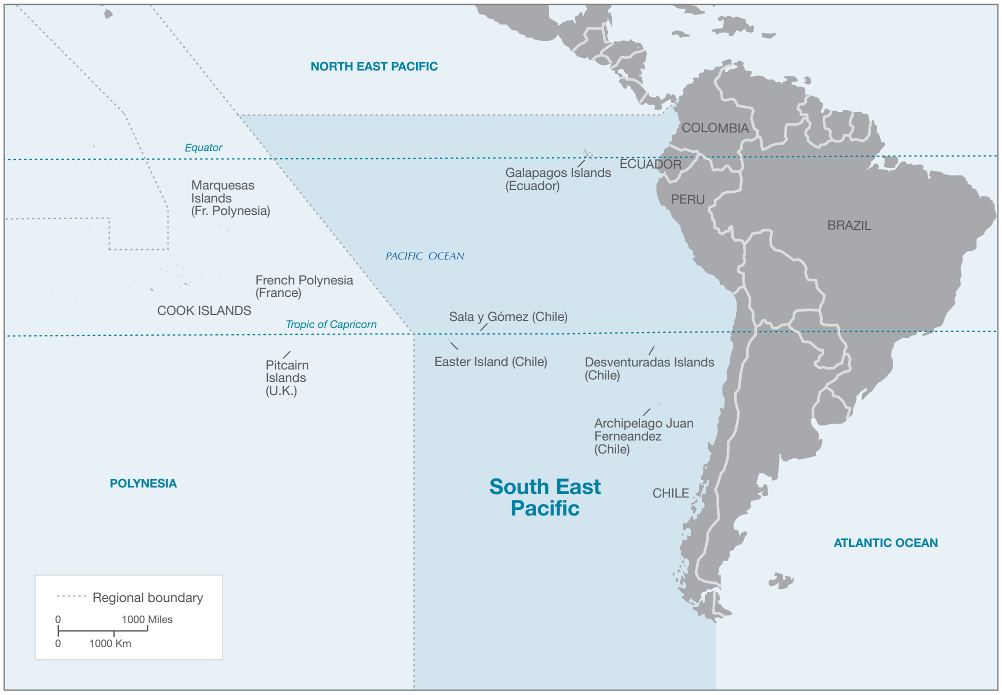
Photo: Regional cooperation via the multinational Eastern Tropical Pacific Seascape Initiative is geared towards protecting entire ranges of highly migratory species such as this green turtle *(Chelonia mydas)* from the Galapagos. (David Lee, courtesy Conservation International)

Four South American countries comprise the South East Pacific Ocean region: Chile, Colombia (Pacific Coast), Ecuador (including Galapagos), and Peru.

The South East Pacific contains high biodiversity in its various coastal and ocean ecosystems, from reefs and islands to wetlands, estuaries, and highly threatened mangroves. Colombia boasts the highest marine biological diversity in South America (Diaz and Acero 2003). The Humboldt Current, which flows along the west coast of South America from southern Chile to southern Ecuador, produces a rich ecosystem and the world's largest upwelling area that influences much of the region (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). These upwelling waters support some of the most significant fisheries in the world, including those in Chile and Peru, two of the world's largest. Throughout the region, aquaculture and fishing (along with agriculture and mining) are the most important economic activities. Chile is the most industrialized country in the region. The FAO ranked the South East Pacific second in terms of worldwide fishing production, after the Northwest Pacific (Food and Agriculture Organization of the United Nations (FAO) 2006). The three countries included in the Humboldt Current area produce 99.5% of the total catches in the South East region; between 1988 and 1992, catches averaged 14.2 million tons, or 22% of the total world production. Periodically, the ENSO event disrupts the upwelling that drives this region's productivity, affecting fish abundance and distribution and often leading to fishery stock crashes and negative socioeconomic impacts. Although the FAO (2006) reported that 60% of demersal stocks and 70% of pelagic species in the region were either fully exploited or overexploited, the total production between 1995 and 1999 in the South East Pacific still averaged 14.5 million tons per year—close to the same production as between 1988 and 1992, despite a catch reduction of 42% in 1998 caused by the ENSO event.

All four broad threats (overfishing and exploitation, climate change, habitat destruction, and pollution) have severe to moderate impacts across the South East Pacific, with invasive species noted as an overall moderate impact threat in the region. An extremely grave threat is pollution, which can create

Map 8: South East Pacific Ocean



Source: International Ocean Commission and The United Nations (www.unep-wcmc.org/gramed) 2008 Lucidity Information Design, LLC

dead zones and algal blooms, alter the ecosystem structure, and jeopardize human systems. Land-based chemicals and nutrients pose severe threats across each country in the region, and wastewater from aquaculture and oil spills and antifouling chemicals are similarly prevalent in each country, with mostly severe impacts. Land-based sedimentation, a form of habitat destruction that can lead to the degradation of critical ecosystems that produce invaluable services and products for society, also occurs as a serious threat in the four countries. So too does commercial fishing, which causes ecological shifts and reduces fish stocks and food supply, thereby endangering human economies and livelihoods. Finally, climate change—in particular sea surface temperature increase—also severely affects all countries in the region by jeopardizing marine ecosystems. Compounded with other threats, climate change has the ability to devastate both marine and human systems. Significantly, these threats do not operate in isolation, but rather function as multiple, compounded stressors that together can devastate marine and human systems.

