PILOT ANALYSIS OF GLOBAL ECOSYSTEMS

Coastal Ecosystems

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ISBN: 1-56973-458-5

Library of Congress Catalog Card No. 2001088657

Printed in the United States of America on chlorine-free paper with recycled content of 50%, 20% of which is post-consumer.

Photo Credits: Cover: Digital Vision, Ltd., Smaller ecosystem photos: *Forests:* Digital Vision, Ltd., *Agriculture:* Viet Nam, IFPRI Photo/P. Berry, *Grasslands:* PhotoDisc, *Freshwater:* Dennis A. Wentz, *Coastal:* Digital Vision, Ltd., Extent and Change: Patuxent River, Maryland/NOAA, Shoreline Stabilization: Georgetown, Guyana/L. Burke, Water Quality: Noctiluca bloom, California/P.J.S. Franks, Scripps Institution of Oceanography, Biodiversity: Caribbean Sea/NOAA, Marine Fisheries: NOAA, Tourism: Bunaken, North Sulawesi, Indonesia/L. Burke.

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Published by World Resources Institute
Washington, DC

This report is also available at http://www.wri.org/wr2000

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December 2000 / paperback / ISBN 1-56973-457-7 / US$20.00

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April 2001 / paperback / ISBN 1-56973-458-5 / US$20.00

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December 2000 / paperback / ISBN 1-56973-461-5 / US$20.00

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The agroecosystem report is also available at http://www.ifpri.org. Printed copies may be ordered by mail from the International Food Policy Research Institute, Communications Service, 2033 K Street, NW, Washington, D.C. 20006-5670, USA.

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Foreword

Earth's ecosystems and its peoples are bound together in a grand and complex symbiosis. We depend on ecosystems to sustain us, but the continued health of ecosystems depends, in turn, on our use and care. Ecosystems are the productive engines of the planet, providing us with everything from the water we drink to the food we eat and the fiber we use for clothing, paper, or lumber. Yet, nearly every measure we use to assess the health of ecosystems tells us we are drawing on them more than ever and degrading them, in some cases at an accelerating pace.

Our knowledge of ecosystems has increased dramatically in recent decades, but it has not kept pace with our ability to alter them. Economic development and human well-being will depend in large part on our ability to manage ecosystems more sustainably. We must learn to evaluate our decisions on land and resource use in terms of how they affect the capacity of ecosystems to sustain life — not only human life, but also the health and productive potential of plants, animals, and natural systems.

A critical step in improving the way we manage the earth's ecosystems is to take stock of their extent, their condition, and their capacity to provide the goods and services we will need in years to come. To date, no such comprehensive assessment of the state of the world's ecosystems has been undertaken.

The Pilot Analysis of Global Ecosystems (PAGE) begins to address this gap. This study is the result of a remarkable collaborative effort between the World Resources Institute (WRI), the International Food Policy Research Institute (IFPRI), intergovernmental organizations, agencies, research institutes, and individual experts in more than 25 countries worldwide. The PAGE compares information already available on a global scale about the condition of five major classes of ecosystems: agroecosystems, coastal areas, forests, freshwater systems, and grasslands. IFPRI led the agroecosystem analysis, while the others were led by WRI. The pilot analysis examines not only the quantity and quality of outputs but also the biological basis for production, including soil and water condition, biodiversity, and changes in land use over time. Rather than looking just at marketed products, such as food and timber, the study also analyzes the condition of a broad array of ecosystem goods and services that people need, or enjoy, but do not buy in the marketplace.

The five PAGE reports show that human action has profoundly changed the extent, condition, and capacity of all major ecosystem types. Agriculture has expanded at the expense of grasslands and forests, engineering projects have altered the hydrological regime of most of the world's major rivers, settlement and other forms of development have converted habitats around the world's coastlines. Human activities have adversely altered the earth's most important biogeochemical cycles — the water, carbon, and nitrogen cycles — on which all life forms depend. Intensive management regimes and infrastructure development have contributed positively to providing some goods and services, such as food and fiber from forest plantations. They have also led to habitat fragmentation, pollution, and increased ecosystem vulnerability to pest attack, fires, and invasion by nonnative species. Information is often incomplete and the picture confused, but there are many signs that the overall capacity of ecosystems to continue to produce many of the goods and services on which we depend is declining.

The results of the PAGE are summarized in *World Resources 2000–2001*, a biennial report on the global environment published by the World Resources Institute in partnership with the United Nations Development Programme, the United Nations Environment Programme, and the World Bank. These institutions have affirmed their commitment to making the viability of the world's ecosystems a critical development priority for the 21st century. WRI and its partners began work with a conviction that the challenge of managing earth's ecosystems — and the consequences of failure — will increase significantly in coming decades. We end with a keen awareness that the scientific knowledge and political will required to meet this challenge are often lacking today. To make sound ecosystem management decisions in the future, significant changes are needed in the way we use the knowledge and experience at hand, as well as the range of information brought to bear on resource management decisions.

A truly comprehensive and integrated assessment of global ecosystems that goes well beyond our pilot analysis is necessary to meet information needs and to catalyze regional and local assessments. Planning for such a Millennium Ecosystem Assessment is already under way. In 1998, representatives from international scientific and political bodies began to explore the merits of, and recommend the structure for, such an assessment. After consulting for a year and considering the preliminary findings of the PAGE report, they concluded that an international scientific assessment of the present and likely future condition of the world's ecosystems was both feasible and urgently needed. They urged local, national, and international institutions to support the effort as stakeholders, users, and sources of expertise. If concluded successfully, the Millennium Ecosystem Assessment will generate new information, integrate current knowledge, develop methodological tools, and increase public understanding.

Human dominance of the earth's productive systems gives us enormous responsibilities, but great opportunities as well. The challenge for the 21st century is to understand the vulnerabilities and resilience of ecosystems, so that we can find ways to reconcile the demands of human development with the tolerances of nature.

We deeply appreciate support for this project from the Australian Centre for International Agricultural Research, The David and Lucile Packard Foundation, The Netherlands Ministry of Foreign Affairs, the Swedish International Development Cooperation Agency, the United Nations Development Programme, the United Nations Environment Programme, the Global Bureau of the United States Agency for International Development, and The World Bank.

A special thank you goes to the AVINA Foundation, the Global Environment Facility, and the United Nations Fund for International Partnerships for their early support of PAGE and the Millennium Ecosystem Assessment, which was instrumental in launching our efforts.

Jonathan Lash
President
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Acknowledgments

The World Resources Institute and the International Food Policy Research Institute would like to acknowledge the members of the Millennium Assessment Steering Committee, who generously gave their time, insights, and expert review comments in support of the Pilot Analysis of Global Ecosystems.

Edward Ayensu, Ghana; Mark Collins, United Nations Environment Programme - World Conservation Monitoring Centre (UNEP-WCMC), United Kingdom; Angela Cropper, Trinidad and Tobago; Andrew Dearing, World Business Council for Sustainable Development (WBCSD); Janos Pasztor, UNFCCC; Louise Fresco, FAO; Madhav Gadgil, Indian Institute of Science, Bangalore, India; Habiba Gitay, Australian National University, Australia; Gisbert Glaser, UNESCO; Zuzana Guziova, Ministry of the Environment, Slovak Republic; He Changchui , FAO; Calestous Juma, Harvard University; John Krebs, National Environment Research Council, United Kingdom; Jonathan Lash, World Resources Institute; Roberto Lenton, UNDP; Jane Lubchenco, Oregon State University; Jeffrey McNeely, World Conservation Union (IUCN), Switzerland; Harold Mooney, International Council of Scientific Unions; Ndegwa Ndiangui, Convention to Combat Desertification; Prabhu L. Pingali, CIMMYT; Per Pinstrup-Andersen, Consultative Group on International Agricultural Research; Mario Ramos, Global Environment Facility; Peter Raven, Missouri Botanical Garden; Walter Reid, Secretariat; Cristian Samper, Instituto Alexander Von Humboldt, Colombia; José Sarukhán, CONABIO, Mexico; Peter Schei, Directorate for Nature Management, Norway; Klaus Töpfer, UNEP; José Galízia Tundisi, International Institute of Ecology, Brazil; Robert Watson, World Bank; Xu Guanhua, Ministry of Science and Technology, People's Republic of China; A.H. Zakri, Universiti Kebangsaan Malaysia, Malaysia.

The Pilot Analysis of Global Ecosystems would not have been possible without the data provided by numerous institutions and agencies.

The authors of the coastal ecosystem analysis wish to express their gratitude for the generous cooperation and invaluable information we received from the following organizations:

Caribbean Association for Sustainable Tourism; Caribbean Tourism Organization; Center for International Earth Science Information Network (CIESIN); Coastal Resources Center, University of Rhode Island; Fisheries Department, Food and Agriculture Organization of the United Nations (FAO); International Tanker Owners Pollution Federation; Island Resources Foundation, Virgin Islands; Japan Oceanographic Data Center; National Ocean Service, National Oceanic and Atmospheric Administration (NOAA); Ocean Voice International, Ottawa, Canada; UNEP/Global Resource Information Database, Nairobi, Kenya; Veridian-MRJ Technology Solutions, Virginia, U.S.A.; UNEP-World Conservation Monitoring Centre (UNEP-WCMC); World Travel and Tourism Council.

The authors would also like to express their gratitude to the many individuals who contributed data and advice, attended expert workshops, and reviewed successive drafts of this report.

Tundi Agardy, Conservation International; Salvatore Arico, Division of Ecological Sciences, UNESCO; Jaime Baquero, Gary Spiller, and Robert Cambell, Ocean Voice International; Barbara Best, USAID; Simon Blyth, Lucy Conway, Neil Cox, Ed Green, Brian Groombridge, Chantal Hagen, Joanna Hugues, and Corinna Ravillious, UNEP-WCMC; Charles Ehler, Suzanne Bricker, Paul Orlando, Tom O'Connor, Dan Basta, Al Strong, Jim Hendee, and Ingrid Guch, NOAA; John Caddy, Luca Garibaldi, Richard Grainger, Serge Garcia, and David James, Fisheries Department, FAO; Gillian Cambers, Coast and Beach Stability in the Lesser Antilles Project; Steve Colwell and Shawn Reifsteck, Coral Reef Alliance; Ned Cyr, Global Ocean Observing System, UNESCO; Charlotte De Fontaubert, IUCN; Uwe Deichmann, World Bank; Robert Diaz, Virginia Institute of Marine Science; Paul Epstein, Harvard Medical School; Jonathan Garber, US Environmental Protection Agency; Lynne Hale, James Tobey, Pam Rubinoff, and Maria Haws, Coastal Resources Center, University of Rhode Island; Giovanni Battista La Monica, Department of Land Science, University of Rome; John McManus, International Center for Living Aquatic Resources Management; Bruce Potter, Island Resources Foundation; Lorin Pruett, Hal Palmer, and Joe Cimino, Veridian-MRJ Technology Solutions; Kelly Robinson, Caribbean Association for Sustainable Tourism; Charles Sheppard, University of Warwick; Ben Sherman, University of New Hampshire; Mercedes Silva, Caribbean Tourism Organization; Matt Stutz, Division of Earth and Ocean Sciences, Duke University; Sylvia Tognetti, University of Maryland.

We also wish to thank the many individuals at WRI who were generous with their time and comments as this report progressed: Dan Tunstall, Norbert Henninger, Emily Matthews, Siobhan Murray, Gregory Mock, Jake Brunner, and Tony Janetos. Johnathan Kool and Armin Jess were extremely helpful in producing final maps and figures. A special thank you goes to Hyacinth Billings, Kathy Doucette, Maggie Powell, and Carollyne Hutter for their editorial and design guidance through the production of the report.

Introduction to the Pilot Analysis of Global Ecosystems

PEOPLE AND ECOSYSTEMS

The world's economies are based on the goods and services derived from ecosystems. Human life itself depends on the continuing capacity of biological processes to provide their multitude of benefits. Yet, for too long in both rich and poor countries, development priorities have focused on how much humanity can take from ecosystems, and too little attention has been paid to the impact of our actions. We are now experiencing the effects of ecosystem decline in numerous ways: water shortages in the Punjab, India; soil erosion in Tuva, Russia; fish kills off the coast of North Carolina in the United States; landslides on the deforested slopes of Honduras; fires in the forests of Borneo and Sumatra in Indonesia. The poor, who often depend directly on ecosystems for their livelihoods, suffer most when ecosystems are degraded.

A critical step in managing our ecosystems is to take stock of their extent, their condition, and their capacity to continue to provide what we need. Although the information available today is more comprehensive than at any time previously, it does not provide a complete picture of the state of the world's ecosystems and falls far short of management and policy needs. Information is being collected in abundance but efforts are often poorly coordinated. Scales are noncomparable, baseline data are lacking, time series are incomplete, differing measures defy integration, and different information sources may not know of each other's relevant findings.

OBJECTIVES

The Pilot Analysis of Global Ecosystems (PAGE) is the first attempt to synthesize information from national, regional, and global assessments. Information sources include state of the environment reports; sectoral assessments of agriculture, forestry, biodiversity, water, and fisheries, as well as national and global assessments of ecosystem extent and change; scientific research articles; and various national and international data sets. The study reports on five major categories of ecosystems:

- ♦ Agroecosystems;
- ♦ Coastal ecosystems;
- ♦ Forest ecosystems;
- ♦ Freshwater systems;
- ♦ Grassland ecosystems.

These ecosystems account for about 90 percent of the earth's land surface, excluding Greenland and Antarctica. PAGE results are being published as a series of five technical reports, each covering one ecosystem. Electronic versions of the reports are posted on the Website of the World Resources Institute [http://www.wri.org/wr2000] and the agroecosystems report also is available on the Website of the International Food Policy Research Institute [http://www/ifpri.org].

The primary objective of the pilot analysis is to provide an overview of ecosystem condition at the global and continental levels. The analysis documents the extent and distribution of the five major ecosystem types and identifies ecosystem change over time. It analyzes the quantity and quality of ecosystem goods and services and, where data exist, reviews trends relevant to the production of these goods and services over the past 30 to 40 years. Finally, PAGE attempts to assess the capacity of ecosystems to continue to provide goods and services, using measures of biological productivity, including soil and water conditions, biodiversity, and land use. Wherever possible, information is presented in the form of indicators and maps.

A second objective of PAGE is to identify the most serious information gaps that limit our current understanding of ecosystem condition. The information base necessary to assess ecosystem condition and productive capacity has not improved in recent years, and may even be shrinking as funding for environmental monitoring and record-keeping diminishes in some regions.

Most importantly, PAGE supports the launch of a Millennium Ecosystem Assessment, a more ambitious, detailed, and integrated assessment of global ecosystems that will provide a firmer basis for policy- and decision-making at the national and subnational scale.

AN INTEGRATED APPROACH TO ASSESSING ECOSYSTEM GOODS AND SERVICES

Ecosystems provide humans with a wealth of goods and services, including food, building and clothing materials, medicines, climate regulation, water purification, nutrient cycling, recreation opportunities, and amenity value. At present, we tend to manage ecosystems for one dominant good or service, such as grain, fish, timber, or hydropower, without fully realizing the trade-offs we are making. In so doing, we may be sacrificing goods or services more valuable than those we receive — often those goods and services that are not yet valued in the market, such as biodiversity and flood control. An integrated ecosystem approach considers the entire range of possible goods and services a given ecosystem provides and attempts to optimize the benefits that society can derive from that ecosystem and across ecosystems. Its purpose is to help make trade-offs efficient, transparent, and sustainable.

Such an approach, however, presents significant methodological challenges. Unlike a living organism, which might be either healthy or unhealthy but cannot be both simultaneously, ecosystems can be in good condition for producing certain goods and services but in poor condition for others. PAGE attempts to evaluate the condition of ecosystems by assessing separately their capacity to provide a variety of goods and services and examining the trade-offs humans have made among those goods and services. As one example, analysis of a particular region might reveal that food production is high but, because of irrigation and heavy fertilizer application, the ability of the system to provide clean water has been diminished.

Given data inadequacies, this systematic approach was not always feasible. For each of the five ecosystems, PAGE researchers, therefore, focus on documenting the extent and distribution of ecosystems and changes over time. We develop indicators of ecosystem condition — indicators that inform us about the current provision of goods and services and the likely capacity of the ecosystem to continue providing those goods and services. Goods and services are selected on the basis of their perceived importance to human development. Most of the ecosystem studies examine food production, water quality and quantity, biodiversity, and carbon sequestration. The analysis of forests also studies timber and woodfuel production; coastal and grassland studies examine recreational and tourism services; and the agroecosystem study reviews the soil resource as an indicator of both agricultural potential and its current condition.

PARTNERS AND THE RESEARCH PROCESS

The Pilot Analysis of Global Ecosystems was a truly international collaborative effort. The World Resources Institute and the International Food Policy Research Institute carried out their research in partnership with numerous institutions worldwide (see *Acknowledgments*). In addition to these partnerships, PAGE researchers relied on a network of international experts for ideas, comments, and formal reviews. The research process included meetings in Washington, D.C., attended by more than 50 experts from developed and developing countries. The meetings proved invaluable in developing the conceptual approach and guiding the research program toward the most promising indicators given time, budget, and data constraints. Drafts of PAGE reports were sent to over 70 experts worldwide, presented and critiqued at a technical meeting of the Convention on Biological Diversity in Montreal (June, 1999) and discussed at a Millennium Assessment planning meeting in Kuala Lumpur, Malaysia (September, 1999). Draft PAGE materials and indicators were also presented and discussed at a Millennium Assessment planning meeting in Winnipeg, Canada, (September, 1999) and at the meeting of the Parties to the Convention to Combat Desertification, held in Recife, Brazil (November, 1999).

KEY FINDINGS

Key findings of PAGE relate both to ecosystem condition and the information base that supported our conclusions.

The Current State of Ecosystems

The PAGE reports show that human action has profoundly changed the extent, distribution, and condition of all major ecosystem types. Agriculture has expanded at the expense of grasslands and forests, engineering projects have altered the hydrological regime of most of the world's major rivers, settlement and other forms of development have converted habitats around the world's coastlines.

The picture we get from PAGE results is complex. Ecosystems are in good condition for producing some goods and services but in poor condition for producing others. Overall, however, there are many signs that the capacity of ecosystems to continue to produce many of the goods and services on which we depend is declining. Human activities have significantly disturbed the global water, carbon, and nitrogen cycles on which all life depends. Agriculture, industry, and the spread of human settlements have permanently converted extensive areas of natural habitat and contributed to ecosystem degradation through fragmentation, pollution, and increased incidence of pest attacks, fires, and invasion by nonnative species.

The following paragraphs look across ecosystems to summarize trends in production of the most important goods and services and the outlook for ecosystem productivity in the future.

Food Production

Food production has more than kept pace with global population growth. On average, food supplies are 24 percent higher per person than in 1961 and real prices are 40 percent lower. Production is likely to continue to rise as demand increases in the short to medium term. Long-term productivity, however, is threatened by increasing water scarcity and soil degradation, which is now severe enough to reduce yields on about 16 percent of agricultural land, especially cropland in Africa and Central America and pastures in Africa. Irrigated agriculture, an important component in the productivity gains of the Green Revolution, has contributed to waterlogging and salinization, as well as to the depletion and chemical contamination of surface and groundwater supplies. Widespread use of pesticides on crops has lead to the emergence of many pesticide-resistant pests and pathogens, and intensive livestock production has created problems of manure disposal and water pollution. Food production from marine fisheries has risen sixfold since 1950 but the rate of increase has slowed dramatically as fisheries have been overexploited. More than 70 percent of the world's fishery resources for which there is information are now fully fished or overfished (yields are static or declining). Coastal fisheries are under threat from pollution, development, and degradation of coral reef and mangrove habitats. Future increases in production are expected to come largely from aquaculture.

Water Quantity

Dams, diversions, and other engineering works have transformed the quantity and location of freshwater available for human use and sustaining aquatic ecosystems. Water engineering has profoundly improved living standards, by providing fresh drinking water, water for irrigation, energy, transport, and flood control. In the twentieth century, water withdrawals have risen at more than double the rate of population increase and surface and groundwater sources in many parts of Asia, North Africa, and North America are being depleted. About 70 percent of water is used in irrigation systems where efficiency is often so low that, on average, less than half the water withdrawn reaches crops. On almost every continent, river modification has affected the flow of rivers to the point where some no longer reach the ocean during the dry season. Freshwater wetlands, which store water, reduce flooding, and provide specialized biodiversity habitat, have been reduced by as much as 50 percent worldwide. Currently, almost 40 percent of the world's population experience serious water shortages. Water scarcity is expected to grow dramatically in some regions as competition for water grows between agricultural, urban, and commercial sectors.

Water Quality

Surface water quality has improved with respect to some pollutants in developed countries but water quality in developing countries, especially near urban and industrial areas, has worsened. Water is degraded directly by chemical or nutrient pollution, and indirectly when land use change increases soil erosion or reduces the capacity of ecosystems to filter water. Nutrient runoff from agriculture is a serious problem around the world, resulting in eutrophication and human health hazards in coastal regions, especially in the Mediterranean, Black Sea, and northwestern Gulf of Mexico. Water-borne diseases caused by fecal contamination of water by untreated sewage are a major source of morbidity and mortality in the developing world. Pollution and the introduction of non-native species to freshwater ecosystems have contributed to serious declines in freshwater biodiversity.

Carbon Storage

The world's plants and soil organisms absorb carbon dioxide (CO_2) during photosynthesis and store it in their tissues, which helps to slow the accumulation of CO_2 in the atmosphere and mitigate climate change. Land use change that has increased production of food and other commodities has reduced the net capacity of ecosystems to sequester and store carbon. Carbon-rich grasslands and forests in the temperate zone have been extensively converted to cropland and pasture, which store less carbon per unit area of land. Deforestation is itself a significant source of carbon emissions, because carbon stored in plant tissue is released by burning and accelerated decomposition. Forests currently store about 40 percent of all the carbon held in terrestrial ecosystems. Forests in the northern hemisphere are slowly increasing their storage capacity as they regrow after historic clearance. This gain, however, is more than offset by deforestation in the tropics. Land use change accounts for about 20 percent of anthropogenic carbon emissions to the atmosphere. Globally, forests today are a net source of carbon.

Biodiversity

Biodiversity provides many direct benefits to humans: genetic material for crop and livestock breeding, chemicals for medicines, and raw materials for industry. Diversity of living organisms and the abundance of populations of many species are also critical to maintaining biological services, such as pollination and nutrient cycling. Less tangibly, but no less importantly, diversity in nature is regarded by most people as valuable in its own right, a source of aesthetic pleasure, spiritual solace, beauty, and wonder. Alarming losses in global biodiversity have occurred over the past century. Most are the result of habitat destruction. Forests, grasslands, wetlands, and mangroves have been extensively converted to other uses; only tundra, the Poles, and deep-sea ecosystems have experienced relatively little change. Biodiversity has suffered as agricultural land, which supports far less biodiversity than natural forest, has expanded primarily at the expense of forest areas. Biodiversity is also diminished by intensification, which reduces the area allotted to hedgerows, copses, or wildlife corridors and displaces traditional varieties of seeds with modern high-yielding, but genetically uniform, crops. Pollution, overexploitation, and competition from invasive species represent further threats to biodiversity. Freshwater ecosystems appear to be the most severely degraded overall, with an estimated 20 percent of freshwater fish species becoming extinct, threatened, or endangered in recent decades.

Information Status and Needs

Ecosystem Extent and Land Use Characterization

Available data proved adequate to map approximate ecosystem extent for most regions and to estimate historic change in grassland and forest area by comparing current with potential vegetation cover. PAGE was able to report only on recent changes in ecosystem extent at the global level for forests and agricultural land.

PAGE provides an overview of human modifications to ecosystems through conversion, cultivation, firesetting, fragmentation by roads and dams, and trawling of continental shelves. The study develops a number of indicators that quantify the degree of human modification but more information is needed to document adequately the nature and rate of human modifications to ecosystems. Relevant data at the global level are incomplete and some existing data sets are out of date.

Perhaps the most urgent need is for better information on the spatial distribution of ecosystems and land uses. Remote sensing has greatly enhanced our knowledge of the global extent of vegetation types. Satellite data can provide invaluable information on the spatial pattern and extent of ecosystems, on their physical structure and attributes, and on rates of change in the landscape. However, while gross spatial changes in vegetation extent can be monitored using coarse-resolution satellite data, quantifying land cover change at the national or subnational level requires high-resolution data with a resolution of tens of meters rather than kilometers.

Much of the information that would allow these needs to be met, at both the national and global levels, already exists, but is not yet in the public domain. New remote sensing techniques and improved capabilities to manage complex global data sets mean that a complete satellite-based global picture of the earth could now be made available, although at significant cost. This information would need to be supplemented by extensive ground-truthing, involving additional costs. If sufficient resources were committed, fundamentally important information on ecosystem extent, land cover, and land use patterns around the world could be provided at the level of detail needed for national planning. Such information would also prove invaluable to international environmental conventions, such as those dealing with wetlands, biological diversity, desertification, and climate change, as well as the international agriculture, forest, and fishery research community.