The South East Pacific Ocean discussion that follows first presents regional trends of overall severe and moderate impact threats; a table lists the levels of threats and impacts in each country. Then, the literature review section offers a more in-depth discussion of the most severe impact threats. Moderate impact threats are also presented if they are prevalent or notable throughout the region. Finally, the last section provides a brief overview of potential solutions to the threats facing this region as a whole.

South East Pacific Regional Trends: Primary Threats and Associated Environmental and Socioeconomic Impacts

The bullets below highlight significant high and moderate impact threats in the South East Pacific based on the impact assessment methodology described in the Introduction.

Based on this assessment, the threats with overall severe impacts across the entire South East Pacific region are:

- land-based chemicals and nutrient pollution identified in four countries.
- land-based sedimentation identified in four countries.
- commercial overfishing identified in four countries.
- wastewater from aquaculture, oil spills, and antifouling chemicals across region.
- coastal development/land reclamation across the region.
- climate change, specifically sea surface temperature increase.

The threats with overall moderate impacts across the region are:

- coastal modification from aquaculture, solid waste disposal, thermal pollution, and artisanal/recreation/subsistence fishing.
- invasive species.
- by-catch and discharge.
- offshore oil/mining.

Key observations regarding research gaps and identified impacts:

- These countries' marine environment is one of the least protected, and most exploited, in South America.
- Ecuador has the greatest number of moderate (nine) to severe (eight) impacts. Colombia has the lowest number of moderate (seven) to severe (four) impacts in the region.
- Large gaps in the research include studies on aquaculture and the impacts of threats in Colombia and Peru as well as ocean-based pollution (ocean waste, toxic dumping, and fishing lines/nets) throughout the region, impacts of climate change, and coastal development/land reclamation.

The following table reveals that the South East Pacific Ocean faces mounting threats. Among the countries in this region, the marine environment is one of the least protected, and most exploited, in the Pacific Ocean. The table documents the identified threats and the environmental and socioeconomic impacts of these threats in the scientific literature. Large gaps in the research include studies on aquaculture and the impacts of threats in Colombia and Peru as well as ocean-based pollution throughout the region, impacts of climate change, and physical alterations to the coast.

TABLE 7: South East Pacific Threats Based on Scientific Literature and Impact Assessment

✓ Identified as Threat
● Severe Impact ● Moderate Impact ● Low Impact
It was documented when an article identified an issue as a present or future threat. If no scientific literature was found on the topic, then no check was assigned. This does not necessarily mean the topic is not a threat; rather, it suggests that no scientific literature was found on the topic.

	CHILE		COLOMBIA		ECUADOR		PERU	
	Threats	Impacts	Threats	Impacts	Threats	Impacts	Threats	Impacts
POLLUTION								
Aquaculture: Wastewater	✓	Moderate	✓	Moderate	✓	Severe	✓	Severe
Land-based Chemicals	✓	Severe	✓	Severe	✓	Severe	✓	Severe
Fishing Lines/Nets					✓	Moderate		
Nutrients	✓	Severe	✓	Severe	✓	Severe	✓	Severe
Offshore Oil/Mining	✓	Moderate	✓	Low	✓	Moderate	✓	Moderate
Oil Spills & Antifouling Chemicals	✓	Severe	✓	Low	✓	Severe	✓	Severe
Radionuclide								
Solid Waste Disposal	✓	Moderate	✓	Moderate	✓	Moderate	✓	Moderate
Thermal	✓	Moderate	✓	Moderate	✓	Moderate	✓	Moderate
Ocean Waste & Toxic Dumping								
HABITAT DESTRUCTION								
Anchor Damage					✓	Low		
Aquaculture: Coastal Modification	✓	Moderate	✓	Moderate	✓	Moderate	✓	Moderate
Coastal Development/Land Reclamation	✓	Moderate	✓	Moderate	✓	Severe	✓	Severe
Destructive Fishing					✓	Moderate	✓	Moderate
Dredging								
Marine Recreation								
Land-based Sedimentation	✓	Severe	✓	Severe	✓	Severe	✓	Severe
Ship Groundings								
Tsunamis								
Typhoons/Cyclones/Hurricanes & Storm Surge								
Wrecks/Military Equipment								
OVERFISHING & EXPLOITATION								
Aquaria Trade								
Artisanal/Recreational/Subsistence Fishing	✓	Moderate	✓	Moderate	✓	Moderate	✓	Moderate
By-Catch & Discharge	✓	Moderate	✓	Low	✓	Moderate	✓	Moderate
Commercial Fishing	✓	Severe	✓	Severe	✓	Severe	✓	Severe
CLIMATE CHANGE								
Acidification								
Sea Level Rise	✓	Moderate						
Sea Surface Temperature**	✓	Moderate	✓	Low	✓	Severe	✓	Severe
INVASIVES								
Invasive Species (Different Vectors)	✓	Low	✓	Moderate	✓	Moderate	✓	Moderate

**Changes in SST is strongly associated with El Niño Southern Oscillation (ENSO) events, which are predicted to increase in frequency and intensity over time due to climate change.
For a complete list of references used for the literature review and synthesis to create this table see Appendix C, Table 7 p.156.

South East Pacific Literature Review of Severe and Moderate Impact Threats

The discussion that follows highlights the greatest documented threats to the North East Pacific based on this synthetic analysis. The most severe threats are discussed (see bullets and table above), and each threat category includes country-specific details on threats 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 socio-economic impacts, and that major gaps exist in the literature.

Pollution: Land-Based Chemicals

Land-based chemical pollution has seriously affected the coastal and ocean environments of the four countries in the South East Pacific, which all show severe impacts. Most of the pollution problem stems from chemicals that enter the ocean from domestic and industrial wastewater from agriculture, mining, and other industries. Not surprisingly, higher levels of chemical pollution are found in urban, densely populated areas along the coast. Along with population growth, toxic industrial activities are expected to increase in the future (Glover and Smith 2003).

Chemical pollution, though it signifies the productivity of the region's coastal areas, has significant environmental, health, and economic impacts. When chemicals accumulate through the food chain or pollute the sediment, they affect all parts of the marine ecosystem. Studies show that chemicals can endanger fishes' reproductive capacities and reduce species abundance (Lancellotti and Stotz 2004), as well as threaten seafood safety and human health. Heavy metals bioaccumulate through the food chain and then pose a risk to people who consume the toxic fish. As agriculture, mining, and industrial activities intensify and new synthetic compounds are developed, chemical pollution has worsened. Many of the impacts on marine ecosystems and humans are unknown.

In northern Chile and southern Peru, mining activities deposit high concentrations of heavy metals (copper, lead, mercury, and cadmium) into the ocean. Chilean waters show evidence of pollution from copper mining tailing disposal and the dumping of untreated mine wastes into coastal bays (Castilla 1978; Castilla 1996a, 1996b). In northern Chile, iron mine tailings created sedimentation in the subtidal zone (Lancellotti and Stotz 2004). Chemical pollution from untreated municipal and industrial wastewater discharges, as well as oil spills from the region's oil terminals and coastal refineries, also contributes to these waters' pollution.

Agricultural pesticides contribute greatly to the South East Pacific's chemical pollution as well. Between 1990 and 1998, the countries in this region used an average of 15,500 tons of pesticides annually, and chemicals from pesticides were found in waters near areas of intensive agriculture (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). In Ecuador and Peru, pesticides have been found in shrimp, crab, and other marine life. Colombia has one of the highest rates of fertilizer consumption on the Pacific Coast of South America (33,000 tons/year of 600 different pesticides). Runoff into the coastal waters produces eutrophic conditions and concentrations of DDTs and pesticides in sediments that exceed national and international standards. Despite relatively limited agricultural development on the Pacific coast, pesticides found there may originate from anti-malaria campaigns, illegal drug crops, and wood treatments (Garay, Marin et al. 2002; United Nations Environment Programme (UNEP) 2006).

Pollution: Nutrients

Like chemicals, land-based nutrients, identified in all four countries as a severe impact threat, also contribute greatly to the South East's pollution. Residuals from aquaculture, fish canneries, fishmeal factories, and wastewater, especially in northern Chile and Peru, provide a significant source of nutrient enrichment to the marine waters (Ahumada 2000). Untreated human sewage inputs nutrients as well (Seguel, Mudge et al. 2001). While nutrients "enrich" the waters, they can cause phytoplankton blooms, eutrophication, hypoxia, and red tides (Afonso and Borquez 2003). These, in turn, threaten marine life, leading to a reduction in the number and abundance of species.

Agricultural runoff contributes to the region's nutrient pollution; about 81,000 tons per year of nitrogen and 7,100 tons per year of phosphorous enter the South East Pacific (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006), much of it from agricultural areas in Ecuador, Peru, and Chile (Borbor-Cordova 2004; Beman, Arrigo et al. 2005). In shrimp farms in Ecuador and Peru, mortalities and low productivity have been shown to result from nutrient pollution, among other factors like poor management (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). Such pollution also affects beach health. The 87,200 cubic meters/day of wastewater that enter the Colombian Pacific from urban centers led, in 2002, to unacceptable levels of coliform bacteria at most of the monitored beaches (UNEP 2006; (Garay, Marin et al. 2002). Terrestrial runoff has also been shown to affect coral communities (Vargas-Angel 2003). Finally, the risk to human

While some threats (such as land-based chemicals, nutrients, land-based sedimentation, and all commercial fishing) have been adequately studied in all South East Pacific countries, others—including ocean waste and toxic dumping, dredging, marine recreation, ship groundings, tsunamis, typhoons, aquaria trade, and ocean acidification–lack research for all countries.

health cannot be overstated; about 50,000 people die annually from water-borne disease in Colombia (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006).