Ecosystem Condition and Capacity to Provide Goods and Services

In contrast to information on spatial extent, data that can be used to analyze ecosystem condition are often unavailable or incomplete. Indicator development is also beset by methodological difficulties. Traditional indicators, for example, those relating to pressures on environments, environmental status, or societal responses (pressure-state-response model indicators) provide only a partial view and reveal little about the underlying capacity of the ecosystem to deliver desired goods and services. Equally, indicators of human modification tell us about changes in land use or biological parameters, but do not necessarily inform us about potentially positive or negative outcomes.

Ecosystem conditions tend to be highly site-specific. Information on rates of soil erosion or species diversity in one area may have little relevance to an apparently similar system a few miles away. It is expensive and challenging to monitor and synthesize site-specific data and present it in a form suitable for national policy and resource management decisions. Finally, even where data are available, scientific understanding of how changes in biological systems will affect goods and services is limited. For example, experimental evidence shows that loss of biological diversity tends to reduce the resilience of a system to perturbations, such as storms, pest outbreaks, or climate change. But scientists are not yet able to quantify how much resilience is lost as a result of the loss of biodiversity in a particular site or how that loss of resilience might affect the long-term provision of goods and services.

Overall, the availability and quality of information tend to match the recognition accorded to various goods and services by markets. Generally good data are available for traded goods, such as grains, fish, meat, and timber products and some of the more basic relevant productivity factors, such as fertilizer application rates, water inputs, and yields. Data on products that are exchanged in informal markets, or consumed directly, are patchy and often modeled. Examples include fish landings from artisanal fisheries, woodfuels, subsistence food crops and livestock, and nonwood forest products. Information on the biological factors that support production of these goods — including size of fish spawning stocks, biomass densities, subsistence food yields, and forest food harvests — are generally absent.

The future capacity (long-term productivity) of ecosystems is influenced by biological processes, such as soil formation, nutrient cycling, pollination, and water purification and cycling. Few of these environmental services have, as yet, been accorded economic value that is recognized in any functioning market. There is a corresponding lack of support for data collection and monitoring. This is changing in the case of carbon storage and cycling. Interest in the possibilities of carbon trading mechanisms has stimulated research and generated much improved data on carbon stores in terrestrial ecosystems and the dimensions of the global carbon cycle. Few comparable data sets exist for elements such as nitrogen or sulfur, despite their fundamental importance in maintaining living systems.

Although the economic value of genetic diversity is growing, information on biodiversity is uniformly poor. Baseline and trend data are largely lacking; only an estimated 15 to 20 percent of the world's species have been identified. The OECD Megascience Forum has launched a new international program to accelerate the identification and cataloging of species around the world. This information will need to be supplemented with improved data on species population trends and the numbers and abundance of invasive species. Developing databases on population trends (and threat status) is likely to be a major challenge, because most countries still need to establish basic monitoring programs.

The PAGE divides the world's ecosystems to examine them at a global scale and think in broad terms about the challenges of managing them sustainably. In reality, ecosystems are linked by countless flows of material and human actions. The PAGE analysis does not make a distinction between natural and managed ecosystems; human intervention affects all ecosystems to some degree. Our aim is to take a first step toward understanding the collective impacts of those interventions on the full range of goods and services that ecosystems provide. We conclude that we lack much of the baseline information necessary to determine ecosystem conditions at a global, regional or, in many instances, even a local scale. We also lack systematic approaches necessary to integrate analyses undertaken at different locations and spatial scales.

Finally, it should be noted that PAGE looks at past trends and current status, but does not try to project future situations where, for example, technological development might increase dramatically the capacity of ecosystems to deliver the goods and services we need. Such considerations were beyond the scope of the study. However, technologies tend to be developed and applied in response to market-related opportunities. A significant challenge is to find those technologies, such as integrated pest management and zero tillage cultivation practices in the case of agriculture, that can simultaneously offer market-related as well as environmental benefits. It has to be recognized, nonetheless, that this type of "win-win" solution may not always be possible. In such cases, we need to understand the nature of the trade-offs we must make when choosing among different combinations of goods and services. At present our knowledge is often insufficient to tell us where and when those trade-offs are occurring and how we might minimize their effects.

Coastal Ecosystems: Executive Summary

Coastal ecosystems, found along continental margins, are regions of remarkable biological productivity and high accessibility. This has made them centers of human activity for millennia. Coastal ecosystems provide a wide array of goods and services: they host the world's primary ports of commerce; they are the primary producers of fish, shellfish, and seaweed for both human and animal consumption; and they are also a considerable source of fertilizer, pharmaceuticals, cosmetics, household products, and construction materials.

Encompassing a broad range of habitat types and harboring a wealth of species and genetic diversity, coastal ecosystems store and cycle nutrients, filter pollutants from inland freshwater systems, and help to protect shorelines from erosion and storms. On the other side of shorelines, oceans play a vital role in regulating global hydrology and climate and they are a major carbon sink and oxygen source because of the high productivity of phytoplankton. The beauty of coastal ecosystems makes them a magnet for the world's population. People gravitate to coastal regions to live as well as for leisure, recreational activities, and tourism.

For purposes of this analysis, the coastal zone has been defined to include the intertidal and subtidal areas on and above the continental shelf (to a depth of 200 meters) and immediately adjacent lands. This definition therefore includes areas that are routinely inundated by saltwater. Because the definition of coastal ecosystems is based on their physical characteristics (their proximity to the coast) rather than a distinct set of biological features, they encompass a much more diverse array of habitats than do the other ecosystems in the Pilot Analysis of Global Ecosystems (PAGE), such as grasslands or forests. Coral reefs, mangroves, tidal wetlands, seagrass beds, barrier islands, estuaries, peat swamps, and a variety of other habitats each provides its own distinct bundle of goods and services and faces somewhat different pressures.

Scope of the Analysis

This study analyzes quantitative and qualitative information and develops selected indicators on the condition of the world's coastal zone, where condition is defined as the current and future capacity of coastal ecosystems to provide the full range of goods and services needed or valued by humans.

In addition to assessing the condition of the different coastal habitats, with the exception of continental slope and deep-sea habitats, the PAGE analysis also includes marine fisheries. The bulk of the world's marine fish harvest—as much as 95 percent, by some estimates—is caught or reared in coastal waters (Sherman 1993:3). Only a small percentage comes from the open ocean.

This study relied on global and regional data sets provided by many organizations, including the United Nations Environment Programme-World Conservation Monitoring Centre (UNEP-WCMC), the Food and Agriculture Organization of the United Nations (FAO), the World Wildlife Fund-US (WWF), IUCN- The World Conservation Union, and others. These global and regional data sets generally focus on a single issue or distinct habitat type, and rarely cover the entire coastal ecosystem. The PAGE analysis also benefited from a variety of national assessments and reviews that provide a wealth of information for certain countries, particularly the United States, Australia, and parts of Europe. These reviews attempt to integrate and summarize the best available information to develop a comprehensive picture of the status of coastal ecosystems. Most of these efforts, however, remain hampered by the limited availability and inconsistencies of the data, and therefore rely heavily upon expert opinion. In addition to these global, regional and national data sets, the PAGE analysis also used case studies from around the world to illustrate important issues, concepts, and trends in the coastal zone.

Because of the lack of global data on coastal habitats, a large part of the efforts in this analysis went into identifying data and information gaps, as well as developing useful, but often proxy, indicators to assess the condition of goods and services derived from coastal ecosystems. Throughout the study the emphasis was placed on quantitative and geographically referenced information.

As mentioned earlier, the coastal zone provides goods and services of immeasurable value to human society. The goods from marine and coastal habitats include food for humans and animals (including fish, shellfish, krill, and seaweed); salt; minerals and oil resources; construction materials (sand, rock, coral, lime, and wood); and biodiversity, including the genetic stock that has potential for various biotechnology and medicinal applications. The services provided by coastal ecosystems are less readily quantified in absolute terms, but are also invaluable to human society and to life on earth. These include shoreline protection (buffering the coastline, protecting it from storms and erosion from wind and waves), storing and cycling nutrients, sustaining biodiversity, maintaining water quality (through filtering and degrading pollutants), and serving as areas for recreation and tourism.

This analysis only considers a subset of goods and services derived from coastal ecosystems. The five categories considered are:

- ♦ Shoreline stabilization;
- ♦ Water quality;
- ♦ Biodiversity;
- ♦ Food production – marine fisheries; and
- ♦ Tourism and recreation.

Other more limited services such as marine transport, including port facilities and channel dredging, are not considered even though marine transport has shaped the development of human history and remains of critical importance today. Likewise, extractive activities, such as the mining of minerals or extraction of oil and construction materials, are not covered.

This study also excludes discussion of the global climate and hydrologic functions of the oceans. Examining these services would be more appropriate in an assessment of the entire marine environment. Activities in the coastal zone only play a small role in the overall volume, carbon storage, and heat storage capacity of oceans. As such, the topic of oceans as climate regulators is beyond the scope of this report.

Key Findings and Information Issues

The following tables summarize the study's key findings regarding the condition of coastal ecosystems and marine fisheries, as well as the quality and availability of the data.

Coastal Zone: Extent and Change

PAGE Measures and Indicators	Data Sources and Comments
Coastal zone extent	Pruett and Cimino 2000, unpublished data. Estimates of coastline length by country calculated from a globally consistent data set (World Vector Shoreline) at a uniform scale of 1:250,000. Other estimates calculated from Global Maritime Boundaries Database (Veridian-MRJ Technology Solutions, 2000).
Characterization of natural features	UNEP-WCMC 1999a and 1999b (coral reefs and mangroves); UNEP-WCMC 1998 (wetlands); NSIDC 1999 (sea ice); LOICZ 1998 (coastal geomorphology); ESRI 1992 and 1993 (river locations); IOC et al. 1997 (coastline location); Stutz et al. 1999; and Stutz 1999, unpublished data (barrier island locations). The typology represents a hierarchical summary of coastal features relevant to the goods and services discussed in this report. Scale and quality of input data vary. This analysis does not directly address climate, currents, or substrate.
Extent of natural habitats	Spalding et al. 1997 (mangroves); Spalding and Grenfell 1997 (coral reefs); UNEP-WCMC 1998 (wetlands); Even though these data sets are incomplete and of varying quality, they provide an indication of the extent of these habitat types around the world.
Loss of natural habitats	Mangrove and coastal wetland loss statistics by country, compiled from multiple sources. The inconsistent habitat classification schemes and the different time periods covered make assessing change difficult.
Natural versus altered land cover within 100 km of coastline	GLCCD 1998. Summary of International Geosphere-Biosphere Programme land cover classes for land areas within 100 km of coastline. The coarse resolution (1km) and the classification scheme which focuses on terrestrial systems does not adequately capture the complexity of the coastal zone, but provides an indicator of the modification of coastal habitats.
Human population within 100 km of coastline	CIESEN et al. 2000. The original data sources are national population censuses by administrative district. Year of census and resolution vary. Estimates are standardized for 1990 and 1995.
Disturbance to benthic community—distribution of trawling grounds	Partial global summary of trawling grounds in 24 countries by McAllister et al. (1999) executed for this study. Does not show the intensity of trawling within each area.

Conditions and Trends

- In 1995, over 2.2 billion people —39 percent of the world's population— lived within 100 km of a coast, an increase from 2 billion people in 1990. The coastal area accounts for only 20 percent of all land area.
- Nineteen percent of all lands within 100 km of the coast (excluding Antarctica and water bodies) are classified as altered, meaning they are in agricultural or urban uses; 10 percent are semialtered, involving a mosaic of natural and altered vegetation; and 71 percent fall within the least modified category. A large percentage of this least modified category includes many uninhabited areas in northern latitudes.
- Many important coastal habitats, such as mangroves, wetlands, seagrasses, and coral reefs, are disappearing at a fast pace. Anywhere from 5 to 80 percent of original mangrove area in various countries, where such data are available, is believed to have been lost. Extensive losses have occurred particularly in the last 50 years.
- In the 24 countries for which sufficient data were available, trawling grounds encompass 8.8 million km^2, of which about 5.2 million km^2 are located on the continental shelves. This represents about 57 percent of the total continental shelf area of these countries.
- Though highly scale dependent, this analysis presents a new standardized estimate of coastline length by country. The associated total coastline length for the world is 1.6 million kilometers. This study also presents new estimates of ocean surface area within the 200 nautical miles limits of most countries.

Information Status and Needs

- Information on the location and extent of coastal ecosystems is very incomplete and inconsistent at the global level.
- Historical data describing previous extent of habitats, against which we might hope to measure change, are very limited. Where no historical data exist, the possibility of predictive mapping should be considered, using existing climatic, oceanographic, and topographic data combined with biogeographic information.
- There is an urgent need for better and more consistent classification schemes and data sets characterizing the world's coasts. Particular effort needs to be focussed on mapping the distribution of sandy and rocky shores, salt marshes, seagrasses, tidal mudflats, and lagoons.
- Coastal habitats occur over relatively small spatial units, are often submerged, and are, therefore, difficult to assess with the coarse-scale global sensors often used for other terrestrial ecosystems. High-resolution remote sensing capabilities in this area are improving rapidly, but are not yet being widely applied.
- The effects of human disturbances to ecosystems, such as trawling, are poorly documented. More accurate evaluation of impacts will require higher resolution data as well as site exploration.

Shoreline Stabilization

PAGE Measures and Indicators	**Data Sources and Comments**
Natural versus altered land cover within 100 km of coastline	GLCCD 1998. Rough indicator of the likelihood of natural shoreline replaced by artificial structures.
Beach area/profile	Cambers 1997. Measured beach erosion/accretion data available for a limited number of countries, with inconsistent time and area coverage.
Severity and impact of natural hazards	Only case studies available. Mostly measured in monetary units and of limited value for comparisons.
Vulnerability to erosion and coastal hazard	Physical vulnerability was estimated by characterization of natural features. (*See section on Extent and Change.*) Level of development was based on population density (CIESIN et al. 2000).
Low-lying areas	USGS 1996 (elevation data). Based upon a coarse-scale (approximately 1 km grid resolution) data set reflecting elevation for the globe, we identified land areas less than one, and between one and two meters elevation. Local hydraulic and geophysical factors, such as subsidence, tectonic uplift, tides, and storms, are not taken into account because of the lack of data.

Conditions and Trends

- Human modification of the shoreline has altered currents and sediment delivery, enhancing coastlines in some areas and starving beaches in others.
- Coastal habitats with natural buffering and adaptation capacities are being modified by development and replaced by artificial structures. Thus, in monetary terms, the damage from storm surges has increased.
- Increasing development in coastal areas is placing more population, infrastructure, and associated economic investments at risk.
- Rising sea levels projected as a result of global warming may threaten some coastal settlements and small island-states.

Information Status and Needs

- The function of shoreline stabilization provided by many natural coastal features is not well documented quantitatively.
- Data on conversion of coastal habitat and shoreline erosion are inadequate.
- No comprehensive data are available to assess shoreline change or sediment flows.
- Because of the dynamic character of the natural processes acting upon the shoreline, and because humans have often responded in an equally dramatic way, it is difficult to distinguish natural from human-induced changes.
- Information on long-term effects of human modifications on shorelines is lacking.
- Nonmonetary measures of severity and damage from natural hazards are anecdotal.
- Sea level rise and storm effects resulting from climate change are speculative.

Water Quality

PAGE MEASURES AND INDICATORS	DATA SOURCES AND COMMENTS
Eutrophication parameters	Bricker et al. 1999 (U.S. data only). Data have incomplete temporal coverage in some areas and are insufficient in detecting clear trends. Similar data are available for other developed countries but were not used in this study.
Harmful algal blooms (HABs) events	HEED 1999. Compiled from reported public health events, as well as mortality and morbidity events for marine organisms. The data do not show the magnitude of each event. In general, there are limited ground-based monitoring initiatives with regular data collection on HABs events around the world.
Global occurrence of hypoxic zones	Diaz and Rosenberg 1995; Diaz 1999. Occurrences are compiled from literature and therefore may be biased toward areas where better reporting mechanisms exist. Most observations are from industrialized countries. The data do not include the duration and size of each event.
Shellfish bed closures	NOAA 1997 (U.S. data only). There is insufficient data coverage for temporal trend analysis and, often, inconsistent criteria for bed closures. Various country programs exist, mostly in developed countries, but the data are not comparable.
Beach closures	NRDC 1998; FEEE 2000. Various local monitoring programs exist, but no comprehensive data are available. A standardized guideline for monitoring recreational water quality is being developed by the World Health Organization.
Beach tar balls	JODC 1999 (Japanese data only). Few of the reported observations show the magnitude of contamination (i.e., size and concentration). Various country and regional monitoring programs exist, but the data are not harmonized and are not complete for all countries and years.
Persistent organic pollutants (POPs) and heavy metal accumulation in marine organisms	NOAA 1999a (U.S. data only). Mussel Watch-type programs that monitor accumulation of heavy metals and POPs exist in other countries, but were not considered in this analysis.
Oil spills (frequency and volume)	ITOPF 1998. The data presented here only include *accidental* spills over 7 tonnes in quantity. The extensive ITOPF database contains information on both the spill (amount and type of oil spilt, cause, and location) and the vessel involved. Data are compiled from published sources as well as from vessel owners and their insurers. Reporting of small operational spillages is incomplete.
Solid waste accumulation on beaches	Center for Marine Conservation 1998. Data are based on coastal cleanup surveys that include parts of 75 countries worldwide. The information, however, is incomplete on the frequency of the cleanup and the area covered.

CONDITIONS AND TRENDS

- Although some industrial countries have improved coastal water quality by reducing input of certain persistent organic pollutants, chemical pollutant discharges are increasing overall as agriculture intensifies and new synthetic compounds are developed.
- As the extent of mangroves, coastal wetlands, and seagrasses declines, coastal habitats are losing their pollutant-filtering capacity.
- On a global basis, nutrient inputs to coastal waters seem to be increasing because of population increase and agricultural intensification.
- Over the past two decades, the frequency of recorded HABs resulting in mass mortality and morbidity of marine organisms has increased significantly.
- Globally reported occurrences of hypoxia indicate that some coastal ecosystems have exceeded their ability to absorb nutrients.
- Although large-scale marine oil spills are declining, oil discharges from land-based sources and regular shipping operations are believed to be increasing.

INFORMATION STATUS AND NEEDS

- Global data on extent and change of key coastal habitats, such as wetlands and seagrasses, are not available.
- Many national and regional monitoring programs exist for a variety of pollutants, but the completeness and accuracy of data collected varies. Standardized sampling methodologies and parameters are necessary for making comparisons on a global basis.
- Increased direct monitoring of water quality parameters, coupled with using satellite sensors, can greatly improve our knowledge of the condition of the world's coastal waters.
- Current information relies heavily on anecdotal observations of extreme events, such as HABs, and not on continuous monitoring.
- More than 70,000 synthetic chemicals have been discharged into the ocean, and only a small percentage of these have been monitored—typically by human health standards, and not by ecological impact.
- Runoff and routine maintenance of oil infrastructure are estimated to account for more than 70 percent of the total annual oil discharge into the ocean, but actual data regarding such nonpoint sources are not available.

Biodiversity

PAGE Measures and Indicators	Data Sources and Comments
Species richness	Littoral community: Groombridge and Jenkins 1996 (diversity of seabirds, marine turtles, seals, and sea lions by region); Spalding 1998 (mangroves); UNEP-WCMC 1999c (distribution and species richness of marine turtles); UNEP-WCMC 1999d (pinnipeds, unpublished data prepared for this study). Information on species richness is only available for some better-known species groups. Continental shelves: Groombridge and Jenkins 1996 (diversity of seagrasses, molluscs, shrimp, lobsters, sharks, and cetaceans); Veron 1995 (corals). The data are limited to better-documented species.
Conservation values	Olson and Dinerstein 1998; Sullivan Sealey and Bustamante 1999; UNEP-WCMC 1999 (marine protected areas); CI 2000. Criteria for evaluation of conservation value, designation of the status, and degree of protection are highly varied.
Threatened species	IUCN 1996. Global list developed through field observation and expert judgment. Application of the criteria for threatened status to littoral and marine species requires further evaluation.
Habitat degradation—coral bleaching	NOAA-NESDIS and UNEP-WCMC 1999, unpublished data. Data on observations of coral bleaching were compiled from multiple sources.
Threats to habitat	Coral reefs: ICLARM 1999. Observed impacts of pollution, sedimentation, and destructive fishing practices on coral reefs. Littoral zone: Evans 1994 (Important Bird Areas). The criteria for ranking the level of threat are qualitative and rely on expert opinion.
Threats to ecosystem structure	Invasive species data compiled from multiple sources. There are no global data sets on introduced species, although comprehensive data are available for some countries and regions.

Conditions and Trends

- Coastal habitats that serve as nurseries for many species are disappearing at an alarming rate. Human modification and disturbance to those habitats are widespread.
- Growth in the number of marine protected areas over the last century indicates increased awareness toward protecting the coastal environment although methods and degree of protection vary greatly among countries.
- Over 25 different coral diseases or variants are recorded in over 50 countries worldwide and the vast majority of records are from the 1970s onward. Reports of coral bleaching have also increased significantly in recent years.
- Even some commercial fish species, such as Atlantic Cod, five species of tuna, and haddock are now threatened globally, as are several species of whales, seals, and sea turtles.
- Invasive species are frequently reported in enclosed seas, such as the Black Sea, where the introduction of the Atlantic comb jellyfish caused the collapse of the thriving anchovy fishery.

Information Status and Needs

- Information on the distribution of remaining natural coastal habitats is only available for some areas. Detailed maps are particularly lacking for submerged habitats, such as seagrasses, coral reefs, salt marshes, and tidal mudflats.
- Loss of coastal habitats (such as mangroves or wetlands) is reported in many parts of the world, but little is documented quantitatively.
- Species diversity is not well inventoried and population assessments are only available for some keystone species, such as sea turtles and whales.
- Available information on the distribution of species needs to be consolidated and integrated with information on habitat distribution.
- Information on invasive species is limited because of difficulties in identifying and inventorying them. Assessing their impact on the native ecosystem is also necessary but currently lacking.
- Limited information is available on the condition of ecosystems at the habitat level. For example, anecdotal observations are available for the world's coral reefs, reflecting coral bleaching, disease, and human impacts, but little data have been compiled on coral condition, such as change in live coral cover.
- Indicators of change in ecosystem structure have not been fully explored.

Food Production — Marine Fisheries

PAGE MEASURES AND INDICATORS	DATA SOURCES AND COMMENTS
Analysis of the condition of fish stocks	Grainger and Garcia 1996 and Garcia and De Leiva Moreno 2000. Analyses include stock assessments covering the period 1950–1994 for the top 200 commercial fisheries, and assessments of 441 fish stocks covering the period 1974–1999.
Commercial harvest of important fish stocks	FAO 1999e. Data refer to marine fisheries production for selected species in the Northwest Atlantic.
Percentage change in catch from the peak year	FAO 1999e and 1999f. Current catch figures for each FAO fishing area were compared to historical peak catches for that same area.
Change in trophic composition of fish catch	Analysis conducted by Caddy, Garibaldi, and Grainger (1999) at FAO Fisheries Department for this study. The analysis uses three indicators to assess the change in species composition of the catch in each FAO fishing area, with the exclusion of the Arctic and Antarctic. The three indicators are: a. sum of catches for the top five species in each of four trophic categories over the 1950–97 period; b. trend relationship between the piscivores and zooplanktivores catches; and c. percentage of catches of the different trophic levels early (1950–54) and late (l993–97) in the series.

CONDITIONS AND TRENDS

- Global marine fish production has increased sixfold since 1950, but the rate of increase annually for fish caught in the wild has slowed from 6 percent in the 1950s and 1960s to 0.6 percent in 1995–96.
- In 1997, fish and shellfish provided 16.5 percent of the total *animal* protein consumed by humans worldwide. Of the 30 countries most dependent on fish as a protein source, all but 4 are in the developing world.
- The capacity of coastal and marine ecosystems to produce fish for human harvest is highly degraded by overfishing, destructive trawling techniques, and loss of coastal nursery areas.
- Seventy-five percent of all fish stocks for which information is available are in urgent need of better management. Twenty-eight percent are already depleted from past overfishing or in imminent danger of depletion from current overharvesting, and forty-seven percent are being fished at their biological limit and therefore vulnerable to depletion if fishing intensity increases.
- The percentage catch of low-value species in the harvest has risen, as the catch from higher-value species has plateaued or declined, masking some effects of overfishing. This change in the piscivore/zooplanktivore ratio provides some evidence of likely ecosystem change.
- Notable ecosystem changes have occurred over the last half century in some fishery areas, such as the North Atlantic and Northeast Pacific.
- Some of the recent increase in the marine fish harvest comes from aquaculture, which has more than doubled in production since 1990.
- Worldwide, some 30 to 40 percent more harvest capacity exists than the resource can withstand.
- Bycatch levels are also high. FAO estimates the amount of fish discarded at about 20 million metric tons per year. This figure is the equivalent of about 25% of the reported annual production from marine capture fisheries.
- Expansion of oceanic fisheries still continues, with a start now being made at exploitation of deep-water resources, which to date are relatively unprotected by international agreements and regulations.