Habitat Destruction: Land-Based Sedimentation

Land-based sedimentation, a form of habitat destruction that can lead to the smothering or degradation of critical ecosystems that produce invaluable services and products for society, occurs as a severe impact threat in all countries within this region as well. Sedimentation affects almost 60% of the region's coasts. Most of it results from deforestation and inadequate agricultural and land use practices, which can cause erosion and then lead to sedimentation in coastal waters. Increased sedimentation produces turbidity, reduces available light, and can suffocate coral reefs and kill fish. Critical areas affected by sedimentation include parts of Ecuador, and in Peru, from Pisco to the Chilean border (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). Sedimentation from erosion, caused by extensive deforestation, has also affected Colombian waters (GIWA Eastern Equatorial Pacific). More research on the threats and impacts of land-based sedimentation, however, needs to be conducted.

Overfishing and Exploitation: Commercial Fishing and Artisanal/Recreational/Subsistence Fishing

Fisheries of all types have heavily overexploited the region's marine resources, and have led to negative socioeconomic and ecological impacts throughout all South East Pacific countries. Commercial/industrial fishing has been identified as a severe impact threat in all four countries, while artisanal/recreational/subsistence fishing has been documented as a moderate impact threat. Both, however, illustrate the negative impact of overexploitation and unsustainable use of ocean resources on marine life and human livelihood. Exploitation has contributed to reducing total catches in the Humboldt Current region in the last decade, since their highest levels of the 1970s and 1980s (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). Artisanal/recreational/subsistence fishing can be just as destructive as commercial fishing. Inside countries' EEZ, artisanal fleets account for significant fishing efforts, and can do as much harm to the marine environment and economy.

The South East Pacific's highly productive waters support some of the most important fisheries in the world. The three countries in the Humboldt Current region produce 99.5% of the total catches in the South East region; between 1988 and 1992, catches averaged 14.2 million tons, or 22% of the total world production. In Chile alone, small-scale fisheries exist for about 60 benthic invertebrates (Castilla and Fernandez 1998).

Commercial fisheries, however, are neither environmentally nor economically sustainable over the long-term. In some sectors (i.e. the Peruvian hake industry), intense fishing pressures have led to temporary fishery closures and economic decline (Carrasco-Guevara 2008). Fisheries in Chile, generally overexploited, have also been subject to periodic bans (Castilla and Fernandez 1998). The export-led growth and competition in the Chilean fishing sector also put tremendous stress on firms to reduce costs, which leaves labor vulnerable (Schurman 2001). In spite of increasingly scarce common-pool resources, inefficient institutional arrangements at marine industrial fisheries exacerbate the overexploitation of marine resources (Pena Torres 1997). In the Galapagos, industrial fisheries have also overexploited the marine environment (Camhi 1995). A sea cucumber crisis in the 1990s revealed not only overfishing and stock depletion, but also complex factors relating to fishing techniques and weak regulatory mechanisms (Bremner and Perez 2002; Shepherd, Martinez et al. 2004). Some studies suggest that overall, commercial fisheries as presently managed may not be sustainable over the long-term (De Young 2007).

Artisanal/recreational/subsistence fishing has also overexploited the region's marine resources. One study showed that fishers in Peruvian coastal waters overexploited small cetaceans for human consumption; the high numbers of these animals captured in gillnets led to a renewed ban on small cetacean exploitation (and a decrease in the illegal meat trade) (Read, Van Waerebeek et al. 1988). In southern Ecuador in 1994, an estimated annual take of 227 bottlenose dolphins in the inner estuary of the Gulf of Guayaquil represented 9% of the resident bottlenose dolphin population—more than twice the species' estimated birth rate (Van Waerebeek, Van Bressem et al. 1997). In the Galapagos, recreational fishing is increasing, and research indicates that artisanal fishing is affecting exploited marine communities, leading to localized decreased abundance of certain species of fish and noncommercial species (Ruttenberg 2001). Subsistence and artisanal fishing, which accounts for about half of total fish catches in Pacific Colombia, have high socioeconomic significance in the region, as fishing provides one of the main sources of income for residents. However, the high level of unemployment in rural areas has spurred migration to the coast for food, security and income, further pressuring fish resources. Some traditionally targeted species such as mackerel, snapper, and sharks, along with crustaceans and mollusks, have declined due to overexploitation and are unsustainable (FAO website 2005). Much information about the status of fishing resources in Colombia is, however, still unknown (United Nations Environment Programme (UNEP) 2006).

Overfishing and Exploitation: By-Catch and Discharge

Commercial and artisanal fleets, as well as recreational users, often use destructive fishing techniques, though the use of such practices is under-reported (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). Throughout the South East Pacific, by-catch and discharge is documented as an overall moderate impact threat, though much information about this destructive practice is missing from the literature. It is discussed here in relation to the discussion on commercial and artisanal fishing above. Fishing gear, from bottom trawls to dredges, gillnets, and longlines, while designed to catch the most fish possible, can be highly destructive to other species and habitats, especially when operated continually. 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). Longline fisheries are considered worldwide to be the main threat to albatross and petrel populations, though technical developments have somewhat mitigated the impact around regions including southern Chile (Moreno, Arata et al. 2006). One consequence of destructive fishing practices is an increase in by-catch.

In Pacific Colombia, shrimp trawling nets and gillnets caught more than 8,000 sea turtles, including the olive ridley and black turtles, in 1998 (Ministerio del Medio Ambiente (MMA) 2002; United Nations Environment Programme (UNEP) 2006; United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006) (Ministerio del Medio Ambiente (MMA) 2002). Directed captures of dolphins for fishing bait, as well as entanglements with multifilament nets, have also been shown to cause high mortality rates of marine mammals along the Pacific coast of Colombia (Mora-Pinto, Munoz-Hincapie et al. 1995). The use of explosives in commercial and artisanal fisheries is also increasing (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). Although no studies of the levels of by-catch exist, it is thought that large quantities of fish are also caught (about 75% are then discarded) as by-catch in the shrimp trawling industry. Much information about the status of fish resources in Colombia is, however, still unknown (United Nations Environment Programme (UNEP) 2006).

In Ecuador, one study estimated that in 1991, Ecuador's trawling catch produced 75% discards—for which reporting is not required (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). Gillnets also led to entanglements with and incidental catches and strandings of Pacific humpback whales along the Ecuadorian coast (Alava 2005).

Along coastal Peru, artisanal gillnet and longline fisheries targeting mahi-mahi and other fish caught more than 150 leatherback turtles as by-catch between 1985 and 2003 (Alfaro-Shigueto, Dutton et al. 2007). A study also showed that fishers in Peruvian coastal waters overexploited small cetaceans for human consumption; the high numbers of these animals captured in gillnets led to a renewed ban on small cetacean exploitation, and a decrease in the illegal meat trade (Read, Van Waerebeek et al. 1988).

Pollution: Aquaculture: Wastewater

Aquaculture, one of the South East Pacific's most important industries, brings important socioeconomic benefits to the region. The aquaculture industry, however, is not without its impacts. The wastewater used in and produced by aquaculture poses one of the marine ecosystem's greatest threats. It has been identified as a major threat across all four countries, with severe impacts in Ecuador and Peru and moderate impacts in Chile and Colombia.

The major aquaculture uses in the region include shrimp farming in Ecuador and Peru, the culture of salmonids, and, to lesser degrees, tilapia, as well as the farming of mollusks and algae in southern Chile's open areas (Winter, Toro et al. 1984; United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). Shrimp farming represents nearly 80% of the total value for regional aquaculture production (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). Fishing and aquaculture products were the second largest export item in 1998 (USD $1.2 billion), higher even than petroleum. Exports have since decreased, however, due to the white spot disease. In other parts of the South East Pacific, aquaculture has expanded. Chile's aquaculture industry (especially salmon farming) has grown dramatically since the 1980s, making it one of the most dynamic, though perhaps unsustainable, sectors of the country (Barton 1997). In Peru, a burgeoning aquaculture industry focuses on shrimp, trout, and scallops, and increases in production and revenue annually (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006 ; Food and Agriculture Organization of the United Nations (FAO) 2006). Fishing exports from Peru between 1992 and 2001 revealed that aquaculture/fishing exports were second only to mining. In 2001, fishing exports reached USD $1.1 billion (Zuzunaga 2002).

Despite the growing economic importance of aquaculture in the South East Pacific, it has associated threats. Wastewater is a major form of pollution affecting the marine environment. Wastewater is occasionally used in aquaculture operations (generally without first being sanitized or treated, in aquaculture) but is more often a byproduct of aquaculture farming. To attain higher production efficiency, artificial feed, chemical additives, and antibiotics are often used. The resulting wastewater can greatly impair all levels of the marine ecosystem by depositing high concentrations of toxic chemicals and nutrients in coastal waters (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). Localized changes in the physicochemical properties of sediments have occurred in areas with salmonid farms, particularly in Chile (Camus 2005). Increased nutrients, especially nitrogen, can also produce HABs that alter the natural functioning of the ecosystem. Over the last three decades HABs in Chile, for example, have been linked to salmon farming (Buschmann, Riquelme et al. 2006). Aquaculture wastewater can also modify the structure of benthic communities. Research shows that at salmon farms along 300 kilometers of Chile's coastline, the benthic biodiversity was reduced by at least 50% on average (Buschmann, Riquelme et al. 2006). Wastewater may also affect native species by introducing pathogens and invasive species, which, although not a major threat in the region, can harm or cause mass mortalities among both farmed and native species, and lead to abrupt production decline (Camus 2005; Castilla, Uribe et al. 2005).