INFORMATION STATUS AND NEEDS

- FAO fisheries production statistics are limited to providing proximate information on *commercial* fish population trends and are, therefore, insufficient to assess the capacity of coastal and marine ecosystems to provide food.
- The FAO database on marine fisheries landings is the most complete data set at the global level; however it has important limitations. Some of the main problems are that much of the catch is not reported at the species level, particularly in the Indian Ocean and Central Pacific, and the subsistence and small-scale fisheries sector is underrepresented in the data collection efforts.
- Catch statistics are also biased as a result of unreported discarding, misreporting of harvests, and exclusion of all information on illegal fishing.
- Data are fragmentary on how many boats are deployed, and how much time is spent fishing, which obscures the full impact of fishing on ecosystems.
- No comprehensive data are available for average fish size, which would help in the assessment of the condition of particular fish populations.
- More extensive stock assessments are necessary to identify Maximum Sustainable Yield (MSY) for various commercially important species.

Tourism and Recreation

PAGE Measures and Indicators	Data Sources and Comments
Value of tourism and employment in the tourism sector	WTTC 1999. Value of tourism is estimated in terms of dollars per year, and employment in terms of jobs in the sector. Statistics are not specific to *coastal* tourism, but to tourism in general.
Importance of tourism to the economy	CTO 1997 (Caribbean data only). Data are expressed in dollars as a percent of gross domestic product (GDP) and number of jobs in the tourism sector as percent of total employment.
Tourist arrivals	CTO 1997 (Caribbean data only).
Equitable distribution of tourism benefit—leakage of tourism revenue	Smith and Jenner1992; Wells 1997. Percentage of gross tourism receipts collected by non-local service providers.

Conditions and Trends

- The travel and tourism industry is the fastest growing sector of the global economy. It is estimated to have generated US$3.5 trillion and almost 200 million jobs globally in 1999. Coastal tourism is a major portion of the gross domestic product in many small island nations.
- Impacts of tourism on the environment are generally local and extremely diverse. Impacts depend upon the local environment, size and growth rate of the tourism sector, and nature of the tourism facilities involved.
- The tourist trade has degraded some areas, but global evidence is insufficient to judge the aggregate capacity of coastal areas to support tourism. As coastal areas are degraded, however, the types of tourism supported can become more limited.
- The degree to which a local economy benefits from tourism varies tremendously, depending on the habitat (resource), ownership and investments, and management of the tourism activities.
- Currently, 21 European countries participate in the Blue Flag Campaign, a certification program for “sustainable” tourism. In 2000, 1,873 beaches and 652 marinas were awarded the Blue Flag, a dramatic increase over a decade, indicating heightened interest from tourist facilities in adopting more efficient and environmentally sound practices.

Information Status and Needs

- Not all countries report tourism statistics, and typically, only national data on tourism are available, rather than data specific to the coastal zone.
- Comprehensive information on the environmental and socioeconomic impacts of tourism is not available or is documented only qualitatively.
- No standard measure of tourism intensity exists.
- Information on the benefit of tourism to the local economy is very limited.
- Marine protected areas and tourism certification programs could help in collecting useful information on the value of nature-based tourism and the degree of benefits and impacts of overall tourism development to the local people and economy.
- A few tourism certification programs with varied criteria exist but no comprehensive data are available.
- The importance of assessing local capacity to physically and socially accommodate tourism development has been acknowledged. However, no standard indicator to measure this capacity has been developed.

Conclusions

Along with direct loss of area, a variety of other factors are significantly altering coastal ecosystems around the world. Some of the major pressures are population growth, pollution, overharvesting and destructive fishing practices, and the looming threat of climate change.

Globally, the number of people living within 100 km of the coast increased from roughly 2 billion in 1990 to 2.2 billion in 1995—39 percent of the world's population. However, the number of people whose activities affect coastal ecosystems is much larger than the actual coastal population because rivers deliver pollutants from inland watersheds and populations to estuaries and surrounding coastal waters. As coastal and inland populations continue to grow, their impacts—in terms of pollutant loads and the development and conversion of coastal habitats—can be expected to grow as well.

An increasing number of pollutants affect the world's coasts and oceans. Most pollution of coastal waters comes from the land, but atmospheric sources and marine-based sources such as oil leaks and spills from vessels also play a role. Nutrient pollution, especially nitrates and phosphates, has increased dramatically this century. Greater use of fertilizers, growth in quantities of domestic and industrial sewage, and increased aquaculture, which releases considerable amounts of waste directly into the water, are all contributing factors (GESAMP 1990:96).

In terms of food production, forty-five years of increasing fishing pressure have left many major fish stocks depleted or in decline. The scale of the global fishing enterprise has grown rapidly and exploitation of fish stocks has followed a predictable pattern, progressing from region to region across the world's oceans. As each area in turn reaches its maximum production level, it then begins to decline (Grainger and Garcia 1996:8, 42–44). Overexploitation of fish, shellfish, seaweeds, and other marine organisms not only diminishes production of the harvested species but can profoundly alter species composition and the biological structure of coastal ecosystems.

Global climate change may compound other pressures on coastal ecosystems through the additional effects of warmer ocean temperatures, altered ocean circulation patterns, changing storm frequency, and rising sea levels. Changing concentrations of CO_2 in ocean waters may also affect marine productivity or even change the rate of coral calcification (Kleypas et al. 1999). Rising sea level, associated with climate change, is likely to affect virtually all of the world's coasts. During the past century, sea level has risen at a rate of 1.0–2.5 mm per year (IPCC 1996:296). Rising sea levels will also increase the impact of storm surges. This, in turn, could accelerate erosion and associated habitat loss, increase salinity in estuaries and freshwater aquifers, alter tidal ranges, change sediment and nutrient transport, and increase coastal flooding.

Because of the current pressures on coastal ecosystems, and the immense value of the goods and services derived from them, there is an increasing need to evaluate tradeoffs between different activities that may be proposed for a particular coastal area. However, to integrate this evaluation into the decisionmaking process, better information on the location, extent, and change in coastal habitats is urgently needed. Information regarding the interaction between ocean, land, and atmosphere is also a key to understanding the functions of the coastal zone but so far most of the information is anecdotal or fragmentary. One factor contributing to this lack of information is the partitioning of disciplines into separate entities. Terrestrial ecology, wetland ecology, and marine ecology are, for example, distinct fields among the biological sciences. The separation between these and the physical, chemical, and social sciences is even greater, making it difficult to conduct a more integrated analysis.

The problems affecting the coastal zone are cross-sectoral and complex. Collaboration among climatologists, ecologists, ocean chemists, toxicologists, soil scientists, statisticians, coastal engineers, economists, and practitioners of monitoring and information technology will be needed to develop the information base and linkages necessary to fully assess the condition of the world's coastal environments.

Recommendations for the Millennium Ecosystem Assessment include the following:

- There is an urgent need to fully utilize existing information on location and extent of coastal habitats. Standardized classification schemes characterizing the world's coasts need to be developed. Amalgamating and harmonizing existing maps and chart series into global data sets based on such classification schemes, combined with the use of high-resolution remote sensing imagery, could more directly assess gaps in knowledge on the location and extent of coastal habitats. Particular efforts need to be directed toward submerged habitats.
- Further descriptive information about the distribution and status of marine and coastal biodiversity is a priority. Basic inventory of coastal and marine species by habitat type is fundamental to subsequent research, management, and conservation. Work needs to include basic taxonomy and species inventory, but also analysis of community structure, ecosystem function, and habitat distribution.
- Identifying and describing areas of high conservation importance at species and ecosystem levels would help improve the effectiveness of conservation activities. Further research into the patterns of interlinkage and energy flow between marine ecosystems is also critical if such high priority areas are to maintain their ecological integrity.

- Compilation of historic or baseline data against which we may measure the condition of ecosystems is a prerequisite for any assessment of current status. Localized baseline data and the identification of thresholds are particularly important for water quality. In order for the condition indicators to be useful as early warning systems, it is important to distinguish between human caused anomalies and natural fluctuations in the system.
- Causal relationships in biological, chemical, and physical systems are also poorly understood, and in the coastal realm are particularly complex and varied. Our predictive capabilities are limited when we attempt to examine how certain threats affect an environment, such as the introduction of nonnative species. Understanding links between pressure and condition would improve our assessment of future trends and human activities that may have profound implications for coastal habitats and biodiversity.
- In many cases, combining the use of low, medium, and high-resolution satellite imagery will be vital to calibrating data and refining observations for conditions in nearshore and surface waters. Satellite data will be useful for habitat mapping, estimating turbidity and organic pollutant discharge, identifying sediment plumes, monitoring the occurrence and extent of algal blooms, mapping the occurrence and extent of oil spills, and monitoring thermal pollution and sea surface temperature anomalies. At the same time, other more direct methods need to be developed to map and monitor the status of the continental shelf, which lies below the shallow layers visible from satellites.
- More integration and collaboration among the various agencies working in the coastal zone, particularly with the different monitoring initiatives, such as the Global Ocean Observing System (GOOS) should be encouraged (GOOS Project Office 1998 and 1999; Summerhayes, personal communication, 1999). Such organizations include the United Nations Environment Programme (UNEP), the Intergovernmental Oceanographic Commission (IOC), the United Nations Educational, Scientific, and Cultural Organization (UNESCO), the United Nations Development Programme (UNDP), the Food and Agriculture Organization of the United Nations (FAO), the International Geosphere-Biosphere Programme (IGBP), nongovernmental organizations, and academic centers.
- There is a need to better understand, evaluate and monitor the goods and services provided by coastal and marine ecosystems.
- Governments and nongovernmental organizations are encouraged to develop techniques for engaging policymakers and civil society so they can evaluate tradeoffs and make decisions with greater understanding and awareness of the consequences.

Coastal Zone: Extent and Change

Working Definition of Coastal Zone

There is no single definition of the coastal zone. Some authors have referred to it as "that part of the land most affected by its proximity to the sea and that part of the ocean most affected by its proximity to the land" (Hinrichsen 1998:2). The PAGE study defined coastal regions to be the intertidal and subtidal areas on and above the continental shelf (to a depth of 200 meters)—areas routinely inundated by saltwater—and immediately adjacent lands. This study also included consideration of marine fisheries, because 90 percent of the world capture fisheries come from the marine environment (FAO 1999a:3) and "nearly two-thirds of all fish harvested depend upon coastal wetlands, seagrasses, and coral reefs for various stages in their life cycles" (Hinrichsen 1998:18). This study does not include continental slope or deep-sea habitats. Therefore, important oceanic features, such as ocean vents, seamounts, and even the highly diverse faunas currently being described from the ocean benthos, are excluded.

Because the world's coastal regions are subdivided by physical rather than biological characteristics, they include a wide array of near-shore terrestrial, intertidal, benthic, and pelagic marine environments. Examples of such communities are shown below. *(See Table 1.)*

Such diverse habitats often coexist and are dynamic systems; therefore, it is difficult to identify exact locations and extent, or delineate clear boundaries between them.

Table 1
Coastal Environments

Near-shore terrestrial	**Dunes, cliffs, rocky and sandy shores, coastal xeromorphic habitats, urban, industrial and agricultural landscapes**
Intertidal	**Estuaries, deltas, lagoons, mangrove forests, mudflats, salt marshes, salt pans, other coastal wetlands, ports and marinas, aquaculture beds**
Benthic	**Kelp forests, seagrass beds, coral reefs, and soft bottom environments above the continental shelf, artificial reefs and structures**
Pelagic	**Open waters above the continental shelf, freestanding fish farms: e.g. plankton blooms, neuston zone, sea ice herring schools**

Box 1

Maritime Areas Definitions

The United Nations Convention on the Law of the Sea (UNCLOS) is an international agreement that sets conditions and limits on the use and exploitation of the world's oceans. This convention also rules on how the maritime jurisdictional boundaries of member states are set. UNCLOS defines territorial sea as the 12-nautical-mile zone from the baseline or low-water line along the coast, on which the coastal state has sovereignty. Even though the established maximum limit for a territorial sea is 12 nautical miles, some countries claim larger areas. A country's Exclusive Economic Zone (EEZ), as established by UNCLOS, extends from the baseline out beyond the territorial sea, up to a width of 200 nautical miles. In cases where countries' baselines are within 400 nautical miles of each other, the EEZ boundaries are generally established by treaty, although there are many cases where these are in dispute. Moreover, many states have yet to sign or ratify UNCLOS, while still others have yet to claim their EEZ. Where claimed and undisputed, a coastal country has certain sovereign rights over the EEZ, namely, rights to exploration, exploitation, conservation, and management of all natural resources of the seabed, its subsoil, and the overlying waters (Baretta-Bekker et al. 1998:118). Some countries have claimed an exclusive fishing zone instead of the more encompassing EEZ. The exclusive fishing zone, in these cases, refers to an area beyond the outer limit of the territorial sea in which the coastal state has the right to fish, subject to any concessions that may be granted to foreign fishermen. The territorial sea and the EEZ or the fishing zone, depending on which has been claimed, comprise what is defined as the total potential maritime area of a country—that is, the total marine surface area (claimed or unclaimed) within 200 nautical miles from the coast. The maritime area definition only applies to marine areas that are not currently under dispute. Given the uncertainties surrounding much of the delimitation of the EEZ, any maps and statistics portraying these boundaries are subject to certain limitations and should be treated with caution.

In contrast to the territorial sea and EEZ, which are essentially political boundaries, the coastline and continental shelf area are delineations based on a natural feature. Coastal length is a frequently cited statistic to indicate the importance of coastal zone to a country. However, its measurement is fraught with difficulty. The main problem is that the measurement of an irregular and curving feature is scale-dependent. Maps of individual islands, for example, frequently show great detail, whereas regional maps summarize complex coastlines into a few simple lines. Coastline lengths are also affected by inclusion or exclusion of coastal features such as bays, lagoons, and river mouths. More detailed maps will, thus, result in longer estimates. For the PAGE analysis, coastline lengths were summarized from a globally consistent data set—the 1:250,000 scale World Vector Shoreline. *(See Table 2.)* Although the estimates presented here can differ significantly from previously published sources, it should be noted that this is the first time such statistics have been developed from a globally consistent source.

Estimating Area and Length of Coastal Zone

To get a rough indicator and a better understanding of the relative size and distribution of coastal areas, this study calculated the spatial extent of coastal zone and maritime areas within national jurisdiction (up to 200 nautical miles from the coastline), such as territorial seas and exclusive economic zones. Although these are not ecologically oriented statistics, jurisdiction over resources has significant implications for governance and effective management of coastal and marine resources *(see Box 1)*. Furthermore, this analysis presents statistics compiled for the first time from a new, globally consistent source.

Table 2 presents coastal zone statistics for selected countries.

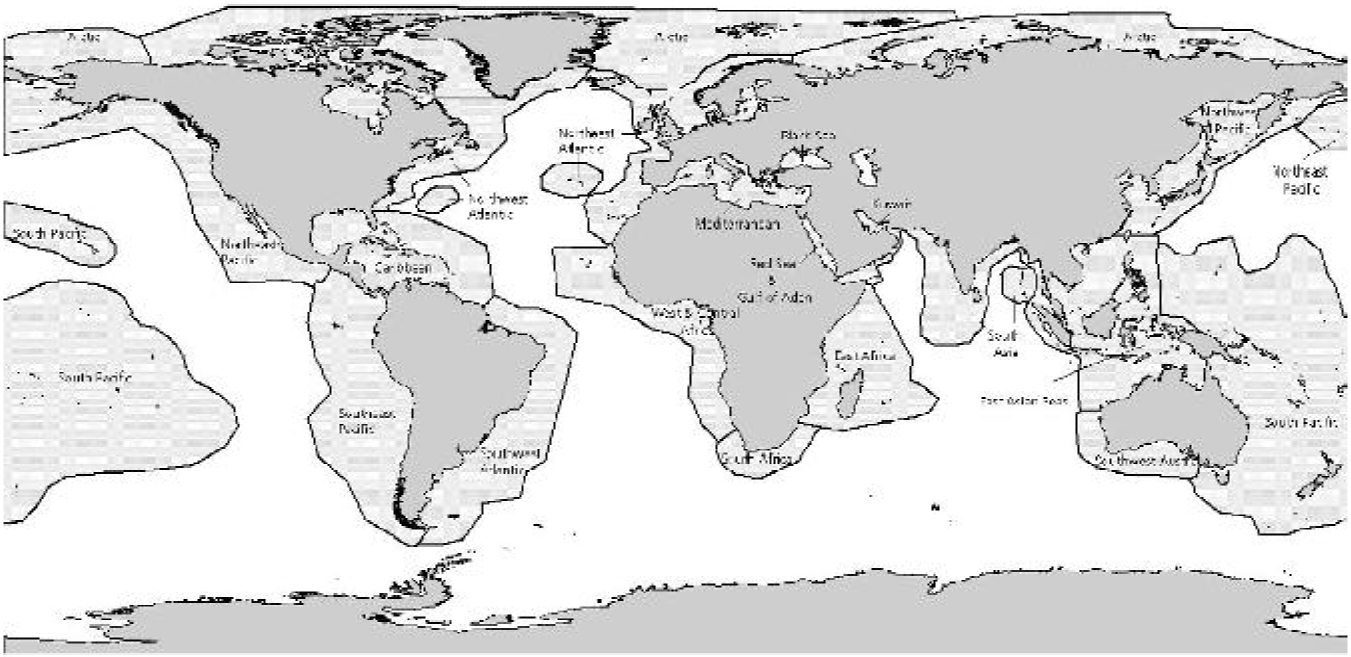
Characterizing the Natural Coastal Features

The habitats and features along the world's coastline are highly varied—from the flat, coastal plains of Argentina, to the mangrove and coral reef-lined shores of Sulawesi, to the rugged, rocky coastline of Norway. The descriptive attributes of coasts provide baseline information and reference points for assessing the condition of the ecosystem's goods and services. They also are a major factor in the vulnerability and resilience of an area to a particular pressure. The extent and loss of these natural habitat types serve as a proxy condition indicator for many of the ecosystem services and values that are otherwise difficult to quantify.

This study's examination of the world's shoreline begins with an exploration of some of the natural characteristics of tidal and near-shore areas. The characterization of the world's shoreline is based upon the occurrence of certain habitats, such as coral reefs, mangroves, other tidal wetlands, barrier islands,

Figure 1

UNEP Regional Seas



Source: Groombridge and Jenkins, 1996; modified at WRI.
Projection: Geographic

estuaries, and sea ice. It also integrates information on continental shelf width and the slope of nearby terrestrial areas. The analysis is implemented at 1-kilometer resolution. The following hierarchical classification scheme is used to simplify the classification of complex ecosystems and overlapping habitat types.

1. Areas where sea ice occurs are classified as such.
2. Areas where mangroves are present, areas that are within 10 km of a coral reef, and areas where both habitat types overlap are classified as “mangroves/coral reefs”.
3. Areas where coastal wetlands occur are classified as such.
4. Areas where barrier islands occur are classified as such.
5. Areas including any combination of the following four habitat types: freshwater and marine interface, wetlands, barrier islands, and river deltas are classified as Wetland/Estuary/BI Systems.
6. Areas not classified in any of the above classes are classified according to the coastal morphology and shelf width categorization from the Land-Ocean Interactions in the Coastal Zone (LOICZ). This classification includes categories such as: mountainous narrow shelf, narrow shelf plains, etc.
7. Some areas remain unclassified.

This characterization, presented in Table 3, is admittedly a gross simplification of the highly varied coastal environments of the world and it does not directly address climate, currents, or substrate. More complex or detailed characterizations are possible and should be explored at national or regional scales. The hierarchy was determined based on both the quality of the data sets and the importance of these habitats for the goods and services examined later in the report.

Table 3 presents summary statistics based on this coastal characterization for regions of the world as defined by UNEP’s Regional Seas Program (Groombridge and Jenkins 1996, *see Figure 1*). In this study, UNEP’s Regional Seas were modified slightly by dividing the North Atlantic Region between Iceland and Greenland, into northeast Atlantic and northwest Atlantic.

Map 1 shows a simplified version of the coastal characterization presented above. The generalized categories include sea ice, wetlands/estuaries/deltas, barrier islands and BI systems (where some habitat types may overlap), mangroves/coral reefs, hilly narrow shelf, narrow and wide shelf plains, hilly wide shelf, and mountainous narrow shelf.

As Map 1 shows, the world’s coastlines are quite diverse in terms of physiographical characteristics. A mountainous, narrow shelf and some estuarine systems dominate the Mediterranean coastline, coral reefs and mangroves are predominant in the Middle East and Insular Southeast Asia, while East Africa has a varied coastline with coral reefs, mangroves, and coastal plains along a narrow shelf.

Table 2

Coastal Zone Statistics by Country

	Coastal Length {a} (km)	Area of Continental Shelf (up to 200 m depth) (000 km²)		Territorial Sea (up to 12 nm) (000 km²)		Claimed Exclusive Economic Zone (000 km²)	Exclusive Fishing Zone (000 km²)	Total Potential Maritime Area (000 km²)	Population Within 100 km from the Coast (percent)
WORLD	1,634,701	24,287.1		18,816.9	b	102,108.4	12,885.2	X	39.0
ASIA (EXCL. MIDDLE EAST)	288,459	5,515.4		5,730.9		11,844.2	249.5	X	X
Azerbaijan {c}	871	78.0		X		X	X	X	55.7
Bangladesh	3,306	59.6		40.3		39.9	X	80	54.8
Cambodia	1,127	34.6		19.9		X	X	35	23.8
China	30,017	810.4	d	348.1		X	X	847	24.0
Georgia	376	2.7		6.1		18.9	X	25	38.8
India	17,181	372.4		193.8		2,103.4	X	2,297	26.3
Indonesia	95,181	1,847.7		3,205.7		2,915.0	X	6,121	95.9
Japan	29,020	304.2		373.8		3,648.4	X	4,022	96.3
Kazakhstan {c}	4,528	139.1		X		X	X	X	3.6
Korea, Dem People's Rep	4,009	26.3		12.7		72.8	X	86	92.9
Korea, Rep	12,478	226.3		81.1		202.6	X	284	100.0
Malaysia	9,323	335.9		152.4		198.2	X	351	98.0
Myanmar	14,708	216.4		154.8		358.5	X	514	49.0
Pakistan	2,599	43.7		31.4		201.5	X	233	9.1
Philippines	33,900	244.5		679.8		293.8	X	974	100.0
Singapore	268	0.7		0.7		X	0.7	2	100.0
Sri Lanka	2,825	19.2		30.5		500.8	X	531	100.0
Thailand	7,066	185.4		75.9		176.5	X	252	38.7
Turkmenistan {c}	1,289	72.4		X		X	X	X	8.1
Uzbekistan	1,707	26.1		X		X	X	X	2.6
Viet Nam	11,409	352.4		158.6		237.8	X	396	82.8
EUROPE	325,892	6,316.0		2,589.4		11,447.1	1,783.0	X	X
Albania	649	6.1	d	6.2		X	6.2	13	97.1
Belgium	76	3.6		1.5		X	2.1	4	83.0
Bosnia and Herzegovina	23	0.0		X		X	X	X	46.6
Bulgaria	457	10.9		6.5		25.7	X	32	29.2
Croatia	5,663	44.9	d	31.7		X	X	55	37.9
Denmark {e}	5,316	102.4		24.8		80.4	X	105	100.0
Estonia	2,956	36.2		24.3		11.6	X	36	85.9
Finland	31,119	82.5	d	55.1		X	55.1	110	72.8
France	7,330	160.7		73.4		706.4	73.4	853	39.6
Germany	3,624	55.5		18.4		37.4	X	56	14.6
Greece	15,147	94.3	d	114.9		X	114.9	494	99.2
Iceland	8,506	108.7		73.0		678.7	X	752	99.9
Ireland	6,437	151.9		39.4		X	358.9	398	99.9
Italy	9,226	110.8	d	155.6		X	155.6	536	79.1
Latvia	565	28.0		12.6		15.6	X	28	75.2
Lithuania	258	5.7		2.0		3.6	X	6	22.9
Netherlands	1,914	64.0		13.2		X	50.3	64	93.4
Norway	53,199	218.5		111.2		1,095.1	X	1,206	95.4
Poland	1,032	30.0		10.6		19.4	X	30	13.5
Portugal	2,830	20.1		64.1		1,656.4	X	1,721	92.7
Romania	696	18.6		5.3		18.0	X	23	6.3
Russian Federation {c}	110,310	4,137.0		1,318.1		6,255.8	X	7,574	14.9
Slovenia	41	0.2		0.2		X	X	0	60.6
Spain	7,268	62.1		115.8		683.2	205.2	1,004	67.9
Sweden	26,384	153.8		85.3		73.2	X	158	87.7
Ukraine	4,953	78.0		53.9		86.4	X	140	20.9
United Kingdom	19,717	522.6		168.1		X	753.8	922	98.6
Yugoslavia	X	3.1	d	X		X	X	X	8.1
MIDDLE EAST & N. AFRICA	47,282	786.5		649.7	b	2,016.0	196.0	X	X
Algeria	1,557	9.7		27.9		X	60.5	88	68.8
Egypt	5,898	50.1		57.0		185.3	X	242	53.1
Iran, Islamic Rep {c}	5,890	160.2		76.4		129.7	X	206	23.9
Iraq	105	1.0	d	0.7		X	X	1	5.7
Israel	205	3.2	d	4.1		X	X	26	96.6
Jordan	27	0.1		0.1		X	0.1	0	29.0
Kuwait	756	6.5	d	5.4		X	X	7	100.0
Lebanon	294	1.2		4.7		X	X	19	100.0
Libyan Arab Jamahiriya	2,025	63.6	d	38.1	b	222.4	20.9	419	78.7
Morocco	2,008	70.4		37.5		328.4	X	366	65.1
Oman	2,809	46.7		51.8		487.4	X	539	88.5
Saudi Arabia	7,572	95.6	d	82.0		X	X	214	30.2
Syrian Arab Rep	212	0.9	f	3.9	b	X	X	10	34.5
Tunisia	1,927	65.3	d	36.8		X	X	103	84.0
Turkey	8,140	53.3		81.0		176.6	81.0	339	57.5
United Arab Emirates	2,871	51.4		31.0		21.2	X	52	84.9
Yemen	3,149	65.3		82.4		465.0	X	547	63.5

Table 2

Coastal Zone Statistics by Country

	Coastal Length {a} (km)	Area of Continental Shelf (up to 200 m depth) (000 km^2)		Territorial Sea (up to 12 nm) (000 km^2)		Claimed Exclusive Economic Zone (000 km^2)	Exclusive Fishing Zone (000 km^2)	Total Potential Maritime Area (000 km^2)	Population Within 100 km from the Coast (percent)
SUB-SAHARAN AFRICA	63,124	987.0		871.9	b	7,866.1	3,111.1	X	X
Angola	2,252	44.2	f	34.7	b	X	438.0	473	29.4
Benin	153	2.8	f	2.5	b	X	26.8	29	62.4
Cameroon	1,799	13.1	f	8.5	b	10.9	X	20	21.9
Congo	205	7.4	f	3.5	b	X	41.4	45	24.5
Congo, Dem Rep	177	0.8		1.0		X	121.0	122	2.7
Côte d'Ivoire	797	8.6		12.3		157.4	X	170	39.7
Equatorial Guinea	603	8.6		12.9		291.4	X	304	72.3
Eritrea	3,446	47.5	d	39.2		X	X	75	73.5
Gabon	2,019	36.8		19.6		180.7	X	200	62.8
Gambia	503	5.7		2.3		20.5	X	23	90.8
Ghana	758	18.1		11.9		216.9	X	229	42.5
Guinea	1,614	49.7		14.2		97.0	X	111	40.9
Guinea-Bissau	3,176	37.2		19.5		86.7	X	106	94.6
Kenya	1,586	8.5		12.4		104.1	X	116	7.6
Liberia	842	14.9	f	12.7	b	X	239.1	252	57.9
Madagascar	9,935	96.7		124.9		1,079.7	X	1,205	55.1
Mauritania	1,268	28.4		19.5		141.3	X	161	39.6
Mozambique	6,942	73.3		70.9		493.7	X	565	59.0
Namibia	1,754	95.0		32.7		536.8	X	570	4.7
Nigeria	3,122	41.8		19.3	b	164.1	X	183	25.7
Senegal	1,327	21.0		11.5		147.2	X	159	83.2
Sierra Leone	1,677	23.2	f	11.2	b	X	155.9	167	54.7
Somalia	3,898	40.4		68.8		X	759.3	828	54.8
South Africa	3,751	160.9		74.7		X	1,450.6	1,525	38.9
Sudan	2,245	15.9		32.6		X	X	92	2.8
Tanzania, United Rep	3,461	17.9		36.6		204.3	X	241	21.1
Togo	53	0.6		1.0	b	10.8	X	13	44.6
NORTH AMERICA	398,835	5,107.5		3,484.1		11,084.4	X	X	X
Canada	265,523	2,877.6		2,687.7		3,006.2	X	5,694	23.9
United States	133,312	2,229.9		796.4		8,078.2	X	8,875	43.3
C. AMERICA & CARIBBEAN	73,703	806.6		1,050.0	b	6,489.0	197.2	X	X
Belize	1,996	8.7		18.5		12.8	X	31	100.0
Costa Rica	2,069	14.8		24.2		542.1	X	566	100.0
Cuba	14,519	51.0		122.8		222.2	X	345	100.0
Dominican Rep	1,612	5.9		14.0		246.5	X	260	100.0
El Salvador	756	17.7	f	6.6	b	X	87.5	94	98.8
Guatemala	445	13.0		7.7		104.5	X	112	61.2
Haiti	1,977	5.9		40.1		86.4	X	127	99.6
Honduras	1,878	58.8		36.5		201.2	X	238	65.5
Jamaica	895	5.6		16.0		234.8	X	251	100.0
Mexico	23,761	393.3		291.6		2,997.7	X	3,289	28.7
Nicaragua	1,915	68.6	f	31.6	b	X	94.9	127	71.6
Panama	5,637	44.2	f	57.8	b	274.6	X	332	100.0
Trinidad and Tobago	704	22.6		13.0		60.7	X	74	100.0
SOUTH AMERICA	144,567	2,203.0		1,030.0	b	9,358.8	1,814.1	X	X
Argentina	8,397	798.5		142.5		925.4	X	1,068	45.1
Brazil	33,379	711.5		218.1		3,442.5	X	3,661	48.6
Chile	78,563	218.9		271.9		3,415.9	X	3,688	81.5
Colombia	5,874	16.2		44.0		706.1	X	750	29.9
Ecuador	4,597	31.5	f	107.3	b	X	957.0	1,064	60.5
Guyana	1,154	48.8		10.9		122.0	X	133	76.6
Peru	3,362	84.8	f	59.6	b	X	746.5	806	57.2
Suriname	620	56.9		9.0		119.1	X	128	87.0
Uruguay	1,096	68.8	f	22.5	b	110.5	110.5	133	78.5
Venezuela	6,762	123.6		136.0		385.7	X	522	73.1
OCEANIA	137,772	2,565.0		2,830.4		30,155.0	X	X	X
Australia	66,530	2,065.2		773.1		6,664.1	X	7,437	89.8
Fiji	4,637	19.5		162.2		1,055.0	X	1,217	99.9
New Zealand	17,209	247.8		176.6		3,887.4	X	4,064	100.0
Papua New Guinea	20,197	132.4		752.3		1,613.8	X	2,366	61.2
Solomon Islands	9,880	25.9		212.3		1,377.1	X	1,589	100.0

Sources: Pruett and Cimino, 2000 unpublished data (maritime areas); CIESIN 2000 (population). Notes: "X" in data column signifies that the data are not available or are not relevant. World totals and regional totals include countries not listed in this table. a. Figures should be interpreted as approximations because of the difficulty of measuring coastline length. Estimates may differ from other published sources. b. Excludes excessive territorial seas claims. For the world, the area of territorial seas in dispute is 2,867,050 km^2. c. No areas claimed in the Caspian Sea have been included. d. Includes continental shelf area of the potential exclusive economic zone even though the country may have not claimed it. e. Excludes Greenland. f. The breadth of the territorial sea is disputed.

Table 3
Coastal Characterization Summary

	Sea Ice	Wetlands	Barrier Islands (BI)	Wetland / Esturay/ BI Systems	Coral Reefs	Mangroves	Coral Reefs and Mangroves	Mountainous, Narrow Shelf	Hilly, Narrow Shelf	Plains, Narrow Shelf	Plains, Wide Shelf	Hilly, Wide Shelf	Unclassified
Mediterranean	0.0%	1.5%	0.9%	14.5%	0.0%	0.0%	0.0%	67.1%	0.8%	9.2%	0.0%	0.0%	8.3%
West and Central Africa	0.0%	5.8%	1.6%	14.8%	5.5%	20.8%	0.4%	0.0%	12.2%	19.6%	9.0%	0.0%	2.8%
South Africa	0.0%	0.6%	0.0%	11.6%	4.4%	2.2%	0.7%	0.0%	42.8%	0.0%	0.0%	37.5%	0.0%
East Africa	0.0%	4.3%	0.7%	9.8%	35.2%	10.2%	6.0%	0.0%	9.9%	12.6%	1.4%	0.0%	7.6%
South Asia	0.0%	14.5%	0.9%	24.7%	20.7%	15.1%	1.7%	6.4%	0.0%	7.5%	0.0%	9.0%	0.3%
NE Pacific	7.4%	2.8%	2.3%	7.6%	0.4%	1.3%	0.0%	31.1%	0.0%	0.4%	0.0%	2.1%	54.3%
SE Pacific	0.0%	0.4%	2.1%	11.4%	12.3%	20.1%	1.3%	60.8%	0.0%	0.0%	0.0%	0.0%	1.9%
South Pacific	0.0%	5.7%	2.3%	4.3%	28.4%	10.4%	5.9%	28.4%	0.0%	0.0%	5.3%	0.0%	10.3%
SW Australia	0.0%	0.0%	2.9%	1.5%	8.8%	4.3%	0.2%	0.0%	0.0%	0.0%	63.4%	0.0%	1.1%
Arctic	63.2%	0.0%	0.0%	2.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	14.8%
Caribbean	0.0%	8.7%	7.9%	14.2%	23.5%	16.9%	5.5%	12.0%	0.0%	0.0%	5.7%	0.0%	5.5%
SW Atlantic	0.0%	24.1%	2.2%	21.5%	2.0%	22.2%	0.4%	0.0%	0.0%	8.2%	13.8%	8.7%	1.2%
NE Atlantic	0.0%	2.2%	0.6%	11.7%	0.0%	0.0%	0.0%	3.4%	0.0%	2.4%	12.9%	9.0%	57.4%
NW Atlantic	21.3%	8.5%	8.7%	7.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	6.9%	0.0%	49.2%
NW Pacific	23.7%	7.4%	0.1%	7.3%	1.7%	0.2%	0.2%	25.1%	0.0%	0.0%	0.9%	28.3%	7.2%
Black Sea	0.0%	9.3%	1.0%	28.9%	0.0%	0.0%	0.0%	13.8%	0.0%	0.0%	0.0%	0.0%	49.2%
Red Sea & Gulf of Aden	0.0%	1.7%	0.0%	0.0%	49.0%	2.4%	10.0%	0.0%	22.0%	4.7%	0.0%	0.0%	0.1%
Kuwait	0.0%	12.2%	0.8%	18.1%	34.0%	1.7%	1.1%	12.0%	10.4%	9.9%	0.0%	0.0%	1.9%
East Asian Seas	0.0%	5.9%	0.2%	5.8%	27.8%	11.7%	3.7%	15.4%	0.3%	0.0%	9.8%	6.0%	2.0%

Sources: UNEP-WCMC [illegible] and [illegible].

Characterizing underwater and benthic ecosystems is even more difficult than describing terrestrial ecosystems. Until the middle of this century, most of our knowledge of continental shelf communities was based on samples dredged or captured by trawls, grab-samples, or even the wax or tallow affixed to the base of plumblines used in hydrographic surveys. The advent of scuba diving, combined with increasing use of manned and remote submersibles, has greatly improved our knowledge base. Unfortunately, this knowledge has expanded in parallel with vastly increased fishing efforts on almost all of the world's continental shelves, including the highly destructive use of benthic trawls. *(See Box 2.)* Thus, we have little knowledge of what pristine environments in the waters just off our shores may have been like even 50 years ago, unless we examine such historic records as the trawl samples taken by early oceanographic cruises and compare them with modern samples.

One of the most fundamental descriptive approaches in terrestrial biogeography at global and regional levels is the identification and description of potential vegetation and the subsequent subdivision of the world into biogeographic ecoregions. Ecoregional mapping combines habitat or ecosystem identification with knowledge of physio-chemical parameters and also historical factors of species evolution and distribution. Such work has also been attempted in the marine environment by a number of authors. Biogeographic patterns in the water column are determined most notably by water circulation patterns driven by wind, Coriolis force, and temperature, as well as salinity and nutrient availability. For example, various researchers have studied patterns of pelagic ecosystems and prepared schemes based on ocean currents, temperatures, productivity, or salinity (Hayden et al. 1984; Bailey 1998; Longhurst 1998). Others have looked at patterns in benthic communities (Ekman 1953; Hedgpeth 1957; Briggs 1974), although the availability of data from nonshelf benthos is so poor that they have only described these in general terms.

The classification used by Bailey and Longhurst includes ecological domains, such as the polar/boreal region, westerly drifts, and trade winds. Longhurst further delineated 56 secondary biogeochemical provinces within such domains, including coastal waters, and used them to report the pelagic primary production (Longhurst 1995). Sherman (1993) developed Large Marine Ecosystems (LMEs) as ecological subdivisions of coastal waters, which are targeted for ecosystem-based monitoring and management, although the LMEs are incomplete in their global coverage. Such biogeographic regionalization is more ecologically grounded than are political units and provide a better spatial analytical framework in organizing the data collection, assessment, and reporting of ecosystem conditions.

The existing regionalization schemes are useful in characterizing various coastal areas; however, no single scheme is either possible or suitable for summarizing all of the data assembled for this study. Some of the data sets presented in the following sections are gathered under particular schemes, often political regions, and reaggregation of such data is not possible.

Extent and Change in Area of Selected Coastal Ecosystem Types

The extent and change of coastal ecosystems is poorly known relative to most other terrestrial habitat types. Because individual coastal ecosystems, such as wetlands or coral reefs, tend to cover relatively small areas, detailed mapping is needed to measure extent or change. Until the advent of remote sensing, such mapping was beyond the reach of most nations. Even today, high resolution mapping of these systems is imperfect, expensive, and has not been attempted globally.

Wetlands are among the most highly altered ecosystems worldwide. Coastal wetlands (both tidal and nontidal) have been destroyed by direct actions (draining, dredging, landfill, spoil disposal, and conversion for aquaculture), and indirect pressures (sediment diversion and hydraulic alteration). The runoff of polluted waters (nonpoint-source pollution) has stressed coastal wetlands, which are already at risk from urban expansion and development in general. Natural processes, such as erosion and subsidence, also contribute to wetland loss, although human actions often aggravate these.

To provide a global overview of the extent and change in the diverse coastal habitat types, this study looked at mangroves, other coastal wetlands, seagrasses, and coral reefs.

MANGROVES

Unlike for most other coastal ecosystems, considerable data are available on the global distribution of mangrove forests. Based on the coastal characterization presented above, mangroves line approximately 8 percent of the world's coastline. A previous estimate by Spalding et al. (1997:20–23) concludes that mangroves are distributed along approximately one-quarter of the world's tropical coastlines, covering a surface area of 181,000 km^2. About 112 countries and territories have mangroves within their borders. Estimates of current mangrove extent vary significantly from one source to another, possibly because of the difference in definition, methodology, and land cover information used *(see Spalding et al. 1997, for more discussion on this issue)*. Table 4 presents mangrove area estimates by country derived from maps and other published sources.

No global or even regional map shows the "original" distribution of mangroves with sufficient resolution to measure the differences between such a distribution and current mangrove area. Scientists are unable to estimate exactly how extensive mangroves were before people began to alter coastlines. However, based on historical records, it can be said that mangrove

Table 4

Mangrove Area by Country (km²)

Country or REGION	Area	Country or REGION	Area	Country or REGION	Area
THE AMERICAS	49,096	WEST AFRICA	27,995	AUSTRALASIA	18,789
Aruba	4.2	Angola	1250	Australia	11,500
Bahamas	2,332	Benin	17	Federated States Micronesia	86
Belize	719	Togo	26	Fiji	385
Bermuda	0.1	Cameroon	2,494	Guam	0.94
Brazil	13,400	Congo	120	Nauru	1
Cayman Islands	71	Côte d'Ivoire	644	New Caledonia	456
Colombia	3,659	Equatorial Guinea	277	New Zealand	287
Costa Rica	370	Gabon	2500	Solomon Islands	642
Cuba	7,848	The Gambia	497	Tonga	10
Dominican Republic	325	Ghana	100	Vanuatu	16
Haiti	134	Guinea	2,963	Western Samoa	7
Ecuador	2,469	Guinea-Bissau	2,484	Papua New Guinea	5,399
El Salvador	268	Liberia	190		
French Guiana	55	Mauritania	1.04	EAST AFRICA/MIDDLE EAST	10,024
Guatemala	161	Nigeria	10,515	Bahrain	1
Guyana	800	Senegal	1,853	Iran	207
Honduras	1,458	Sierra Leone	1,838	Oman	20
Jamaica	106	Zaire	226	Qatar	<5
Anguilla	5.17			United Arab Emirates	30
Antigua and Barbuda	13.16	SOUTH & SOUTHEAST ASIA	75,173	Comoros	26.21
Barbados	>0.07	Bangladesh	5,767	Mayotte	10
British Virgin Islands	4.35	Brunei Darussalam	171	Seychelles	29
Dominica	1.56	Cambodia	851	Djibouti	10
Grenada	2.35	China and Taiwan	366	Egypt	861
Guadeloupe	39.83	Hong Kong	2.82	Eritrea	581
Martinique	15.87	India	6,700	Saudi Arabia	292
Montserrat	>0.02	Indonesia	42,550	Somalia	910
Netherlands Ant. (LW)	10.51	Japan	4	Sudan	937
Netherlands Ant. (WW)	0.87	Malaysia	6,424	Yemen	81
St. Kitts and Nevis	>0.71	Myanmar	3,786	Kenya	530
St Lucia	1.25	Pakistan	1,683	Madagascar	3,403
St Vincent	>0.45	The Philippines	1,607	Mozambique	925
US Virgin Islands	9.78	Singapore	6	South Africa	11
Mexico	5,315	Sri Lanka	89	Tanzania	1,155
Nicaragua	1,718	Thailand	2,641		
Panama	1,814	Vietnam	2,525		
Peru	51				
Puerto Rico	92				
Surinam	1,150				
Trinidad and Tobago	>70				
Turks and Caicos	111				
United States	1,990				
Venezuela	2,500				

Source: Spalding et al. 1997.

Table 5

Mangrove Loss for Selected Countries

Region and Country	Current Extent (km^2)	Approximate Loss (%)	Period	Source
Africa				
Angola	*1,100*	50.0	Original extent to 1980s	a
Cote d'Ivoire	640	60.0	Original extent to 1980s	a
Gabon	*1,150*	50.0	Original extent to 1980s	a
Guinea-Bissau	*3,150*	70.0	Original extent to 1980s	a
Kenya	*610*	3.9	1971 - 1988	b
Tanzania	*2,120*	60.0	Original extent to 1980s	a
Latin America				
Costa Rica	*413*	-5.9 (gain)	1983 - 1990	c
El Salvador	*415*	7.8	1983 - 1990	c
Guatemala	161	31.0	1960s -1990s	d
Jamaica	106	30.0	Original extent to 1990s	d
Mexico	5,315	64.7	1970s - 1990s	d
Panama	*1,581*	67.5	1983 - 1990	c
Peru	51	24.5	1982 - 1992	d
Asia				
Brunei	*200*	20.0	Original extent to 86	e
Indonesia	*24,237*	54.9	Original extent to 1980s	e
Malaysia	*2,327*	74.1	Original extent to 92-93	e
Myanmar	*4,219*	74.6	Original extent to 92-93	e
Pakistan	*1,540*	78.0	Original extent to 1980s	a
Philippines	*1,490*	66.7	1918 to 87-88	f
Thailand	*1,946*	83.7	Original extent to 93	e
Vietnam	2,525	36.9	Original extent to 93	d,g
Oceania				
Papua New Guinea	*4,627*	8.0	Original extent to 92-93	e

Sources: a. World Resources Report 1990; b. UNEP 1997*a*; c. Davidson and Gauthier 1993; d. Spalding et al.1997; e. MacKinnon 1997; f. World Bank 1989; g. BAP Planning 1993.
Note: Current extent estimates in italics are not in agreement with the estimates in Table 4, because of differences in year assessed and methodology.

area has declined considerably. Overall, according to one estimate, 50 percent of the world's mangrove forests have been lost (Kelleher et al. 1995:30). Indeed, as Table 5 shows, a number of countries, for which data are available, have lost somewhere between 5 and nearly 85 percent of original mangrove extent. Extensive losses from the original distribution, particularly in the last 50 years, include an estimated 83.7 percent of mangroves in Thailand, and 67 percent in Panama during the 1980s. *(See Table 5.)* Although the net trend is clearly downward, in some regions, mangrove area is actually increasing as a result of plantation forestry and small amounts of natural regeneration (Spalding et al. 1997:24).

NON-MANGROVE COASTAL WETLANDS

Unlike mangroves, other wetland types, such as marshes, swamps, and peatlands, are less clearly defined. In addition, it is difficult to distinguish *coastal* wetlands from *freshwater* wetlands. A broad definition of wetlands used by the Convention on Wetlands, also known as the Ramsar Convention, and which is internationally accepted, also encompasses reef flats and seagrass beds in coastal waters (Davies and Claridge 1993:1). No comprehensive global information, and only limited reliable national information, is available to document change in seagrass habitats, salt marshes, peat swamps, or in other types of coastal wetlands. Where data do exist, however, the habitat loss is often dramatic. For example, some 46 percent of Indonesia's peat swamps and as much as 98 percent of Vietnam's are believed to have been lost (Mackinnon 1997:104,175). Table

Table 6

Coastal Wetland Extent and Loss for Selected Countries

Country	Habitat Classification	Original Extent (km^2)	Current Extent (km^2)	Approximate Loss (%)	Source
Asia					
Brunei	Peat Swamp	1,643	1,236	25	a
Cambodia	Peat Swamp	15,189	0	100	a
India	Seasonal Salt Marsh	23,524	23,985	-2 (gain)	a
Indonesia	Peat Swamp	196,123	106,136	46	a
Malaysia	Peat Swamp	13,806	5,703	59	a
Pakistan	Seasonal Salt Marsh	8,736	8,736	0	a
Vietnam	Peat Swamp	14,819	230	98	a
Latin America					
Costa Rica	Peat Swamp	X	370	X	b
El Salvador	Peat Swamp	X	90	X	b
Honduras	Peat Swamp	X	4,530	X	b
Nicaragua	Peat Swamp	X	3,710	X	b
Panama	Peat Swamp	X	7,870	X	b
Other					
Brittany, France	Coastal Wetlands	X	X	40	c
US	Coastal Wetlands	X	274,000	50	d, e

Sources: a. MacKinnon 1997; b. Davidson and Gauthier 1993; c. Dugan 1993; d. Field et al. 1991; e. NOAA 1999.
Note: X signifies that the data are not available.

6 reflects coastal wetland extent and loss estimates for a selected number of countries.

SEAGRASSES

As with coastal wetlands, information on the extent and loss of seagrass habitat is also limited. Historically, most seagrass habitat loss has been the result of degrading water quality primarily caused by high nutrient and sediment loadings. Direct damage from vessels, dredging, and trawling are other activities that have significantly harmed many seagrass beds.

Even though global information on seagrass extent and loss is extremely limited, the magnitude of loss in these ecosystems is thought to be high. Twelve of the 34 responses to the “Global Seagrass Survey,” conducted in 1997 and covering 23 countries, report that seagrass area in those countries has declined (Global Seagrass Survey 1999). Given that the survey only represents a fraction of the countries that have seagrass beds within their territory, the results are alarming. In the United States, for example, over 50 percent of the historical seagrass cover has been lost from Tampa Bay, 76 percent from the Mississippi Sound, and 90 percent from Galveston Bay (NOAA 1999b:19). These losses are partly attributed to population growth and the resulting deterioration in water quality (NOAA 1999b:19).

CORAL REEFS

Information on the extent and distribution of coral reefs is probably greater than for any other marine habitat. Indeed, rough global maps of coral reefs have existed since Darwin’s time. The World Conservation Monitoring Centre (UNEP-WCMC) has compiled a coarse-scale (1:1,000,000) map of the world’s shallow coral reefs and more detailed maps exist for many countries. Worldwide, there are an estimated 255,000 km2 of shallow coral reefs, with more than 90 percent of that area in the Indo-Pacific region (Spalding and Grenfell 1997:225–230). Table 7 presents two global estimates of coral reef area. The first column summarizes estimates from a 1997 study that focused on emergent reef crest and very shallow coral reef systems. The second column is from a 1978 study, which used a less detailed approach, but included estimates of deeper reef areas, that are extremely poorly mapped.

In general, coral reef degradation is a more significant problem than outright reduction in coral reef area on a global basis. However, coral reef area has been significantly reduced in some parts of the world through land reclamation and coral mining. Additionally, as increasing numbers of coral reefs become weakened from coral bleaching, coral diseases, and other stresses, mortality is likely to increase. When reefs do not recover, the reef will eventually erode and as a result there will be a loss in coral reef area.

Table 7
Comparison of Two Coral Reef Area Estimates

Region	Coral Reef Area (km^2) from Spalding and Grenfell 1997	Coral Reef Area (km^2) from Smith 1978
Middle East	20,000	39,000
Atlantic and Caribbean	23,000	97,000
Indian Ocean	36,000	146,000
Southeast Asia	68,000	182,000
Pacific	108,000	153,000
World	255,000	617,000

Note: Spalding and Grenfell estimates focus on shallow and emergent reef areas.