Wastewater from aquaculture not only alters the marine ecosystem, but it can also result in coastal modification, including destruction of mangrove ecosystems. The shrimp industry in Ecuador is a case in point. Shrimp larvae depend on relatively pristine mangrove areas. But as polluted wastewater from the farms is released into the ocean and neighboring lands and production expectations intensify, the need for pristine mangrove areas for aquaculture increases. Compounded with other factors, coastal modification ultimately decreases the economic efficiency of the farms, sometimes leading to abandonment of the farms, economic loss, and loss of livelihood (Parks and Bonifaz 1995; Borbor-Cordova 1999). Peru, although it has less abundant mangroves, shows a similar trend (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). In Pacific Colombia, particularly at Nariño, 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).

Pollution: Oil Spills and Antifouling Chemicals

Marine oil pollution is a grave threat in the region. Oil spills along the coasts of Ecuador, Peru, and Chile have been documented with significant negative impacts to the marine environment. Oil pollution results from offshore drilling, shipping, the growing numbers of harbors and ports, as well as the transport of oil in tankers. It can be chronic and acute, as well as infrequent but nonetheless still acute. There have been a number of devastating spills, such as the Jessica oil spill in Ecuador, where the localized effect of the spill killed marine life, from primary producers to top predators, and destroyed entire wetland and mangrove systems (Banks 2003; Alava and Salazar 2006). Oil spills can also decrease local income and revenue from marine resources, including loss of tourism income. Antifouling chemicals are also extremely toxic to marine systems. Although not documented in the literature in this region, they are commonly present in harbors and ports.

Invasive species are identified as a moderate impact threat for South East Pacific countries, but they are nonetheless vastly understudied throughout the entire region.

Habitat Destruction: Coastal Development and Land Reclamation

Along the Pacific Coast of South America, the South East Pacific Ocean region has a heavily altered coastline, with development and land reclamation present in every country, with severe or moderate impacts in each. Coastal populations are growing rapidly, accompanied by increasing urbanization. Tourism is expanding in the region as well. Such growth requires infrastructure development, including roads, along the coast. The threats and impacts of roads are understudied, but there is no doubt they affect coastal habitats. Some types of land loss are better documented. In Peru, the estimated loss of mangroves between 1982 and 1990 was 24.5% (Burke, Kura et al. 2001). In 1980, Colombia had an estimated mangrove area of 4,000 square kilometers; this area since decreased to 3,580 square kilometers (Spalding, Blasco et al. 1997). Ecuador, which had an estimated mangrove area in 1979 of 2,037 square kilometers, saw a decrease in 1991 to 1,620 square kilometers (Parks and Bonifaz 1995). Mangrove forest cover is likely to be lower in both countries today.

Climate Change: Sea Surface Temperature Increase

Global climate change affects all aspects of an ecosystem, including increasing ocean temperatures. In the South East Pacific, elevated sea surface temperatures have been identified in all four countries, with severe impacts in Ecuador and Peru. Sea warming creates the potential for the increased frequency and severity of ENSO-like events. When combined with more localized stresses like wastewater or coastal modification caused by aquaculture, overfishing, and pollution, global climate change and sea surface temperature increase can negatively affect not only the ocean ecosystem, but the region's economic viability as well.

Repeated extreme high- and low-water temperatures (ENSO) are an important natural community-structuring determinant in the region, but they generally have negative impacts on coral. ENSO events can prevent coral communities from increasing in diversity and limit the development of significant reef features (Vargas-Angel 2003). The 1982–1983 ENSO event, which significantly raised sea surface temperature, devastated eastern Pacific coral reefs (between 70–95% of reefs), with slow recovery and extensive reef erosion (Glynn and Colgan 1992). In the Galapagos, repeated ENSO events prevent coral communities from increasing in diversity or surviving erosion after reef death (Colgan 1990); the 1987 ENSO event resulted in 95% coral mortality on most Galapagos reefs (Podesta and Glynn 1997). In Colombia, the 1997–1998 ENSO sea warming event led to massive coral bleaching and mortality at sites around Gorgona Island, with variable recovery (Vargas-Angel, Zapata et al. 2001). It is estimated that if sea temperature continues to increase at the current rate, in about a century, sea temperatures could exceed the thermal tolerance of some reef fishes and threaten them with extinction (Mora and Ospina 2001).