Human Modification of Coastal Ecosystems

Humans have modified large areas of the coastline for centuries. Some of the major pressures significantly altering coastal ecosystems around the world are land use changes and population growth in the terrestrial communities, and trawling in the benthic communities. The following section presents indicators of the degree of modification of coastal ecosystems.

TERRESTRIAL COMMUNITIES

Land Cover

In the absence of detailed estimates of habitat conversion, which would be more suitable in directly measuring the human modification of coastal ecosystems, this study estimated the overall level of alteration in coastal ecosystems by using remote sensing to evaluate how much terrestrial coastal area remains in natural vegetation, such as forests or grasslands, versus modified habitats, such as urban and agricultural lands. This analysis made use of the 1-kilometer resolution Global Land Cover Characteristics Database (GLCCD 1998) derived from the Advanced Very High-Resolution Radiometer (AVHRR) satellite data covering the period between 1992 to 1993. A classification using 15 different land cover classes (excluding water bodies) was used as the base for this analysis. These were aggregated into "natural," "altered," and "semialtered" classes as shown in Map 2 and Figure 2. Excluding Antarctica, 19 percent of all lands within 100 km of the coast are classified as altered, meaning they are in agricultural or urban use; 10 percent are classified as semialtered, involving a mosaic of natural and altered vegetation; and 71 percent fall within the "natural" or least modified category, meaning that the natural habitat remains. This 71 percent includes large uninhabited areas of the world, mostly in northern latitudes.

Figure 2 summarizes the land cover types and human modification by the UNEP's Regional Seas Program (with the same modification for the North Atlantic as discussed earlier). The "natural" vegetation classes are grouped into "forests", "grasslands", "other natural", and "snow and ice".

As shown in Map 2, the terrestrial coastal area surrounding the Black Sea, Mediterranean, and South Asia regions have the highest percentage of "altered" lands, while the coastal zone of the Arctic, Northeast Pacific, South Pacific, West and Central Africa, East Africa, Red Sea and Gulf of Aden, and Kuwait regions have the highest proportion of least modified land cover.

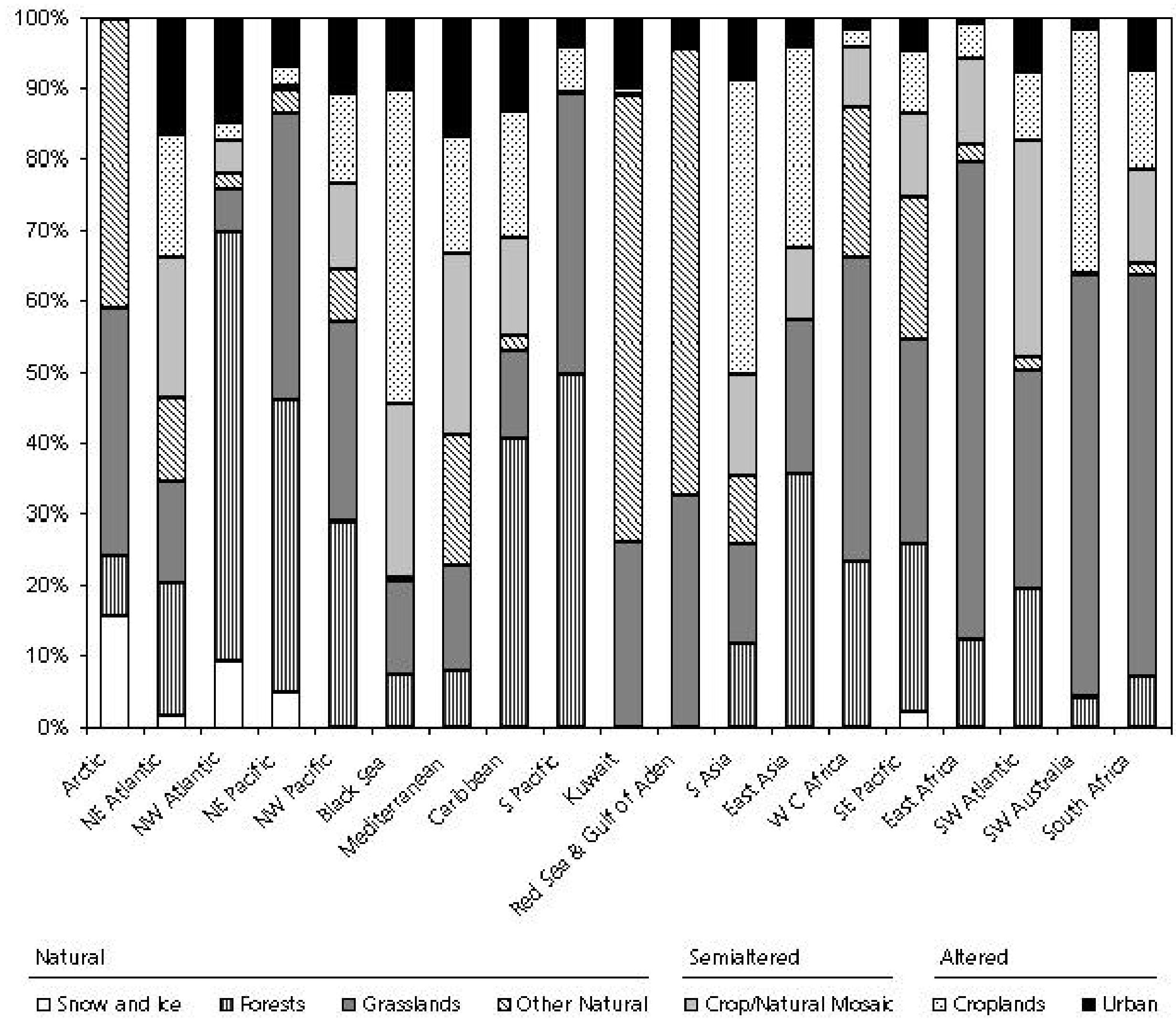
Population Density

As human population increases in coastal areas, so does pressure on coastal ecosystems through habitat conversion, increased pollution, and demand for coastal resources. The degree of direct human modification of coastal ecosystems can be inferred by looking at the population density within the coastal zone. There are many published estimates of the percent of the global population living on the coast, as well as more detailed figures for various countries. In most cases, these estimates have made use of various definitions of coastal population. Some are based on a fixed distance from the coastline (i.e., 60, 100, or 200 km), others on administrative units adjoining the coast, and others upon topography, and land areas discharging directly into brackish or salt water.

In order to measure the direct and indirect impact of population on coastal ecosystems, an ideal definition of the "coastal population" should take into consideration the potential influence that this given population would have upon the coastal environment. Some of the important factors to take into account would include: access or travel time to the coast, because it provides an estimate of how many people can get to the area; presence of rivers or hydrographic boundaries, such as watersheds, as a means of human access, and a medium for pollution transport; topography, such as local slope, which affects runoff, erosion, etc.; and socioeconomic factors, such as trade and consumption, because they provide basic information on what economic activities the population is engaging in and the relative impact of these activities on the coastal zone. Because of the complexity and subjectivity of integrating these factors, as well as the need to provide a definition of coastal population more consistent with previous published estimates, this study assessed the level of *direct* human modification of the coastal zone, by examining the population within 100km from the coast. *(See Map 3.)* This estimate was calculated using a new spatially explicit database reflecting global human population developed for this project (CIESIN et al. 2000). In addition, Table 8 presents population count and percentage of total population for 1990 and 1995 for the world, as well as for land areas within 25, 50, and 100 km of the coast. Globally, the number of people

Figure 2

Natural versus Altered Land Cover Summary



Source: GLCCD, 1998.

living within 100 km of the coast increased from roughly 2 billion in 1990 to 2.2 billion in 1995—39 percent of the world's population. If Map 2 on land cover is compared with Map 3 on population density, one can see that high population density correlates with urban areas classified in Map 2 as "altered" lands. The most uninhabited areas, as is expected, are in northern latitudes, where much of the "natural" land cover remains.

BENTHIC COMMUNITIES

Our lack of knowledge of sea bottom habitats and species distribution on the world's continental shelves precludes most direct measures of changes in these environments. There have been only site-specific studies of geophysical characterization or mapping of near-shore benthic habitat. One way of inferring the level of human modification to these habitats is to identify the areas where destructive activities take place. One of the most direct and globally pervasive threats facing the soft sediment benthic communities on continental shelves around the world is bottom trawling. The PAGE study commissioned a global analysis on the extent of benthic trawling grounds. Data was compiled and mapped for trawling grounds in countries containing 41 percent of the world's continental shelf area. Within the areas captured by this analysis, trawling grounds cover 57 percent of the total continental shelf area. These findings presented in Box 2 and Map 4, show that this activity disturbs the vast majority of the world's continental shelf benthos to some extent.

Table 8

Coastal Population Estimates for 1990 and 1995

Proximity to Coastline	Population in 1990 (millions)	Population in 1995 (millions)	Percentage of total population in 1995
Within 25 km	1,070	1,144	20%
Within 50 km	1,544	1,646	29%
Within 100 km	2,075	2,213	39%
Global population total	5,267	5,667	100%

Source: CIESIN 2000.
Note: Figures are expressed in cumulative totals and calculated from a GIS database with the grid resolution of approximately 5km by 5km, and thus, may differ from other published estimates.

Box 2

Global Distribution of Known Trawling Grounds

Benthic trawling is a significant source of pressure on the biodiversity of coastal and benthic ecosystems. Modern trawlers are powerful and effective fish-locating and -catching machines. Habitats in trawl-swept areas—seabed terrains over which a trawl has passed—may be lightly damaged with effects lasting only a few weeks or intensively damaged with some impacts on corals, sponges, and other bottom-living species lasting decades or even centuries. Increasingly, trawling is taking place beyond the continental shelf, regularly in depths up to 400m, and in some places to depths of over 1500m.

Trawling grounds are areas of the ocean where commercial trawling, legal or illegal, is prevalent. Some of these areas may be repeatedly swept each year, some perhaps never. Globally, an estimated 14.8 million km^2 of the seafloor is touched by trawling gear (the "trawl swept area") (Watling and Norse 1998:1190). For this study, the distribution of trawling grounds (both swept and unswept) for 24 countries for which sufficient data were available was mapped. These countries represent about 41 percent of the world's continental shelves. *(See Map 4.)* Trawling grounds in these countries encompass 8.8 million km^2, of which about 5.2 million km^2 are located on the continental shelves, or some 57 percent of the total continental shelf area of these countries.

Information Status and Needs

Information on the location and extent of coastal features and ecosystems types often provides the basis for subsequent analyses of condition of the ecosystem, relationships between different habitats, and overall trends. Yet, despite this fundamental importance, such information is incomplete and inconsistent at the global level. Benthic ecosystem mapping, for example, has only been performed for a limited number of habitats and over certain portions of the globe. Data on the distribution of important and restricted habitats, such as kelp beds and seagrasses, are not available at the global level.

The data sets presented in this study made use of the best information currently available at the global scale. UNEP-WCMC has attempted to develop base maps of coral reefs, mangroves, and wetlands for the world by harmonizing and integrating available sources. These are the best base maps currently available for these habitat types, still, they reflect the uneven quality of the original data sources. Differences in definitions as well as variations in resolution and interpretation further complicate the numerical measurement of habitat extent from global maps. There is an urgent need for better global classifications and data sets characterizing the world's coasts, particularly the distribution of sandy and rocky shores, salt marshes, tidal mudflats, and lagoons.

Much data could be gathered from existing maps, chart series, aerial photographs, and high- resolution satellite imagery. Priority should be given to amalgamating and harmonizing available data into global data sets, from which gaps in knowledge could be more directly assessed. Once assembled, it is important that these data sets be freely and publicly available.

Historical data describing previous extent of habitats, against which we might hope to measure change, is highly limited. No comprehensive global assessments of changes in the extent of coastal habitats have been carried out. The tables presented above are a compilation of recorded habitat loss measured by different habitat classification schemes and covering various time periods. Therefore, they reflect the gaps in such data collection. Where no historical data exist, the possibility of predictive mapping should be considered, using existing climatic, oceanographic, biogeographic, and topographic knowledge.

Remote sensing, particularly the use of high-resolution satellite imagery, can play an important role in the development of improved information on current habitat extent as the costs of imagery and processing continue to decrease. It will be vital for evaluation of change in habitat area over time. Monitoring changes in extent of various habitat types will often rely on multiscale approaches and should include some ground-based measurements to improve accuracy and assess reliability. Satellite data, at the required spatial and spectral resolution, have yet to be assembled and interpreted for this purpose. Through coarse-scale satellite sensors focused on marine and coastal environments, we have relatively good global information on sea surface temperature (SST), sea level, phytoplankton productivity (from ocean color), and ocean currents. Some countries have performed habitat inventories and mapping, but this is more the exception than the rule. Monitoring priorities also vary by country. The United States, for example, does not possess a detailed base map of all coral reefs within its territorial waters, but has performed detailed mapping of all major estuaries by salinity zone.

Although the extent and change data presented above are an important basis for assessing the condition of other ecosystem goods and services—and are referred to as such throughout this report—these are mere proxies for measuring the condition of the ecosystems. Data with higher resolution and accuracy are needed to sufficiently capture the level of human modification in the complex and narrow coastal zone. We do not have a good understanding of the overall impacts on coastal ecosystems caused by human modification of landscape and other anthropogenic disturbances, such as dredging and trawling. These changes and disturbances influence the quality and structure of these ecosystems, which may not be as easily observed as habitat loss. We need better quantitative analysis of how the change in the extent of various habitats is affecting the array of goods and services that are derived from them. Nevertheless, the degree of degradation suggested by the available information reinforces the need for precautionary action.

SHORELINE STABILIZATION

Importance of Shoreline Stabilization

Coastlines are constantly changing—eroding and accreting, from the routine and irregular forces and events associated with winds, waves, storms, and tectonic processes. A natural shoreline responds to these forces and events, including tides, storms, floods, long-term changes in sea level, and human modification of coastal processes, by attempting to move toward equilibrium. Coastal ecosystems provide shoreline stabilization and buffering services. For example, coral reefs, mangroves, kelp beds, and seagrasses reduce erosion by mitigating wave impact. Sandy and rocky shores serve as a first line of defense, mitigating and responding to natural forces like waves and storms. Barrier islands, which develop from these ephemeral forces, absorb much of the energy, leaving calmer, protected waters on the leeward side. Wetlands, seagrasses, and mangroves help stabilize soils, reducing erosion and associated sediment pollution. Even the presence of sea ice mitigates shoreline erosion. However, these stabilization and buffering capacities are not absolute—the service is mitigation, not outright protection. Yet, compared with human-modified coastlines with artificial structures, natural systems are more adaptive to routine, irregular, as well as long-term changes in the dynamic coastal system. The best way to take advantage of this invaluable service provided by beaches and other coastal habitats is to allow them the space to move in a seaward direction during accretionary phases and in a landward direction during erosionary phases.

In developed areas where there is considerable economic investment, the shoreline is often protected by fixed engineering solutions (groins, jetties, and seawalls), which are often successful in protecting a particular aspect of the shoreline, but eliminate the natural response capacity of the system. Decisionmakers often undervalue the shoreline protection service that natural landscapes provide, and often don't take it into account in the decisionmaking process. Part of the reason is that there are no quantitative measures of this service. There have been some areas where a quantitative assessment of the value of a few coastal ecosystem types in protecting shoreline has been documented. In the United Kingdom, the increased width of salt marshes buffering the sea walls, for example, can dramatically reduce the cost of construction and maintenance of sea defenses (King and Lester 1995:180). In Sri Lanka, Berg et al. (1998) attempted to put an economic value on the fringing reefs that protect against coastal erosion.

Shoreline protection is a very important issue, particularly in countries with small land area or limited arable land, because any erosion or change in the shoreline can affect the amount of land available for different activities. One way of estimating the value of this service is to estimate the cost of replacing it, which in many cases can be extremely expensive. A measurement of the relative importance of shoreline stability to a country or area can be estimated by how much monetary investment is made on shoreline protection, and by the percentage of the shoreline on which some stabilization measures are taken. The most well-known example is the Netherlands, where the extensive system of dikes and dams protects nearly half of the total land area from being flooded (Central Intelligence Agency 1998). Japan has identified approximately 46 percent of its shoreline as requiring stabilization measures, and during 1970–98 the total investment on shoreline protection works was 4.5 trillion Yen (more than US$40 billion) (Japan Ministry of Construction 1998). Sri Lanka provides an example that directly relates the loss of coastal habitat to the cost of replacing the service lost. It spent US$30 million on revetments, groins, and breakwaters in response to severe coastal erosion that occurred in areas where coral reefs were heavily mined (Berg et al. 1998:630).

Effects of Artificial Structures on the Shoreline

For centuries, human activities have modified shorelines and interfered with coastal processes. The exploitation of shoreline and near-shore environments for transportation, industry, residential development, and recreation has had profound impacts on the ecosystem as well as on other chemical, material, and energy cycles in the near-shore aquatic environment. Coastal civil engineering works disrupt natural sediment movement in a variety of ways, in many cases causing accelerated erosion or unforeseen problems in adjacent shorelines. Efforts to stabilize shorelines have been substantial in many parts of the world because property values are high and development has often occurred too close to the shoreline.

Major human modifications to the shoreline include: construction of harbors with breakwaters; construction or modification of inlets for navigational purposes; intentional modification of longshore sediment transport; construction of dams; sand mining from riverbeds near coastal areas; and extraction of ground fluids resulting in coastal subsidence (National Research Council 1990). Modification of the river flow through dams has led to changes in sediment budgets, with deposition in reservoirs and frequent erosion of deltas. The impacts have been observed in several parts of the world. In the north of Italy, for example, reduced sediment loads in the Arno River have resulted in a shoreline retreat of 1.3 km—as much as 20m per year in recent years (Aminti et al. 1999:7).

Another example of a jetty's impact on coastal morphology is the accelerated migration of Assateague Island along the Atlantic coast of the United States. A hurricane striking in 1933 opened an inlet between what are now called Fenwick and Assateague Islands. Jetties were built on either side to maintain the inlet. These jetties trapped sand to form a wide beach at Ocean City, on the northern side, resulting in a sediment-starved Assateague Island. The situation accelerated the retreat of the shoreline from 5 ft per year to 30 ft per year. The retreating island now has a 500 meter offset from a once straight barrier island (Williams et al. 1995).

Partly because of the negative aspects of hard stabilization techniques, sand replenishment in beaches has become increasingly popular as a shoreline stabilization measure. Sand or beach replenishment is an expensive technique that must be implemented properly and repeatedly to be effective. The grain size of replacement sand must be the same size or slightly larger than that of the natural beach. The source of the sand must be chosen carefully to make sure that removal does not result in unwanted side effects. This technique is more in line with natural processes than hard stabilization approaches, but is expensive. Since 1965, the United States has spent US$3.5 billion on 1,305 beach replenishment projects. For example, the beach replenishment of Miami Beach in the late 1970s alone cost US$64 million (Williams et al. 1995). The beach nourishment of the East Coast barrier island shoreline of the United States is by far the most extensive in terms of both sand volume and cost. It is estimated that the state of New Jersey would require US$1.6 billion over 10 years to replenish and maintain its 90 miles of *developed* open ocean shoreline (Trembanis et al. 1998:246–251).

For many countries, protection of coastal ecosystems is likely to be one of the most cost-effective means of defending coastal development from the impact of storms and floods. As in the Sri Lankan example mentioned earlier, it is clear that, with the significant loss in extent of various coastal ecosystems, the capability of most nations' coasts to provide this service has been significantly diminished, resulting in additional investment for artificial protection.

Condition of Shoreline Stabilization Services

Useful indicators to assess the condition of the world's shoreline stabilization services can be grouped into three broad categories. (1) Measures that show the extent and change in area and quality of coastal habitats from which a loss or gain in stabilization services can be inferred. (2) Indicators that measure directly the extent and change in human-made features or indirectly show resource pressures from higher population density, development, and economic activities. (3) Indicators that measure changes in shoreline protection services—for example, by estimating changes in the severity and impacts of natural hazards, such as erosion, sedimentation, and flooding, that would normally be mitigated by shoreline protection services. The following section discusses some of these indicators in more detail.

CHANGES IN NATURAL AND HUMAN-MADE FEATURES

Two ways of measuring the condition of shoreline stabilization services are the degree to which coastlines are comprised of natural features, and the extent of human-made features interfering with coastal processes. As discussed earlier, human modification of terrestrial habitats has been extensive and can be documented, albeit in a coarse scale. However, the degree of modification by artificial structures and their effect on shorelines tend to be monitored locally, if at all. As such, few national-level summaries exist, and most information is anecdotal.

Map 2 and Figure 2 showing a summary indicator of habitat conversion are, thus, a global proxy measure of the potential loss of natural buffering capacity and imply an increased likelihood of replacement with hard stabilization structures.

As is the case with monitoring change in natural and human-made features, changes in such coastal processes as sediment transport, erosion, and accretion, tend to be monitored locally; no comprehensive global level statistics are available. However, for some habitat types and some countries, better data are available. For example, sandy shores and beaches are an important monitoring unit for which some quantitative measurements have been developed. These include using the volume of sand, size of the beach, and the rate of erosion or accretion to measure the stability of the shoreline. Beach width can fluctuate on a seasonal basis, depending on climatic patterns, and needs to be monitored over a longer time period to be meaningful.

Physical changes in beaches were measured in several small islands of the Eastern Caribbean with an application of coastal development planning guidelines (UNESCO 1997; Cambers 1998). The Coast and Beach Stability in the Lesser Antilles Program (COSALC) supports the development of in-country capabilities so that island-states can measure, assess, and manage their own beach resources within an overall framework of integrated coastal zone management. Concentrating on measuring physical changes in beaches, they monitor changes in cross-sectional area (profile area) and beach width (from a fixed monument) (UNESCO 1997; Cambers, personal communication, 1999). In most of the eastern Caribbean islands, beach profiles have been regularly surveyed as part of the COSALC project since the late 1980s. These data are detailed and far more accurate than estimates from aerial photography. However, because of inconsistent time and area coverage of the monitoring programs, aggregation of the data and trend analysis is difficult. The data presented below were compiled from measured beach change for selected islands with data records of three or more years. *(See Table 9.)* Over the period 1985–95, 70 percent of the monitored beaches have eroded (Cambers 1997:29–47).

This general erosional trend of the monitored beaches indicates that the shoreline protection capacity in the region is declining. Maintenance of the monitoring activities and database facilitated by COSALC is key to better coastal development planning in the Eastern Caribbean in order to avoid further erosional problems. The methodology and institutional arrangements could be expanded to other parts of the world, provided that sufficient funding and technical capacity are in place.

CHANGES IN SEVERITY AND IMPACT OF NATURAL HAZARDS

Our perception as to whether we are observing natural change or erosional problems along a coastline has to do with whether or not an area is developed. For example, barrier islands naturally migrate landward in response to rising seas. If a house or road is built on the island, this change will appear as a loss of

Table 9

Average Beach Profile Change in Selected Eastern Caribbean Islands

Island Name	Period	Number of sites	Eroding sites	Accreting sites	Mean change in beach width (m/year)
Antigua	1992-94	30	24	6	-0.85
British Virgin Island	1989-92	44	32	12	-0.36
Dominica	1987-92	23	21	2	-1.06
Grenada	1985-91	40	26	14	-0.31
Montserrat	1990-94	10	2	8	+1.07
Nevis	1988-93	17	13	4	-0.85
St. Kitts	1992-94	35	22	13	-0.27

Source: Cambers 1997.

beachfront. Similarly, wetland accretion in response to rising seas, if limited by development will result in a decrease in wetland area. Whether such problems are intensifying, and how they relate to the loss of the shoreline stabilization function provided by the ecosystems, is hard to discern. However, it is important to describe the magnitude of the problems to fully realize the importance of this ecosystem service to humans.

Quantitative measurements of the change in the magnitude of, and the damage caused by, coastal hazards, such as storms, floods, and erosion, are useful statistics for describing the extent of the problems. However, such statistics are often only available as a country aggregate and in monetary terms. In addition, the level of damage caused by a coastal hazard is a function of the magnitude of the event and the local vulnerability—including the level of investment already made in the area.

The economic and human costs of coastal storm damage are growing as expanding coastal settlements place more people and property at risk. Economic losses in Europe from floods and landslides between 1990–96 were 4 times the losses suffered in the 1980s, and 12.5 times those of the 1960s (European Environment Agency 1998:274). From 1988–99, the United States sustained 38 weather-related disasters that reached or exceeded US$1 billion each, adding up to a total cost in excess of US$170 billion (NCDC 2000). In both Europe and the United States, many of these weather-related natural disasters involved flooding in coastal areas or, in the case of the United States, hurricane impacts in coastal regions. Worldwide, an estimated 46 million people per year are currently at risk of flooding from storm surges (IPCC 1996).

The level of severity and impact of a natural hazard cannot simply be compared in monetary terms from one country to another. Susceptibility to natural hazards may differ between developed and developing countries. Developed countries can mitigate fatalities through evacuation directed by early warning systems and through better emergency support after the disaster occurs. In the United States, all Atlantic and Gulf coastal areas are subject to hurricanes and tropical storms. Parts of the Southwest United States and Pacific Coast also suffer heavy rains and floods each year from the remnants of hurricanes spawned off Mexico. However, such tropical cyclone fatalities are relatively small: 17 persons in 1995, 37 in 1996 (an active year for tropical storms and hurricanes because of La Niña), and only 1 in 1997 (National Weather Service 1995, 1996, and 1997). The economic recovery after the event is also faster. However, insured damage can be enormous because of high property values. In developing countries, where emergency planning and disaster mitigation measures are weak and the people often reside in more vulnerable areas or conditions (Anderson 1990), slow recovery from the hazardous event causes disruption in other socioeconomic functions of society, which can be more devastating. One of the worst examples is hurricane Mitch in 1998, causing more than 11,000 deaths and severely affecting 3 million people in Central America, particularly in Honduras and Nicaragua (NCDC 1999).

Bangladesh is a good example of systematically monitoring the magnitude of floods and assessing the damage in nonmonetary terms. The severity of a flood event is measured by its duration above the so-called Danger Level, a fixed water level threshold. Although there is no clear indication of the peak flood level increasing, longer duration of floods above Danger Level were observed in 1998, compared to 1987 and 1988 (Matin 1998). Damage was substantial to Bangladesh's food production—a 10 percent shortfall from the expected production level of 21 million tons for that year (Shahabuddin 1999). This crop damage was estimated to be around 7 percent of Bangladesh's GDP. As a result, average daily per capita food grain available for consumption was estimated to be 443g as opposed to the requirement of 465g (Shahabuddin 1999). An analysis of the vulnerability of Bangladesh to climate change and sea level rise, conducted under the Intergovernmental Panel on Climate Change (IPCC) Working Group III, indicated that under the business-as-usual scenario (IPCC 1990 estimate), the increase in inundation resulting from severe climate change would affect 17.5 percent of the total land area, and 71 million people—or 60 percent of the total population (IPCC 1994).

Capacity of Coastal Ecosystems to Continue to Provide Shoreline Stabilization

Assessing whether there has been or will be a change in the underlying capacity of coastal ecosystems to provide shoreline stabilization services is a challenge, especially considering the difficulties that exist in obtaining a global picture of the extent and magnitude of these services. We will discuss two indicators in more detail: one looking at areas at risk of losing the buffering capacity provided by living coastal habitats; the other looking at areas at risk of sea level rise. These indicators will provide a crude impression of where this shoreline stabilization capacity could be undermined in the future.

AREAS AT RISK OF LOSING SHORELINE PROTECTION SERVICES

The vulnerability of coastal areas to erosion and storm effects varies according to a range of factors including topography, substrate, habitat types, coastal morphology, and climate. Physical characteristics are important factors in the relative vulnerability of a particular area to future erosion and natural hazards. Our characterization of natural shoreline features presented in Map 1 reflects some of the natural habitat features protecting the shoreline. This indicates areas where conversion of natural habitat would reduce the natural buffering capacity of the ecosystem.

INCREASED POPULATION AND DEVELOPMENT

Increased development in coastal areas amplifies the risk from coastal hazards in two ways. First, development often results in the conversion of natural habitat, with associated loss of the buffering capacity described earlier. Secondly, development close to the coast or in low-lying areas results in increased population, infrastructure, and the associated economic investments at risk. As presented earlier, as of 1995, 39 percent of the world's population lived within 100 km of coastline with an increasing density. Increasing population means that more investments in shoreline protection are necessary to accommodate the population where the shoreline is physically susceptible to erosion. Good coastal development planning, evaluation, and use of precautionary measures, such as construction setbacks, can greatly reduce the risks and costs associated with coastal development in vulnerable areas.

The Italian shoreline was assessed for susceptibility to erosion by combining the two types of information described above: physical characterization of shoreline, and level of development and economic activities along the coasts. Although qualitative, this analysis provides a helpful framework for combining the two major components of the erosion risk (D'Alessandro and La Monica 1998).

CLIMATE CHANGE AND SEA LEVEL RISE

The frequency, magnitude, and consequences of coastal hazards may increase in the future with changes in global climate. Current research focuses on reducing uncertainties in this area. Sea level rise (SLR) associated with global warming can increase the vulnerability of some coastal populations to flooding and erosional land loss by displacing the habitats that protect shoreline and increasing the severity of storm surges. In many areas, intensive human alteration and use of coastal environments have reduced the capacity of natural systems to respond dynamically to such threats.

During the past century, global sea level has risen between 10 and 25cm (Warrick et al. 1996). The IPCC Working Group I projected global SLR of 15 to 95cm by the year 2100, primarily because of the thermal expansion of the ocean and the melting of small mountain glaciers (IPCC 1996). Rising sea level presents the risk of increased impact associated with storm surges, which in turn could accelerate erosion and associated habitat loss, increase salinity in estuaries and freshwater aquifers, alter tidal ranges, change sediment and nutrient transport, and increase coastal flooding. Reduction in the extent and duration of seasonal sea ice will increase erosion in those areas (Martinson and Steele 1999). Habitats particularly at risk from sea level rise are saltwater marshes, coastal wetlands, coral reefs, and river deltas (NOAA 1999b). Coastal states with a high percentage of tidal area, and small island nations, especially those that are low-lying, are particularly at risk from sea level rise.

Global projections only provide a generalized view of what the magnitude of SLR might be. The impact would more likely be felt locally. Various regional hydraulic and geophysical factors, such as subsidence, tectonic uplift, tides, and storms, need to be taken into account but global data on these variables are lacking (Hoozemans et al. 1993). However, an analysis of coastal areas below a certain elevation still points to the distribution of areas that are potentially vulnerable to SLR. The low-lying coastal areas that are most at risk, are those where development limits options for landward retreat of the shore, and where important urban and agricultural areas are concentrated. Additionally, small island states, which typically have very long shorelines relative to their land area, can be seriously affected by even a slight retreat of the shoreline. The increasing popularity of coastal areas for housing and tourism has led to more development investment in these areas and higher potential for damage caused by SLR, floods, hurricanes, and storms.

Based upon a coarse scale (approximately 1-km grid resolution) data set reflecting worldwide elevation, we identified land areas that are at less than one, and between one and two meters elevation. Map 5 presents the results for the Caribbean, and Southeast Asia.

Based on the IPCC WGI scenario, the Coastal Zone Management Subgroup of Working Group III developed a framework for assessing the vulnerability of coastal areas to a 1 meter SLR. The assessment based on this framework is completed or planned to be implemented in 30 countries. An exploratory global assessment used countries as a unit of analysis and included socioeconomic impact as well as ecological impact. The major parameters assessed were limited to population, irrigated areas, wetlands in low-lying areas, and protection cost by country, largely because of the lack of reliable global data sets for other parameters. In addition, the hydraulic and geophysical conditions, such as subsidence and mean high water were taken into account to rank vulnerability. The impact of the SLR on the ecosystem itself is only estimated by the loss of wetland habitat extent, in combination with "coastal configuration types," which are similar to the shoreline characterization parameters presented earlier (Hoozemans et al. 1993; IPCC 1994). The results indicate that coastal wetlands in the United States, the Mediterranean Sea, the African Atlantic coast, the Asian Indian Ocean coast, Australia, and Papua New Guinea are more susceptible to accelerated sea level rise at a global scale comparison (Hoozemans et al. 1993; IPCC 1994:viii).

Information Status and Needs

We do not fully understand how and to what extent each ecosystem type stabilizes the shoreline, or how human modification of the coastal ecosystems and processes affects this capacity. As discussed previously, information on the current, as well as historic, distribution of natural coastal features and human modification of the coastal zone is essential for identifying areas where the natural capacity of shoreline protection has been reduced, and therefore, are vulnerable to SLR. Such data are limited at the global scale. *(See Extent and Change section.)* Therefore, our analysis of shoreline stabilization services, which uses existing country and regional statistics, was confined to presenting the type of information that is helpful for inferring the capacity of ecosystems to stabilize the shoreline.

With regard to monitoring coastal change, there are three broad categories of parameters that require improved data collection: (1) changes in coastal habitat extent (wetlands, mangroves, seagrasses, coral reefs, and others); (2) shoreline changes, coastal transport processes, and sediment budgets; and (3) climate change-related aspects (ocean currents, storm frequency, and SLR).

In general, quantitative, rather than qualitative, documentation of the shoreline stabilization function provided by different ecosystem types, and the damages caused by the loss of this service, are needed to better evaluate the importance of the natural coastal features and processes. Likewise, a quantitative understanding of short- and long-term shoreline changes is essential for establishing rational policies to regulate development in the coastal zone (National Research Council 1990). Shoreline position, and the rate of erosion or accretion are the two major indicators for assessing the change, but they are not extensively monitored on a global scale. In many areas, existing knowledge and data on the process and the mechanism of shoreline change are inadequate for managing beaches and barrier islands. Hydraulic and geophysical parameters that are important in assessing the local and regional variability of relative SLR are often not available at appropriate levels.

Difficulty in quantifying the change in this shoreline stabilization capacity stems from three factors: (1) the world's coastal zone consists of a number of relatively small and distinct forms; (2) coastal change is affected by a wide range of natural processes and human activities; and (3) although records of coastline change are kept by most coastal nations, these records are highly varied in type, length, and accuracy (Turner 1990). Because of the dynamic character of the natural processes acting upon the coast, and because humans have often responded in an equally dramatic way, it is difficult to distinguish natural from human-induced changes.

Proper management of shoreline protection requires information on both local and large-scale phenomena. Although field-based measurements will be necessary for refined estimates of sediment budgets and transport, remote sensing (including the use of aerial photography and new high-resolution sensors) will be valuable for monitoring changes in shoreline extent and sediment movement. Remotely-sensed data can provide valuable preliminary estimates of change.

In many instances, we do not have sufficient baseline information to assess the implications of coastal modifications and habitat alterations, or to track down the causes of adverse impacts that occur. The damage and the cost of intervention are usually very high. To avoid inappropriate and costly development actions in vulnerable coastal areas, more research and monitoring are needed.

WATER QUALITY

Coastal Water Quality

Coastal ecosystems provide an important service in maintaining water quality by filtering or degrading toxic pollutants, absorbing nutrient inputs, and helping to control pathogen populations. This is a natural function of coastal ecosystems, from which humans directly and indirectly benefit, and which influences the capacity of the ecosystem to provide other important goods and services. This capacity is limited and can be reduced by such human actions as the conversion of wetlands or the destruction of seagrass beds.

Many pollutants disperse widely and enter coastal waters from a range of pathways: direct discharge into water bodies, runoff from land, atmospheric deposition, or through ocean circulation. Accumulation of persistent chemical pollutants in marine organisms can lead to high mortality or morbidity and, in turn, disrupt the balance of the ecosystem. Contaminated fish and shellfish are no longer suitable for human consumption. High concentrations of pathogens in the water column can cause health hazards for humans, as well as beach and shellfish bed closures, which can have substantial economic impact. Pollution sources include industrial and domestic sewage, agricultural runoff, sediment pollution, oil discharges and spills, and solid waste from household, industrial, and marine sources. Ship ballast is also a source of oil, nutrients, and pathogen pollution.

DIFFICULTIES IN WATER QUALITY ASSESSMENT

Many factors make comprehensive assessment of water quality difficult. These include: differing vulnerability to pollution, broad range of water quality standards tied to a variety of goals, lack of a comprehensive analytical unit, and the wide variety of pollutants entering coastal ecosystems.

- *Differential vulnerability to pollution.* Coastal habitats respond to pollutants in various ways depending on local physical and hydrological conditions, such as shoreline, habitat and sediment type, bathymetry, flushing rate and dilution capacity, and existence of submerged aquatic vegetation (SAV). In general, an enclosed sea, bay, or estuary tends to trap pollutants within a relatively small area, and even a small amount of a pollutant can accumulate to a toxic level or become harmful to the environment. In more open coastal waters with stronger currents, the same amount of pollutant may easily mix and disperse into the open ocean. Some natural habitat types, such as coastal wetlands, are known to mitigate pollutant runoff from land. The existence and extent of natural vegetation may be one of the contributing factors determining the level of susceptibility.
- *Data interpretation—thresholds and standards.* Largely because of the differential vulnerability described above, it is difficult to identify a threshold beyond which the level of chemical concentration can be interpreted as “harmful” to

the ecosystem. Unlike conventional water quality standards that are identified based on potential human health impacts, ecosystem health-based standards would have to take into account a range of concerns. In addition, indirect or long-term effects of exposure to contaminants, such as endocrine disruption, are difficult to distinguish from natural changes and fluctuations (GESAMP 1990).

- *Lack of comprehensive analytical unit.* In order for the water quality monitoring data to be meaningful, a spatial framework for organizing the information is required. Monitoring sites need to be selected such that they are representative of an area within which physical conditions are fairly homogenous. Identifying key analytical units with boundaries that can be delineated is useful to this end. Estuaries are a commonly used unit, although these are sometimes too large and need subdivisions. Defining analytical units for specific habitat types, such as for coral reef or seagrass areas, is more difficult as these tend to be patchy, discontinuous habitats. Sandy beaches are another common unit for analysis because of the direct link between water quality and economic value.
- *Variety of pollutants.* Many pollutants entering coastal waters have different chemical properties and require different data collection and monitoring methodologies, depending on their intrinsic characteristics, such as toxicity and persistence in the environment. The adverse effects caused by water contamination can have acute, seasonal, or chronic impacts on the ecosystem.

Condition of Coastal Waters

A vast range of pollutants affects the world's coasts and oceans. This study selected key pollutants and categorized them, based on their implications for ecosystem integrity, and on existing indicators and relevant monitoring programs. The groups of pollutants selected are nutrients, pathogens, persistent organic pollutants and heavy metals, oil, and solid waste.

NUTRIENTS

Important parameters for monitoring nutrient pollution in coastal waters include the following: nitrogen and phosphorus concentrations; maximum bottom dissolved oxygen levels; extent and duration of anoxic and hypoxic conditions; extent of SAV; chlorophyll-*a* concentrations; turbidity; and duration and extent of algal blooms (by type). Some parameters are important in assessing the vulnerability of an area to the pollutants, such as nitrogen and phosphorus, or in determining baseline conditions of the area.

Estuaries—semienclosed waterbodies where fresh- and saltwater mix—are among the most productive ecosystems on earth. Their semienclosed physiography makes them more susceptible to pollution, and the variable temperature and salinity conditions within an estuary make it more difficult to monitor its ecological health. Estuarine eutrophication can have significant adverse effects on overall biological productivity, in light of the crucial role of estuaries on at least one trophic stage of many marine organisms.

Analysis of nutrients and potential eutrophication within an estuary needs to be watershed-based. All land within the watershed can contribute nutrients to the estuary. It is necessary to characterize land cover within the watershed, including agricultural use and agricultural inputs of nutrients, and examine changes in land cover. Point sources of nutrients, such as sewage outflows, must also be considered as part of the nutrient budget. These nutrient sources can then be linked with observed nutrient levels and other condition indicators described above.

Within the United States, NOAA developed a "Coastal Assessment Framework" for the watershed-based collection, organization, and presentation of data related to coastal water quality. Spatial analytical units called "Estuarine Drainage Areas" were identified based on local typography, including both land and water components (NOAA 1998). This unit has been linked with a national eutrophication survey that assesses existing conditions and trends for 16 water quality parameters, providing insight into the magnitude, timing, frequency, and spatial extent of eutrophication-related conditions in 137 estuaries in U.S. waters. Monitoring is performed for three salinity zones: tidal freshwater, saltwater, and mixed (Bricker et al. 1999).

Map 6 identifies areas of high and increasing nutrient concentration; however, the data are insufficient to detect the overall trend. Of the 137 estuaries assessed, high nitrogen concentrations (greater than 1 mg per liter) occur in 55 estuaries, covering a spatial extent of 13 percent of the nation's estuarine area, mostly in the tidal freshwater and mixing zones. It is extremely difficult to identify the threshold beyond which nutrient loading is excessive and contributes to eutrophication. The capacity of particular coastal areas to assimilate nutrients and maintain trophic balance varies, depending on the physical and chemical conditions. Hence, the vulnerability, or susceptibility, of the coastal area is an important consideration, beyond simply looking at nutrient loadings in a waterbody.

PATHOGENS

A variety of pathogenic organisms, including viruses, bacteria, protozoa, and parasitic worms, exist in seawater and can cause diseases in plants, animals, and people. Impacts include human illness, seafood contamination, and recreational beach closures. Pathogens are discharged to coastal waters through both point and nonpoint sources, especially insufficiently treated sewage that is released from septic systems on land and on ships, and from agriculture and stormwater runoff. Higher concentrations tend to occur after storms and related overflow of sewer systems, making it difficult to interpret trend and temporal fluctuations (Natural Resources Defense Council 1998). Because of the relatively low persistence of pathogens in the coastal environment, impacts are usually seasonal or acute.

Pathogen contamination has been monitored locally and concentration of coliform bacteria in the water column is the most commonly used indicator. Although often subjective and nonsystematic, standards with an application to shellfish bed and beach closures have been set locally in many of the developed countries, such as the United States and the European Union (USEPA 1997; FEEE 2000). *(See Capacity of Coastal Ecosystems to Continue to Provide Clean Water section and Map 9.)* In support of wider regional comparisons, the World Health Organization (WHO) is developing a more standardized guideline for monitoring recreational water quality to ensure the quality of analytical data and to help design and implement more consistent monitoring programs (WHO 1998).

PERSISTENT ORGANIC POLLUTANTS AND HEAVY METALS

Persistent organic pollutants (POPs) are a number of synthetic compounds, including the industrial polychlorinated byphenyls (PCBs); polychlorinated dioxins and furans; and pesticides, such as DDT, chlordane, and heptachlor, that do not exist naturally in the environment. A number of POPs often persist in the environment and accumulate through the food chain or in the sediment to a toxic level that is directly harmful to aquatic organisms and humans.

Heavy metals exist naturally in the environment and it is sometimes difficult to distinguish variations arising from anthropogenic inputs and those from the natural hydrological cycle and the atmosphere. Among the trace metals commonly monitored are cadmium, copper, mercury, lead, nickel, and zinc. When they accumulate through the food chain, at moderate to high concentrations, some of these metals can affect the human nervous system.

Bivalves and sediments are common monitoring media for both POPs and heavy metal concentrations. Bivalves are relatively immobile and accumulate algal biotoxins, heavy metals, and chemical pollutants. They are more useful for looking at current concentrations because the concentration of POPs in their body tissue reflects and responds to the change in the concentration in the water column. Monitoring sediments is more important for examining concentrations over a longer time period. Although marine sediments have been considered a reliable indicator for monitoring trace metals, interpreting the level of concentration is extremely difficult without knowledge of prior sediment composition and properties. Because chlorinated hydrocarbons persist in sediments, from which they may be reintroduced to the wider ecosystem, sediment monitoring should be designed for longer temporal coverage and be expanded to other regions.

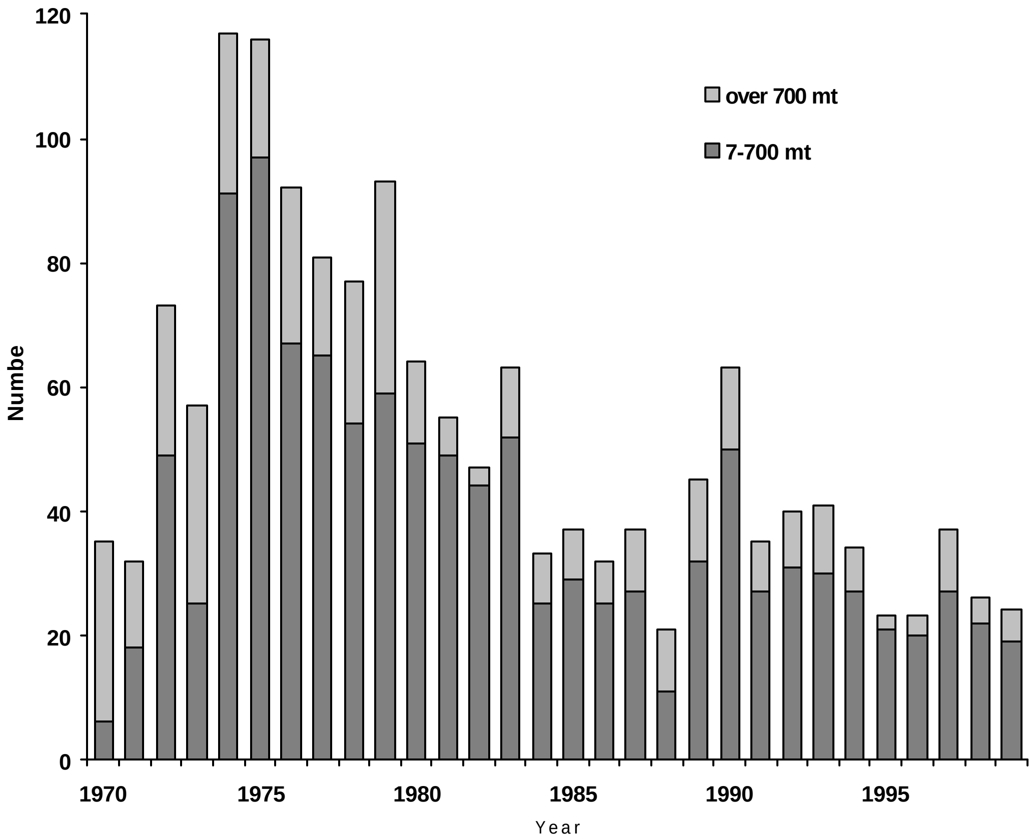
"Mussel Watch" programs in the United States, Latin America and the Caribbean, and France have provided a tool for assessing the concentration of, and monitoring changes in, POPs as well as trace metals in coastal ecosystems. There have been attempts to standardize the assessment methodology and to do regional comparisons of the data (Cantillo 1998; Beliaeff et al. 1996). Direct comparison of the measured data between regions is inappropriate because of some variations in data collection and analytical methodologies, the chemicals and metals examined, and the species monitored. These programs have established the beginnings of a global network, tracking long-term changes in POPs and trace elements. There have also been similar efforts made to compile the data at a regional scale in Europe (ICES 2000) and in Southeast Asia (Ismail, personal communication, 1999). Even within a single monitoring program, it is not appropriate to simply compare the concentration figures for different sites, as local ecosystem vulnerability will vary. Time series analysis of the sampled values within local areas can indicate improving or degrading water quality. Map 7 presents the distribution of current PCB concentrations for several sites within the U.S. program. The charts show the change in the annual average over 10 years for selected sites that have relatively high PCB concentrations. Higher concentrations tend to be observed near urban and industrial areas, and there is no clear trend over the time period.

On a global basis, contaminant levels have not caused widespread harm to marine life so far, with the exception of impaired reproduction in some mammals and fish-eating birds. Chlorinated hydrocarbons—although still high in the sediments of industrial coastal areas, and in fatty tissue of top predators, such as seals—are now decreasing in some northern temperate areas where restrictions on their use have been well enforced for some time (GESAMP 1990:52).

In the United States, for example, an analysis of trends at 186 sites revealed that although the most common observation was no trend in the chemicals monitored, where trends did occur, decreases greatly outnumbered increases. Contamination is decreasing for chemicals whose use has been banned (e.g., chlordane, DDT, dieldrin). For other chemicals, there is no evidence on a national scale for either increasing or decreasing trends (O'Connor 1998). Trends for heavy metals were also examined for 1986–1996 in the United States. Most sites showed no trend for most metals. At the national level of aggregation, there were more decreasing than increasing trends for cadmium, copper in mussels, and zinc in mussels (O'Connor 1998). In Europe, several monitoring programs examine organic and heavy metal contaminants in sea water, sediment, and mussels in both estuarine and coastal waters. Concentrations of cadmium, lead, and mercury vary from very low (similar to background levels) in some sample sites to very high in sites near contaminated areas. Throughout European coastal waters, there is no clear trend in cadmium concentrations, although lead concentrations appear to be declining overall (European Environment Agency

Figure 3

Number of Oil Spills



Source: ITOPF 2000.

1998). Contamination appears to be rising in tropical and subtropical areas because of the continued use of chlorinated pesticides (GESAMP 1990:37).