Climate change and increased sea surface temperatures threaten marine mammals as well. ENSO events, which reduce productive foraging, have been shown to negatively affect sperm whale conception (Whitehead 1997). The 1982–1983 and 1997–1998 events (along with anthropogenic effects like oil spills, fishery interactions, etc.) contributed to large reductions in pinniped populations (Alava and Salazar 2006). In Peru, ENSO events have led to decreased breeding among sea lions and reduced sightings of fur seals, sea lions, and seabirds (Majluf 1998).

Because sea warming changes food web relationships, it by extension threatens fisheries as well (Karl, Bidigare et al. 2001). Parts of South America 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 ENSO, 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. ENSO 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). It is expected that climate change effects associated with sea temperature increases will be exacerbated during warm periods and ameliorated during cooler periods.

Other Regional Threats

Invasive Species

Although the existing literature identifies invasive species as having an overall moderate impact in the South East Pacific (particularly in Colombia, Ecuador, and Peru), they are currently understudied and may be underrepresented as a threat. Throughout the region, biological invasions from ballast water threaten the marine environment and can be costly to society (Drake and Lodge 2004). In Chile, invasive species are linked to aquaculture; such

Photo: Paele's Dolphins *(Lagenorhynchus australis)*, Chilean Patagonia. (Tom Crowley/Marine Photobank)

invasives can threaten native species, or, in some cases (like salmonids), enhance artisanal and sport fishing. Overall, however, the number of non-indigenous species is low, though the impact may be underestimated (Castilla, Uribe et al. 2005). In Colombia, around 96 species of fish are known to have been introduced, mostly via ballast water (United Nations Environment Programme (UNEP) 2006). Though understudied, marine invasive species could have effects as far-ranging as HABs. In Colombia, two HABs were reported as the result of recently introduced species. The first was observed in 2001 off Tumaco Bay on the Pacific coast of Colombia; it soon spread north to Gorgona Island. The second, in 2002, affected Cabo Corrientes North to Solano Bay (Garcia-Hansen, Cortes-Altamirano et al. 2004). Overall, the impact of marine invasives requires further study.

Highlighting Regional Solutions

This section highlights regional solutions to the threats facing the South East Pacific. Large gaps exist in the literature for this region; below are some highlights gleaned from the research.

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

MPAs and marine reserves offer the coast and ocean protection from overuse and exploitation. Many reserves have already been established throughout the region, and some go even further than simply setting aside habitat. In the Galapagos, the landmark 1998 Special Law provides a legal framework for fostering conservation and sustainable development activities, though implementation is a challenge. As illegal fishing still occurs within the reserve, effective enforcement is needed (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). Mainland Ecuador also has a large number of marine and coastal reserves, which protect mangroves. In Peru and Ecuador, some important wetlands, sandy beaches, and mangroves are now in protected areas, though such protection encompasses a small percentage compared to the areas that have been disturbed. In Peru, the area of protected areas approaches 1,309 square miles (EarthTrends 2003). Pacific Colombia has three protected areas, which include marine areas.

Studies have identified urgent needs to establish a network of MPAs in Chile (Castilla 1996a, 1996b). Although many of Chile's southernmost small islands are included in the National System for Protected Areas, one goal is to preserve 10% of the representative marine habitats along Chile's coasts (Fernandez, Jaramillo et al. 2000; Fernandez and Castilla 2005). But overall, initiatives that tend to promote exploitation of the ocean (i.e. fisheries) have been prioritized over, and tend to conflict with, initiatives designed to conserve and protect the coastal and ocean areas (Fernandez, Jaramillo et al. 2000; Fernandez and Castilla 2005). Still, a number of conventions and laws specific to the protection of the region's marine resources exist (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006).

Regional Governance, Agreements, and Approaches

Although in the 1990s a number of international fisheries instruments provided an impetus for countries to strengthen their fisheries management, the aquaculture and fisheries sector in the South East Pacific has grown disproportionately with regional agreements and enforcements designed to support it. While individual countries implement measures aimed to reduce the fishing impact (i.e. 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) and Permanent Commission for the South Pacific (CPPS) 2006).

Peru and Chile may provide one regional model for cooperative management. A regional workshop for the joint stock evaluation of sardine and anchovy for southern Peru and northern Chile was organized in 1999 by Chile's Fisheries Research and Development Institute and Peru's Marine Research Institute. The key players and relevant departments are the two governments, commercial and artisanal fisheries, mining, petroleum, and other industries affecting the coastal zone, the port authorities, tourism interests, and donor agencies (NOAA LME 13 website 2004).

Studies have identified the importance of regional economic institutions and agreements, such as APEC and NAFTA, in protecting marine resources (Cid 2004). The rapid development of 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). The FAO (2006) cited the need for greater organization and coordination between the private sector and government to achieve larger economic and social goals (Winter, Toro et al. 1984). Regional management plans may also help alleviate the effects of ENSO events (Thatje, Heilmayer et al. 2008).