OIL

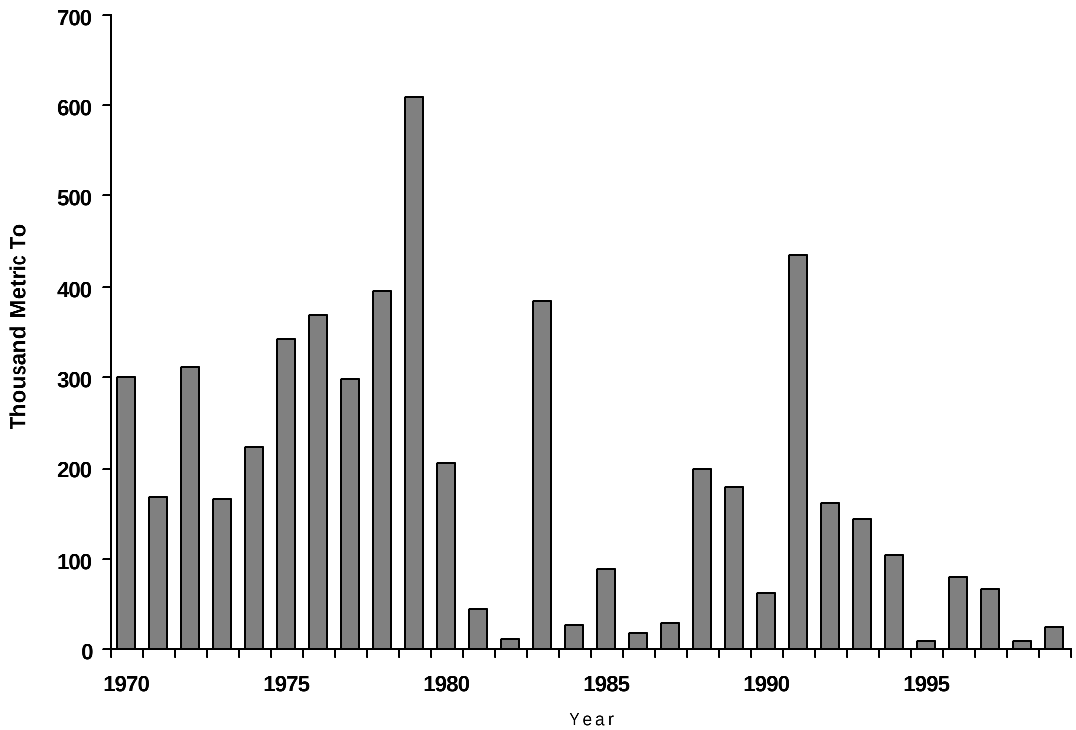
Petroleum residues can contaminate marine and coastal waters through various routes: accidental oil spills from tankers, pipelines, and exploration sites; regular shipping and exploration operations, such as exchange of ballast water; runoff from land; and municipal and industrial wastes. Although the main global impact is due to tar balls that interfere with recreational activities at beaches (GESAMP 1990), the impact of petroleum hydrocarbon concentrations in the ocean on marine organisms in the neuston zone—particularly fish eggs and larvae—requires more attention. Large-scale oil spills from tankers often make the headlines; yet nonpoint sources, such as regular maritime transportation operations and runoff from land, are actually considered to be the main contributors to the total oil discharge into the ocean, although conclusive statistics are lacking. Runoff and routine maintenance of oil infrastructure are estimated to account for more than 70 percent of the total annual oil discharge into the ocean (National Research Council 1985). Both the number and amount of *accidental* oil spills have been monitored and seem to have been in decline for the past decade (Etkin 1998). Figures 3 and 4 reflect trends in oil spills between 1970–97, with overall decline in number of major (over 700 metric tons) and intermediate (7-700 metric tons) spills. A single catastrophic event can, however, influence the statistics significantly *(see 1991 in Figure 4)* and have a localized, yet tremendous impact on the ecosystem.

SOLID WASTE

Inappropriate disposal of plastic material on land and from ships results in littering of beaches and puts marine wildlife at risk, particularly sea mammals, diving birds, and reptiles (GESAMP 1990). Some 267 species of marine organisms, particularly

Figure 4

Total Quantity of Oil Spilled



Source: ITOPF 2000.

mammals, birds, and reptiles are known to ingest or become entangled in marine debris that causes higher mortality and morbidity of those species (NOAA 1999b). Unsightly debris on beaches is an overall aesthetic impact and may influence coastal tourism revenue.

Coastal debris surveys conducted between 1989 and 1997 reveal valuable information on patterns of marine debris. Since 1989, the Center for Marine Conservation has helped organize an international coastal cleanup, which included 75 countries in 1997. The cleanup event results in the tangible benefit of cleaner beaches and valuable data on sources and amount of coastal debris. In 1997, more than 14,000 km of beach in 75 countries were cleaned of 2,800,000 kg of dangerous and unsightly trash. Plastic materials comprise the majority of the debris found (62 percent), followed by metal (12 percent), glass (10 percent), paper (10 percent), and wood (3 percent). Plastics as a percent of total have increased from 54 percent in 1993 to 62 percent in 1997 (Center for Marine Conservation 1998). The increased presence of plastics is a result of both the composition of waste discarded and the longevity of plastics in the environment.

Such coastal debris surveys, if systematically implemented, contribute to our knowledge about the degree of littering on beaches and the extent of solid waste pollution in the coastal zone. To make regional comparisons, the survey results need to be examined in the context of the frequency of the cleanup and the area extent covered. Within the existing monitoring efforts, such information is not available for all the participating countries. No comprehensive data on subtidal litter are available.

Capacity of Coastal Ecosystems to Continue to Provide Clean Water

Researchers often measure coastal pollution by how much pollution is discharged into the sea, such as the number of oil spills, the amount of sewage, or the level of pollutants in a given environment at one point in time. However, a better way to determine if the condition of the ecosystem is degraded by that pollutant is to monitor whether the ecosystem is changing as a result of the pollution and whether there is a loss of ecosystem integrity. The indicators presented below reflect biological changes in the systems and their impact on other ecosystem goods and services. Global data are available for only a few of these indicators.

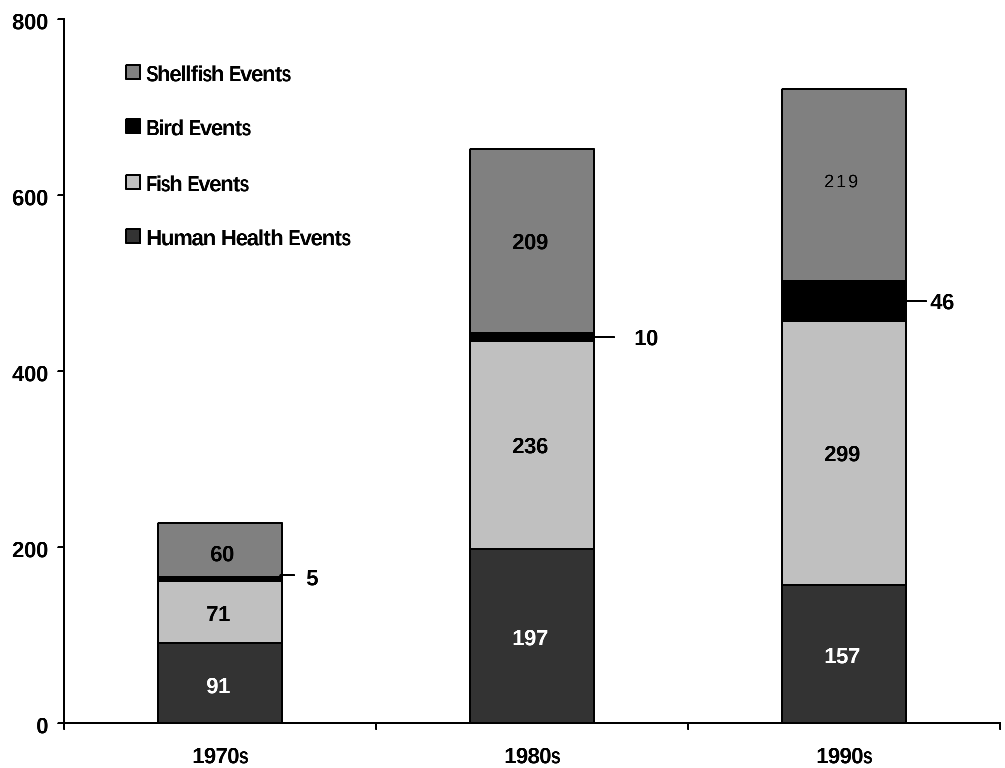
Significant changes in ecosystem condition are often detected when a coastal system exceeds its capacity to absorb additional nutrients. Dissolved oxygen levels below 2 mg/liter is a condition called hypoxia where a majority of the marine organisms cannot survive. Although historical information on hypoxia is limited, experts believe that the prevalence and extent of hypoxic zones have increased in recent decades. Map 8 presents observations of hypoxic zones around the world. This map should not be considered a complete representation of hypoxia occurrence, but rather a subset of the areas where it occurs. Such mapping is inevitably biased toward areas with better reporting mechanisms. Consequently, most observations take place in industrialized countries.

Somewhat better historical information exists for algal blooms. In particular, scientists have assembled information on Harmful Algal Blooms (HAB), which are comprised of species producing compounds that can cause health hazards. Over 60 harmful algal toxins are known today, which are responsible for at least 6 types of food poisoning, including several that can be lethal (National Research Council 1999:52). The cause of the HABs is not entirely clear and is often attributed to the introduction and colonization of some exotic algal species which subsequently develop toxicity. Algal blooms are also associated with an increase in nutrient pollution, which may enhance the rapid increase of such species. Global and regional initiatives, such as the International Oceanographic Commission (IOC) and Woods Hole Oceanographic Institution (WHOI), have compiled information on the frequency and impact of such HAB events documented at national or local scales (UNESCO 2000; WHOI 2000). Over the past two decades, the frequency of recorded HABs has increased significantly. The total number of incidents that are known to have affected public health, fish, shellfish, and birds has increased from around 200 in the 1970s to more than 700 in the 1990s. *(See Figure 5.)* This trend is, in part, due to an increase in the likelihood that an event will be reported, but a similar trend was observed even in coastal regions where monitoring systems have been in place for decades (Anderson 1998).

HAB events can be linked to economic impacts (associated with mass fish mortality) and health concerns. Since 1991, HABs in the United States have caused nearly US$300 million in economic losses in the form of fish kills, public health problems, and lost revenue from tourism and the sale of seafood (McGinn 1999:25).

Figure 5

Number of Harmful Algal Bloom Events: 1970s–1990s



Source: HEED-MMED 1999.

The data sets presented above are based on a compilation of anecdotal events, most of which are extracted from literature or media coverage. Only limited ground-based monitoring initiatives with regular data collection exist. These monitoring programs may help prevent public health events by allowing for interventions before the events occur.

Better monitoring mechanisms exist for pathogen contamination. Shellfish bed and beach closures are symptoms of the ecosystem's declining capacity to provide clean water identified by locally set thresholds. The declining capacity also represents an economic loss, linking this ecosystem's service to provide clean water to other ecosystem goods, particularly food and tourism. By combining this information with a spatial framework, such as the Estuarine Drainage Areas described earlier, it is possible to summarize and interpret the results reported for each shellfish growing area, or each beach, in a more logical watershed-oriented manner. Despite its importance in linking cause and effect of water quality degradation, current monitoring of pathogen contamination is inadequate in terms of regional comparisons and trend analysis because this is an indirect and subjective indicator that relies upon the selection of a threshold at each reporting location.

Shellfish-growing waters are more consistently monitored in some countries. For example, in the United States in 1995, out of over 10 million hectares of shellfish-growing waters that were monitored, some 69 percent were approved for harvest—up from 58 percent in 1985 (Alexander 1998:6). In 1995, the commercial harvest of these waters totaled 77 million pounds of oysters, clams, and mussels, worth approximately US$200 million at dockside (Alexander 1998). *(See Map 9 for closures in Northeast United States.)*

Another indicator directly linked to loss of other ecosystem goods is beach tar balls. Oil residue stranded on the beach or floating in the open ocean is a direct hindrance to tourism and biodiversity. IOC's Marine Pollution Monitoring Programme (MARPOLMON) was implemented in the 1980s and has compiled data collected by ships and coastal monitoring stations on oil residue in the ocean. The major limitations of this data set are the following: only a few of the reported observations show the magnitude of contamination (size and concentration); the trend in frequency may be the result of increased shipping traffic and reporting; and data are not complete for all countries and years. Map 10 reflects recent observations and trends for several sites in Japan, which is a subset of the data collected under MARPOLMON. Some of the sites are located in major coastal tourism destinations. The general trend seems to be a decline, although the incidence of accidental spills skewed the statistics in some sites.

Information Status and Needs

IDENTIFICATION OF THRESHOLDS

There are a number of monitoring programs at national and regional scales around the world. The completeness and accuracy of the data they provide vary, often relying upon different sampling methodologies and parameters. The data, therefore, are not comparable on a global basis, but are still useful for examining trends and making local comparisons (European Environment Agency 1998). Increased direct monitoring of water quality parameters, coupled with using satellite sensors, can greatly improve our knowledge of the condition of the world's coastal waters. Wider and more consistent data coverage, identification of ecosystem-based thresholds, and baseline data to help identify those thresholds are all required for the directly-measured pollution parameters to be useful. The U.S. Environmental Protection Agency's (USEPA) Total Maximum Daily Load (TMDL) Program encourages subnational governments to monitor and regulate pollutant inputs to *freshwater* bodies. TMDL is a calculation of the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards, which local governments set based on their own criteria, for drinking water, recreation, or ecological uses (USEPA 2000). Identification of the ecosystem-based threshold is a major challenge, considering the varied ecological characteristics and vulnerability of different coastal areas. However, for more proactive policy interventions to take place, setting conservative standards and systematic monitoring are essential.

REMOTE SENSING

Beyond traditional direct monitoring of water quality, satellite imagery can be used to monitor a number of key parameters over a wide spatial scale. In many cases, the use of high-resolution satellite imagery and *in-situ* monitoring data will be vital to calibrate lower-resolution remote sensing data and refine observations. For example, SeaWifs is a relatively new, coarse resolution sensor designed to monitor sea surface characteristics, particularly ocean color and marine phytoplankton concentrations. Phytoplankton concentrations, as indicated by chlorophyll-A, is relatively easy to detect, but determining concentrations is complicated by suspended sediments and dissolved organic matter in the water (Edwards and Clark 2000). For the SeaWifs sensors to be useful for differentiating types of algal blooms, improved calibration of the sensor and integration with data from ground and higher-resolution satellites is necessary. This calibration is the focus of a large research effort at present: SIMBIOS—Sensor Intercomparison and Merger for Biological And Interdisciplinary Oceanic Studies (Mueller et al. 1998).

There is a mismatch between the temporal and spatial scale of most of the pollution events, and the information provided by satellite sensors, which make the sensors of limited use for monitoring. It is possible to obtain data with an appropriate temporal and spatial scale, but it may not be cost-effective, and careful assessment of how to balance this with the cost of *in-situ* monitoring is necessary.

Satellite data can be useful for the following:

1. Habitat mapping, such as wetland extent and submerged aquatic vegetation extent. *(Described previously in the Coastal Zone: Extent and Change section.)*
2. Turbidity and sediment plumes. The extent of sediment plumes and sediment transport along the coast in surface waters is easily detected in visible wavelengths. Additionally, water color, clarity, and turbidity can be evaluated.
3. Sea surface temperature (SST). Thermal pollution and SST anomalies can be measured using either coarse-resolution or high-resolution imagery, depending upon the scale of the phenomena to be quantified.
4. Algal blooms. Coarse-resolution satellite imagery can be used to monitor the occurrence and extent of algal blooms as an early warning system.
5. Oil slicks. The occurrence of oil slicks can be detected using a wide range of satellite sensors, including visible, infrared, and microwave wavelengths, in addition to Synthetic Aperture Radar (SAR) (Edwards and Clark 2000).

IN-SITU WATER QUALITY MONITORING

To quantitatively describe pollution and related problems, water quality parameters require ground-based monitoring and collection of baseline information. The U.S. National Eutrophication Survey is a prime example. It is not possible or feasible to try to monitor every single pollutant. Careful selection and prioritization of the monitoring parameters would be necessary based on the relevance and vulnerability of the locality.

Enhanced *in-situ* monitoring is needed for the following:

1. Eutrophication-related parameters *(see Nutrients section)*.
2. Coliform concentrations and harmful bacteria. Fecal coliform, such as *Escherichia coli*, is a commonly monitored water quality parameter, but monitoring needs to be expanded in many areas. Additionally, other harmful bacteria need to be monitored in areas of elevated risk.
3. Persistent Organic Pollutants (POPs) and heavy metals. Long-term monitoring of sediment and bivalves would improve our understanding of changes in the accumulation of these toxic substances. Mussel Watch-type programs need to be more widely adopted.
4. Salinity. Salinity is a factor affecting vulnerability to pollution and is important in understanding the stratification of estuaries.
5. Indicator species. Identification of key species that are more susceptible to changes in water quality, and monitoring of that population can be useful in assessing the health of the system. No such species have been identified at a global scale.
6. Endocrine disrupters. Although causes are complex and uncertain, monitoring changes in species populations will be an important aspect of monitoring overall water quality.
7. Marine organisms mortality and morbidity events. Another way of tracking the condition of coastal waters relates to quantifying the impacts of changes. Although many effects cannot be directly tied to a single cause, they remain good indicators of when the capacity of the system has been exceeded.

BIODIVERSITY

Importance of Biodiversity

Coastal and marine biodiversity encompass a wide range of species which underpin most of the goods and services derived from coastal ecosystems. The state of knowledge about the world's marine species is limited, with the majority of them yet to be discovered. Of the 1.7 million species cataloged to date (Heywood 1995:118), about 250,000 are from marine environments (Winston 1992:149–150); however, this apparent disparity may simply arise from our lack of knowledge concerning the coasts and oceans. Life first evolved in the sea and still today marine ecosystems harbor a much greater variety of life forms than terrestrial realms do—of the 33 animal phyla (major kinds of organisms) categorized on the planet, 32 are found in the marine environment, of which 15 are found exclusively in that marine realm (Norse 1993:14–15). The wide diversity of marine organisms and habitats has lead scientists to suggest that these organisms can be an important source of new biochemical products, including medicines (Norse 1993:20–21). But many of the products that can potentially be derived from these environments have yet to be realized.

DEFINITIONS

Biodiversity is defined as "the variety and variability among living organisms and the ecological complexes in which they occur" (OTA 1987:3). Species are the most commonly used index of biodiversity. Components of biodiversity include the genetic- (gene to genome and population diversity), taxonomic- (species to higher categories, such as genera, and phyla), and ecosystem-levels (habitat, ecosystem to biogeographic realms), along with some ecosystem functions or service-levels. In the following section, we loosely define the term "biodiversity" to provide a measure of the importance of biological systems beyond that provided by the other goods and services.

The definition of habitats (generally defined as living spaces in which organisms occur) or ecosystems (more broadly defined to include physical as well as biological parameters) provides an important framework on which to build our understanding of the natural environment. Although consensus is difficult to achieve with such classification, a number of general terms are widely used and understood. *(See Table 1.)* The sheer complexity of different ecosystems, combined with the lack of knowledge regarding many of them, has restricted the scope of the current study to the following: littoral (intertidal) systems (including mangrove forests); and marine benthic systems on continental shelves (including seagrasses and coral reefs).

DIVERSITY OF COASTAL ECOSYSTEMS

One of the simplest measures of biodiversity is species richness, the number of species in a given area or system (α-diversity). A number of other measures look at genetic variety; variation at higher taxonomic levels, such as genus, family, or phylum; and variation in the habitat composition of a region or system (β-diversity). The presence of species with highly restricted distribution has been used with considerable success in highlighting areas of conservation importance in the terrestrial environment. Levels of endemism have also been used in identifying biogeographic realms and provinces. The high degree of connectivity in marine and coastal communities is responsible for generally lower levels of endemism; however, knowledge relating to marine species distribution is still insufficient for detailed analysis of patterns for most groups. Endemism is important in particularly isolated marine ecosystems, such as the Hawaiian Archipelago or hydro-thermal vent communities.

DISTRIBUTION OF REMAINING NATURAL ECOSYSTEMS

Current extent is the descriptive measurement of these biological systems using a range of measures, including the distribution of habitats *(see Coastal Zone: Extent and Change section)* and the numbers of species or endemic species, associated with the habitat. With these biological systems as a baseline we are able to assess the status or condition of these systems, using direct measures of habitat loss, degradation, or threatened species, or using proxy measures that may indicate the same thing.

At the national and subnational level, increasingly detailed and accurate maps are becoming available that show the distribution of coastal and marine ecosystems. Global maps are still poor and largely restricted to a few physical and oceanographic layers and a few ecosystems, although broader biogeographic realms, such as the large marine ecosystems (LMEs) have been mapped at the global level *(see Coastal Zone: Extent and Change section for habitat extent discussion)*. These biogeographic characterization schemes capture "natural" or "potential" distribution of habitat types and can only infer where those habitats may occur without human modification of the coastal areas.

SPECIES RICHNESS

Two sources of data are available for the compilation of multispecies distribution data sets: checklists for particular sites or countries; and global distribution maps for particular species or restricted groups. Typically, the former provide highly accurate location information, but are unavailable for many geographic areas, while the latter are often less accurate and tend to fill in gaps in apparent distribution, including small countries. Increasingly, global data are becoming available that have been compiled using either or both methods. Some of these are presented in this section.

a. Littoral Ecosystems

The communities that have adapted to live in the littoral zone are unique and of critical importance. Here, one finds a vast diversity of evolutionary adaptations, with widely differing communities often within a few centimeters of one another. Such a high β-diversity is probably unparalleled elsewhere on the planet, while α-diversity is also often very high. Littoral ecosystems contain some of the most highly productive benthic communities, with a high turnover rate, high nutrient levels, and high-energy inputs. Moreover, the littoral zone is a place of great value in many cultural and religious settings, as well as of great aesthetic significance.

The availability of data describing patterns of species richness is poor for most littoral habitats, although some data are available for the better known groups, including pinnipeds (seals and sea lions), marine turtles, and seabirds. Table 10 presents numbers of species of seabirds, marine turtles, and pinnipeds known to occur in different regional sea areas, together with percentage of global totals, and numbers of endemic species. Data were only compiled for species whose distribution is well documented and, hence, totals are comparable, but may not reflect true totals for all species in a group. Although often found in the open sea, each of these groups makes at least some use of the littoral zone.

In addition to this general information, detailed global maps are now available showing the distribution of turtle nesting beaches, and pinniped haul-out and pupping localities. The former data set has been developed over the last five years and provides comprehensive global coverage. The pinniped data were prepared for the present work and have been completed for 23 species, including all species in the subfamilies *Artocephalinae* (fur seals, family *Otariidae*) and *Phocine* (northern seals, family *Phocidae*). The data have been summarized into species totals in different coastal nations, with subdivision of larger nations into smaller political units (i.e., states, provinces, territories, island groups). Map 11 provides a visual presentation of the turtle and seal diversity along different coastal regions.

Mangroves

The term *mangrove* is alternately used to describe a group of plants and the communities in which these plants occur. Mangrove plants are shrubs or trees that live in or adjacent to the intertidal zone and have adapted to a regime of widely varying salinities, and to periodic and sometimes prolonged inundation. There are some differences in definition of which plants are truly mangrove species, however, the *World Mangrove Atlas* (Spalding et al. 1997) uses a broad definition, including some 70 species worldwide, which is widely applicable to most mapping studies and, hence, is also used here. Typically, mangrove communities are restricted to the tropics and are located along more sheltered shores and in estuarine environments. Mangroves are of considerable importance to humanity. Their role in fisheries has been widely recognized: many fish species use mangroves as breeding and nursery grounds. They are also a source

Table 10

Number of Known Littoral Species for Selected Species Groups

UNEP Regional Sea	Seabirds: Number of Species	Seabirds: % of Total	Seabirds: Number of Endemics	Pinnipeds: Number of Species	Pinnipeds: % of Total	Pinnipeds: Number of Endemics	Turtles: Number of Species	Turtles: % of Total	Turtles: Number of Endemics
Black Sea	17	6	1	2	3	0	0	0	0
Mediterranean	22	8	1	1	3	0	3	43	0
North Atlantic	56	19	4	8	24	1	2	29	0
Caribbean	23	8	1	0	0	0	6	86	1
Southwest Atlantic	33	11	1	5	15	0	5	71	0
West and Central Africa	51	18	2	5	15	0	5	71	0
South Africa	39	13	0	4	12	0	2	29	0
East Africa	44	15	2	0	0	0	5	71	0
Red Sea and Gulf of Aden	22	8	0	0	0	0	3	43	0
Kuwait	21	7	0	0	0	0	4	57	0
South Asia	26	9	0	0	0	0	5	71	0
East Asian Seas	39	13	2	0	0	0	6	86	0
Northwest Pacific	69	24	6	8	24	1	4	57	0
Northeast Pacific	66	22	14	11	32	2	4	57	0
Southeast Pacific	68	23	21	8	24	2	4	57	0
South Pacific	115	39	39	8	26	3	6	86	0
Southwest Australia	22	8	0	6	18	1	3	43	0
Antarctic	51	17	14	7	23	5	0	0	0
Arctic	27	9	0	9	26	0	0	0	0

Source: Groombridge and Jenkins 1996.
Note: The percentage represents the number of species in the region as a percentage of the world's total known species in each group of organism. The percentages do not add up to one hundred because many species are found in more than one regional sea.

of timber and fuelwood and play a critical role in coastal protection as described earlier in the section, *Shoreline Stabilization*. In many areas, mangroves are also highly productive, typically exporting large quantities of carbon to neighboring systems, but also becoming important carbon sinks, both from their own biomass and also from the nutrients delivered from upstream ecosystems.