Regulation and Enforcement

Regulation is greatly needed to curb the chemical, nutrient, and sedimentation pollution that threatens the South East Pacific. While countries in the region have developed national regulations and protocols to deal with pollution from land-based sources (some more effective than others), lack of regional coordination hampers their effectiveness (United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006). Chile alone, for example, has incorporated the concept of self-regulation for industrial wastewater discharges. A greater need exists to develop uniform criteria and environmental quality standards to limit and manage the environmental and socioeconomic problems caused by wastewater and other land-based contaminants discharged to the marine environment, and to enforce these regulations (Permanent Commission of the South Pacific (CPPS) 2001; United Nations Environment Programme (UNEP) and Permanent Commission for the South Pacific (CPPS) 2006).

Infrastructure Development

In many areas throughout the South East Pacific, the environmental and socioeconomic impact of infrastructure (dams, roads, port facilities, sewage treatment plants, etc.) has not been adequately considered, leading to drained wetlands, beach erosion, and coastal and marine pollution. In particular, there is a substantial need for greater investment in sewage treatment plants and sewage systems throughout the entire region.

X. Appendices: References

Photo: Big Sur coastline looking north to Bixby Canyon Bridge in Monterey Bay, California (Robert Schwemmer, CINMS, NOAA)

Appendix A: Attendees at the August 2008 Honolulu Workshop

Anderson, Cheryl, Director, Hazards, Climate & Environment Program, University of Hawaii, U.S.A.

Birkeland, Charles, Associate Professor, Zoology Department, University of Hawaii, U.S.A.

Bustamante, Rodrigo, Team Leader, Marine & Atmospheric Research, Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia

Caldwell, Margaret, Executive Director, Center for Ocean Solutions, Stanford University, U.S.A.

Chabot, Warner, Chief Executive Officer, California League of Conservation Voters (CLCV), U.S.A.

Chen, Allen, Research Fellow, Research Center for Biodiversity, Academia Sinica, Taiwan

Costello, Mark, Associate Professor, Leigh Marine Laboratory, University of Auckland, Australia

Davies, Neil, Executive Director, South Pacific Research Station, University of California-Berkeley, U.S.A.

Deo, Seema, Communications Officer, Oceania Regional Office, International Union for Conservation of Nature (IUCN), Fiji

Gilman, Eric, Marine Science Advisor, Global Marine Programme, International Union for Conservation of Nature (IUCN), Hawaii, U.S.A.

Hoegh-Guldberg, Ove, Director, Centre for Marine Studies, University of Queensland, Australia

Hoffman, Jennifer, EcoAdapt, Seattle, U.S.A.

Howorth, Russell, Deputy Director, Pacific Applied Geoscience Commission (SOPAC), Fiji

Idechong, Noah, Vice Speaker & Delegate of the State of Ngiwal, House of Delegates, 7th Palau National Congress, Palau

Kostka, Willy, Executive Director, Micronesia Conservation Trust, Federated States of Micronesia

Kruger, Jens, Physical Oceanographer, Pacific Applied Geoscience Commission (SOPAC), Fiji

Leong, Jo-Anne, Director, Hawaii Institute of Marine Biology, U.S.A.

Lubchenco, Jane, Administrator, National Oceanic and Atmospheric Administration (NOAA), U.S.A.

Manoka, Billy, Professor, Economics Department, University of Papua New Guinea, Papua New Guinea

Palmer, Jennifer, Marine Programme Officer, International Union for Conservation of Nature (IUCN), Washington, D.C., U.S.A.

Palumbi, Steve, Professor/ Director, Hopkins Marine Station, Stanford University, U.S.A.

Ponia, Ben, Aquaculture Advisor, Marine Resources Division, Secretariat of the Pacific Community (SPC), New Caledonia

Teisch, Jessica, Associate, T. C. Hoffmann and Associates, LLC., U.S.A.

Veitayaki, Joeli, Associate Professor, School of Marine Studies, University of the South Pacific, Fiji

Wang, Yamin, Professor, College of Ocean, Shandong University, China

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Appendix C: Table References

Table 1: North East Pacific Threats Based on Scientific Literature and Impact Assessment

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Table 3: Pacific Ocean and East Asian Seas Threats Based on Scientific Literature and Impact Assessment

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XI. Pacific Ocean Synthesis Index

Note: Italic page numbers indicate illustrations, tables, and boxed material.

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The findings of the Pacific Ocean Synthesis led to a consensus statement signed by over 400 scientists from around the Pacific: *Ecosystems and People of the Pacific Ocean—Threats and Opportunities for Action: A Scientific Consensus Statement*. To view or sign the Consensus Statement visit the Center for Ocean Solutions online at: **http://poi.stanford.edu** or send an e-mail with your name and institution to: **POIstatement@stanford.edu**.

Back Cover Photo: Mollusk *(Order Nudibranchia)* swimming on the flank of Davidson Seamount at 1,498 meters water depth. (NOAA/Monterey Bay Aquarium Research Institute)

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