In terms of species richness, mangroves are often considered as relatively homogenous. However, in some environments—notably the arid coastlines of the Middle East, and parts of Australia—mangroves may represent areas of important species richness and structural complexity. In terms of species distributions, Map 12 illustrates the general patterns of species richness. The center of mangrove diversity is located in insular Southeast Asia, particularly the Indonesian Archipelago, and drops away rapidly from this center. The species of the western Indian Ocean and the Middle East are all part of the same "eastern group" of mangrove species. By contrast, the species that make up the mangrove communities of West Africa, and the Americas, is a totally separate flora with links only at the level of genus or family. Endemism is not a significant feature of mangrove communities.

b. Continental Shelf Communities

The area between the lowest tides down to the edges of the continental shelf is one of the sea's most productive zones. Light typically penetrates 50-100m and may reach below 200m in clear oceanic waters, supporting benthic as well as planktonic photosynthesis. Inputs of organic and inorganic materials from the adjacent land areas further enhance such productivity. Although our knowledge base has greatly improved because of technological innovation, we have little historic and current knowledge of the status of benthic biodiversity. *(See section on Coastal Zone: Extent and Change for discussion on human modification of benthic communities.)*

Seagrasses

Seagrasses are an unusual group of marine angiosperms, all having a somewhat grass-like appearance (they are not true grasses). They are found growing in soft substrates, and often forming extensive underwater meadows. As with mangroves, they are not particularly diverse as a group, being made up of about 48 species from two families. Despite their low species richness, they remain of critical importance and, in many areas, account for a large proportion of inshore marine productivity.

Table 11
Number of Known Marine Species for Selected Species Groups

UNEP Regional Sea	Seagrass			Molluscs			Shrimps			Lobster			Sharks			Cetaceans		
	Number of Species	% of Total	Number of Endemics	Number of Species	% of Total	Number of Endemics	Number of Species	% of Total	Number of Endemics	Number of Species	% of Total	Number of Endemics	Number of Species	% of Total	Number of Endemics	Number of Species	% of Total	Number of Endemics
Black Sea	4	8	0	6	0	0	6	2	0	1	0.7	0	1	0.3	0	3	3	0
Mediterranean	5	10	1	138	3	0	31	2	0	11	7	0	43	12	0	16	18	0
North Atlantic	5	10	0	432	10	0	55	16	0	22	15	1	87	25	4	39	44	2
Caribbean	7	15	2	633	15	0	45	13	0	23	15	8	76	22	14	30	34	0
SW Atlantic	1	2	0	299	7	0	32	9	0	14	9	2	68	19	6	43	49	2
West and Central Africa	1	2	0	238	6	1	36	10	0	11	7	3	89	25	1	38	43	1
South Africa	7	15	0	145	3	0	20	6	0	22	15	2	93	27	7	32	41	0
East Africa	11	23	0	80	2	0	54	16	0	37	25	2	73	21	3	27	35	0
Red Sea and Gulf of Aden	11	23	0	57	1	0	24	7	0	14	9	0	39	11	0	25	28	0
Kuwait	5	10	0	66	2	0	14	4	0	12	8	0	34	10	1	26	30	0
South Asia	9	19	0	246	6	0	94	27	0	23	15	0	58	17	6	28	32	0
East Asian Seas	17	35	1	1,114	27	0	162	47	0	48	32	6	140	40	23	28	32	0
Northwest Pacific	13	27	5	404	10	4	91	26	0	37	25	7	93	27	9	37	42	0
Northeast Pacific	17	15	3	517	12	0	34	10	0	11	7	6	57	16	5	39	44	1
Southeast Pacific	5	10	0	393	9	2	25	7	0	8	5	2	67	19	9	39	44	2
South Pacific	19	40	2	984	23	7	63	18	0	42	28	13	128	37	35	43	49	1
SW Australia	17	35	5	197	5	0	15	4	0	10	7	1	64	18	7	36	41	0
Antarctic	0	0	0	7	0	0	0	0	0	3	2	2	0	0	0	13	15	1
Arctic	1	2	0	44	1	0	9	3	0	0	0	0	5	1	0	14	19	0

Source: Groombridge and Jenkins 1996.
Notes: The percentage represents the number of species in the region as a percentage of the world's total known species in each group of organism. The figures do not add up to one hundred because many species are found in more than one regional seas.

Moreover, they serve as an important habitat, adding structural complexity as well as a source of nutrition for many species. Unlike mangroves, seagrass communities are widely distributed in both tropical and temperate seas. The complex and often deep root structures, combined with the surface layer of leaves, serve to stabilize sediments, contributing to coastal protection and shoreline stability. They provide more directly tangible economic benefits through their importance to many artisanal and commercial fisheries. Seagrass habitat is vital as the feeding ground for a number of threatened species, notably seahorses, green turtles, and dugongs.

Given the lack of information on habitat distribution, it is not possible to map with great accuracy the actual distribution of seagrass species, although some data at the national and regional level suggest species richness patterns. Table 11 presents data on a number of species groups for which crude distribution data are available.

Coral reefs

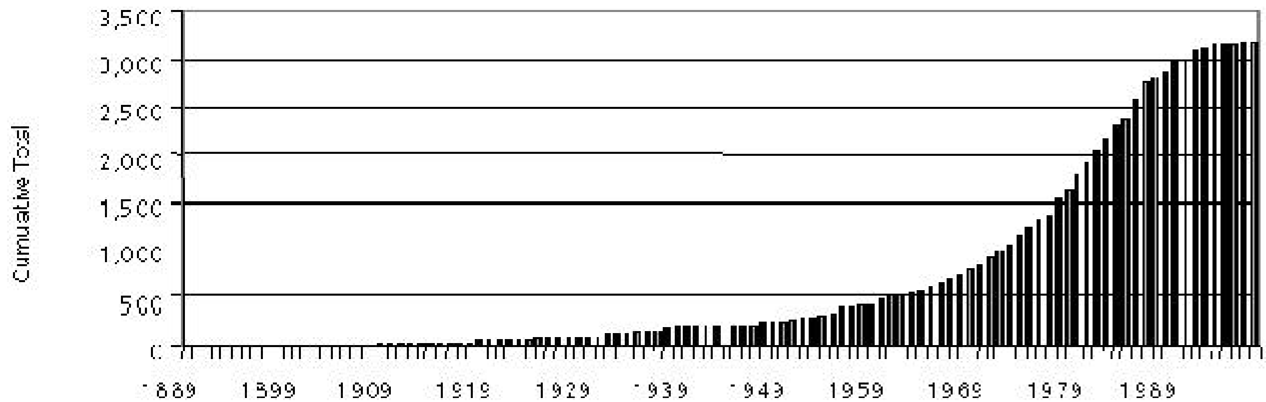
In the marine world, coral reefs are frequently singled out for special attention. Although they occupy less than a quarter of 1 percent of the global benthic environment, they are the most diverse marine habitats. Their location, in shallow waters typically close to coastlines, and their high productivity make them a critical resource in many fisheries, particularly artisanal fisheries. Their complex structure and diverse life-forms make them visually spectacular. Combined with their location in warm shallow waters around the world, their striking appearance gives them an aesthetic appeal far greater than any other marine habitat.

The vast diversity of species found on coral reefs has only just begun to be explored. It has been estimated that some 93,000 scientifically named species regularly inhabit coral reefs. However, according to Reaka-Kudla (1997), this number may be closer to one million if one includes those species yet to be discovered, named, and classified.

Despite this knowledge gap, there is considerable information available describing the distribution of certain groups of coral reef species, notably reef-building corals and coral reef fish. Analysis of these groups shows broadly similar patterns in the distribution of species richness. Map 13 shows the distribu-

Figure 6

Growth in Number of Marine Protected Areas over the Last 100 Years



Source: UNEP-WCMC 1999e.

tion of coral diversity, plotting numbers of species for different regions. As the map indicates, the Indo-Pacific region has far higher species richness in most major species groups than other regions. Within this region, the highest numbers of species are clearly centered in the Philippines, Malaysia, and Indonesia.

The coral reef fauna of the Atlantic is largely centered in the Caribbean but also to the north, across the Bahamas Bank, Florida, and Bermuda. In terms of species richness, it is far lower than the Indo-Pacific region, but it is also unique. There are very few species in common between the two regions.

CONSERVATION VALUE OF COASTAL AND MARINE BIODIVERSITY

Various conservation organizations have identified the priority areas for their activities, often based on the type of information presented above. World Wildlife Fund-US identified more than 200 ecoregions across the globe based on *biological distinctiveness* and *conservation status*, as their conservation priority areas, including 61 coastal and marine ecoregions (Olson and Dinerstein 1998). The Nature Conservancy selected conservation priority areas within Latin America and the Caribbean region using similar, but different, criteria including *urgency for conservation action* and *feasibility for conservation investment* (Sullivan Sealey and Bustamante 1999). Conservation International's priority areas for marine conservation are called "Critical Marine Areas", based on areas of high biodiversity, functional importance, and degree of threat (Conservation International 2000). These priority-setting schemes are aimed at improving effectiveness of conservation activities, particularly the targeted designation of protected areas within identified priority areas.

Marine Protected Areas

The designation of sites of particular conservation importance has received considerable support in recent decades, and the subsequent growth in the global network of marine protected areas provides a measure of biodiversity protection. Global data are available on the location of these areas, although protected area boundaries and extents are not always available. Legal protection for portions of coast or open sea is one widely used means of managing these areas and preventing or reducing certain anthropogenic impacts. Such protection may be driven primarily by the desire to protect the natural environment, but marine protected areas are also increasingly being used as tools in fisheries management or tourism. Methods and degree of protection are highly diverse. Similarly, effectiveness of protection varies and may bear little relationship to the legal status of any site.

UNEP-WCMC maintains a global database of marine protected areas for and on behalf of IUCN's World Commission on Protected Areas. The sites included in this database follow a recognized definition, embracing areas that are entirely marine, to sites that may only contain a small proportion of intertidal land. Figure 6 plots the growth in number of marine protected areas (MPAs) over the last century, indicating an increased interest in protecting the coastal environment. The vast majority of the earliest sites are terrestrial coastal and do not contain subtidal elements. The apparent tailing off in numbers of sites in recent years probably reflects the state of information in the UNEP-WCMC database rather than a significant decline in the designation rate of sites. Although the overall size of most of these sites is known, the proportion of each that is actually marine or intertidal is rarely documented. Many contain substantial terrestrial areas, and thus, it remains impossible to re-

Table 12
Threatened Littoral Species

Class	Order	Family	Common name	Number of species
Mammalia	Carnivora	Mustelidae	Otters	1
		Otariidae	Sea lions	7
		Phocidae	Seals	7
Aves	Sphenisciformes	Spheniscidae	Penguins	5
	Procellariiformes	Diomedeidae	Albatrosses	3
		Procellariidae	Petrels and shearwaters	27
		Hydrobatidae	Storm petrels	1
		Pelecanoididae	Diving petrels	1
	Pelecaniformes	Sulidae	Boobies	1
		Phalacrocoracidae	Cormorants	8
		Fregatidae	Frigatebirds	2
	Anseriformes	Anatidae	Ducks	2
	Charadriiformes	Laridae	Gulls and terns	10
		Alcidae	Murrulets	1
Reptilia	Sauria	Iguanidae	Iguanas	1
	Testudines	Cheloniidae	Turtles	7
		Dermochelyidae	Leatherback turtle	1
			Total species	85

Source: IUCN 1996.

port the actual proportion of the world's coasts and oceans that are protected. Also, the designation as "protected" does not insure that adequate management and protection of resources will occur. Many "protected" areas are inadequately funded and staffed, resulting in "paper parks."

In addition to nationally designated sites, there are many regional and global initiatives under which member-states declare protected areas of international significance. The three major global schemes in operation are the World Heritage sites nominated under the Convention Concerning the Protection of the World Cultural and Natural Heritage (the World Heritage Convention); "Ramsar Sites" declared under the Convention on Wetlands (Ramsar Convention); and Biosphere Reserves declared under UNESCO's Man and the Biosphere Programme. A number of sites under these programs include coastal and marine habitats.

Even the most effective MPAs are not isolated from their surrounding waters and face considerable problems from such indirect pressures as pollution, climate warming, and the invasion of alien species. It is clear that dealing with these problems requires far more broadly based management controls.

Condition of Coastal and Marine Biodiversity

Two broad approaches are used to assess the condition of biodiversity. One is to look directly at the status of specific species; the other, to look at the distribution and status of habitats. Reduction in population size, whether because of natural fluctuation or anthropogenic disturbances, may lead to irreversible change in the community structure and also may directly affect other goods, such as food. Direct habitat loss, through land reclamation, mangrove clearance, or destructive fishing practices, is a clear and irrefutable impact; however, the more subtle degradation of habitats over wide areas is less easily discerned. Given that there are few direct sources of information describing the condition of many of the world's coastal habitats, this study considered parameters that are potential threats to biodiversity as proxy indicators for condition.

CONDITION OF SPECIES

The Species Survival Commission of IUCN maintains a list of species threatened with extinction at the global level. These same threatened species can be used as a measure of biodiversity's condition around the world. In the absence of quantitative population trend data at global scale for most coastal and marine species, the list of threatened species serves as the only proxy, because its criteria include observed, estimated, or inferred large reductions in population and narrowed extent of occurrence. Unfortunately, the application of threat status for marine species worldwide has received relatively little attention to date. The criteria used to identify threatened species in *The 1996 IUCN Red List of Threatened Animals* are more suitable for terrestrial species. A preliminary guideline exists to evaluate threat status of marine species (IUCN 1996) and the review of the criteria for marine fishes is in process (IUCN 1999).

Therefore, the following lists for littoral and marine species are preliminary and should be interpreted with caution.

Littoral species

Direct measurement of species' condition in littoral environments is limited to a small number of case examples. Table 12 provides a list of all the threatened species from the IUCN Red List that can be regarded as littoral. The total of some 85 species is probably an accurate reflection of the groups that have been studied, as the status of most mammals, birds, and reptiles in the marine environment is relatively well known. Note that the table only includes species that spend part of their lives on intertidal or terrestrial environments. All other marine species are listed in Table 13.

Marine Species

The state of marine fisheries with respect to future supplies of food from the continental shelves and oceans of the world is considered in a separate section of this report *(see Food Production–Marine Fisheries section)*. Various human activities have had adverse impacts on biodiversity in marine environments. The collapse of the great whale stocks in the first half of this century, for example, is a classic case; however, this is not an isolated case. As described in the *Marine Fisheries* section, the majority of fisheries, at least in terms of catch statistics, focus on a limited number of highly abundant species. Even here overfishing is taking a toll. Some stocks have now almost disappeared from commercial catches. A small number of these commercially important species are now on the IUCN list of threatened species, including the Atlantic cod (*Gadus morhua*) and five pelagic species of tuna, as well as some benthic species, such as the haddock (*Melanogrammus aeglefinus*), Atlantic halibut (*Hippoglossus hippoglossus*), and yellowtail flounder (*Pleuronectes ferrugineus*). Aside from these species, numerous others that form the basis of more specialized fisheries are threatened—many shark stocks around the world have significantly decreased as have some swordfish species. Numerous species of seahorse (Family *Syngnathidae*) and sea-moth (*Pegasidae*) have been added to the list of threatened species as a result of extensive collection for traditional medicines. Other species have been impacted in collection for high-value specialty food markets and the aquarium trade.

The application of threat status to wholly marine species is a challenge. Efforts are underway to improve knowledge of threat status for marine species, however, and significant numbers have been added to *The 1996 IUCN Red List of Threatened Animals. (See Table 13.)* Although this list is far from comprehensive for most groups (with possible exceptions being marine mammals and seahorses), it warns that the extinction crisis may not only be a problem for terrestrial species. Note that other marine species that spend part of their lives on intertidal or terrestrial environments are listed in Table 12.

CONDITION OF HABITATS

Measures of habitat loss and degradation are useful indicators of habitat condition. If there are sufficiently accurate data on historical extent and status of habitats, it could be compared with the current situation. Unfortunately, for the majority of cases, even current extent data in the form of maps are highly limited at the global level and such work is usually restricted to case studies. An alternative to such data is anecdotal information reporting known localities of degradation. In such cases, there is difficulty in differentiating increased cases of true degradation from increased reporting-frequency, but such models may provide a critical tool in the absence of better information.

One example of such anecdotal information is the reported incidence of coral reef degradation. Coral reef degradation may be manifest in a number of ways, including loss of coral cover or species, and macroalgal or plankton blooms. There is concern about apparent increases in the incidence of coral diseases and coral bleaching, although the ultimate causes of the former are sometimes unclear. Coral diseases are a broad range of apparently pathogenic attacks that are being reported from reef sites across the world. In a new survey of these diseases, Green and Bruckner (2000) have developed a database with records of over 2,000 individual disease incidents. Although earliest records date back to 1902, the vast majority is from the 1970s onward. Over 25 different diseases or variants are recorded from over 50 countries. Although the mechanisms of transmission and the causes of these diseases remain unclear, they have been linked to the increasing vulnerability of corals as a result of other stresses, notably pollution and siltation, and pathogenic infection.

One further direct measure of coral stress is the phenomenon of coral bleaching and mortality associated with widespread elevated sea surface temperatures (SSTs) during the last decade (Hoegh-Guldberg 1999). This is widely predicted to increase in the future. *(See Box 3.)*

THREATS TO HABITATS

Direct measures of state and change in biodiversity are currently lacking for most coastal ecosystems. Therefore, it is necessary to infer the condition of biodiversity, at habitat level, based on some of the other measures already described in the previous sections. Knowledge of the causal relationships driving change allows the development of proxy indicators where no direct measures exist. The proxy indicators might include level of pollution, human population density, urban growth parameters, or even terrestrial land-use patterns or fisheries information. A number of these pressure indicators have already

Table 13
Threatened Marine Species

Class	Order	Family	Common name	Number of species
Mammalia	Cetacea	Balaenidae	Baleen whales	7
		Balaenopteridae	Baleen whales	6
		Eschrichtiidae	Gray whales	1
		Delphinidae	Dolphins	1
		Monodontidae	Beluga	1
		Phocoenidae	Porpoises	5
		Physeteridae	Toothed whales	1
	Sirenia	Dugongidae	Dugongs	1
		Trichechidae	Manatees	4
Elasmobranchii	Hexanchiformes	Hexanchidae	Sharks	1
	Lamniformes	Odontaspididae	Sharks	1
		Lamnidae	Sharks	2
		Cetorhinidae	Sharks	1
	Carchariniformes	Carcharhinidae	Sharks	4
	Squaliformes	Squalidae	Sharks	1
	Pristiformes	Pristidae	Sawfish	5
Actinopterygii	Acipenseriformes	Acipenseridae	Sturgeonfish	30
	Clupeiformes	Clupeidae	Sardines	2
	Siluriformes	Ariidae	Sea catfish	1
	Salmoniformes	Osmeridae	Smelt	1
		Plecoglossidae		1
		Salangidae		1
		Salmonidae	Salmon	2
	Gadiformes	Moridae		1
		Gadidae		2
	Ophidiiformes	Bythitidae		1
	Batrachoidiformes	Batrachoididae	Toadfish	5
	Lophiiformes	Brachionichthyidae		1
	Gasterosteiformes	Pegasidae		4
	Syngnathiformes	Syngnathidae	Seahorses and pipefish	37
	Scorpaeniformes	Scorpaenidae	Scorpionfish	3
	Perciformes	Polyprionidae	Seabass	1
		Serranidae	Groupers	17
		Pseudochromidae	Dottybacks	1
		Lutjanidae	Snappers	2
		Haemulidae	Grunts	1
		Sparidae	Porgies	1
		Chaetodontidae	Butterflyfish	5
		Pomacanthidae	Angelfish	1
		Pomacentridae	Damselfish	3
		Labridae	Wrasses	4
		Scaridae	Parrotfish	1
		Chaenopsidae	Blennies	2
		Callionymidae	Dragonets	1
		Xiphiidae	Swordfish	1
		Scombridae	Mackerel and tuna	8
	Pleuronectiformes	Pleuronectidae	Flatfishes	2
	Tetraodontiformes	Balistidae	Triggerfish	1
		Tetraodontidae	Pufferfish	2

Table 13 (continued)

Threatened Marine Species

Class	Order	Family	Common name	Number of species
Sarcopterygii	Coelacanthiformes	Latimeriidae	Coelacanth	1
Bivalvia	Veneroida	Tridacnidae	Clams	4
Gastropoda	Archaeogastropoda	Turbinidae	Turban shells	1
	Basommatophora	Siphonariidae		1
	Neogastropoda	Conidae	Cone shells	4
Anthozoa	Actinaria	Edwardsiidae	Anenomes	1
	Gorgonacea	Plexauridae	Gorgonians	1
			Total species	201

Source: IUCN 1996.

been reviewed in other sections of this report. *(See the sections on Coastal Zone: Extent and Change, and Water Qualty.)*

Threats to Littoral Habitats

One data set used to assess threats to littoral habitats was the Important Bird Areas (IBAs), identified by BirdLife International as conservation priority areas in the Middle East.

The level of threats to these IBAs was assessed, based on criteria such as habitat degradation, bird population, and level of legal protection. Approximately 30 percent of the IBAs in this region include coastal wetland and marine habitat as the predominant habitat type. Over 20 percent of coastal or marine IBAs are categorized under high to moderate threats *(see Map 15)*, mostly because of habitat destruction (Evans 1994:32–35).

Box 3

Coral Bleaching

The majority of corals found on reefs contain microscopic algae (*zooxanthellae*), living within their tissues in a mutually dependent partnership. This partnership breaks down when corals are stressed. One of the most common causes of such stress is high temperatures. The corals lose the algae from their tissues and become a vivid white color, as if they had been bleached. Although they may recover from such an event, if the cause of stress reaches particularly high levels, or remains for a long time, the corals may die. Exposure for one month at temperatures 1 or 2 degrees Celsius higher than the mean averages at the warmest time of year is sufficient to cause the corals to bleach.

Although some records of local coral bleaching date back decades, reports of widespread bleaching have been increasing in recent years. The most recent event was from late 1997 until mid-1998 and was global in extent, as shown in Map 14. This event was not only widespread, but was also more severe in many areas than earlier occurrences. Actual coral death reached 95 percent in some locations. In a few places massive, centuries-old corals have died; in others there has now been at least a partial recovery, with loss of only a few corals.

The ultimate cause of this bleaching was higher than average water temperatures, during one of the largest El Niño events of this century. While this may be an entirely natural phenomenon, two points are important to consider for climate change. First, background rises in ocean temperatures exacerbate El Niño events. Second, the temperatures that drove this particular change are not significantly higher than those predicted to be occurring regularly in tropical environments in 50 to 100 years.

Individuals of some coral species show wide variations in temperature tolerance. There may be sufficient genetic variance to support some adaptation to changes in temperature. What is not clear, however, is whether such adaptation will occur sufficiently quickly to enable maintenance of functional reef habitats. The species themselves may survive, but the habitats may be severely degraded.

Even assuming a rapid adaptation, there are additional concerns that changing concentrations of carbon dioxide in surface waters may alter the proportion of the mineral aragonite in the same waters. Corals require aragonite for calcification and it is predicted that concentrations of this mineral could be reduced by 14-30 percent over the next 50 years, greatly reducing reef-building potential.

The impacts of wide-scale decline or loss of coral reefs are many: declines in reef fisheries, loss of coastal protection, loss of unique species assemblages, and significant drops in tourism activities and revenues. There is an urgent need to address these issues in more detail and further consider how other anthropogenic stresses may exacerbate these problems.

Table 14

Level of Threats to Coral Reefs

A) Regional Summary

Region	Reef Area By Threat Category (square km) Total	Low	Medium	High	Percentages Low	Medium	High
Middle East	20,000	7,800	9,200	3,000	39%	46%	15%
Caribbean	20,000	7,800	6,400	5,800	39%	32%	29%
Atlantic	3,100	400	1,000	1,700	13%	32%	55%
Indian Ocean	36,100	16,600	10,500	9,000	46%	29%	25%
Southeast Asia	68,100	12,300	18,000	37,800	18%	26%	56%
Pacific	108,000	63,500	33,900	10,600	59%	31%	10%
Global Total	255,300	108,400	79,000	67,900	42%	31%	27%

B) Selected Country and Geographic Grouping Summary

Country/region	Reef Area By Threat Category (square km) Total	Low	Medium	High	Percentages Low	Medium	High
Australia	48,000	33,700	13,700	600	70%	29%	1%
Fiji	10,000	3,300	4,800	1,900	33%	48%	19%
French Polynesia	6,000	4,900	1,100	0	82%	18%	0%
India	6,000	1,400	500	4,100	23%	8%	68%
Indonesia	42,000	7,000	14,000	21,000	17%	33%	50%
Lesser Antilles	1,500	0	300	1,200	0%	20%	80%
Maldives	9,000	7,900	1,100	0	88%	12%	0%
Marshall Islands	6,000	5,800	200	0	97%	3%	0%
New Caledonia	6,000	5,000	800	200	83%	13%	3%
Papua New Guinea	12,000	6,000	4,500	1,500	50%	38%	13%
Philippines	13,000	50	1,900	11,050	0%	15%	85%
Saudi Arabia	7,000	2,500	4,100	400	36%	59%	6%
Solomon Islands	6,000	3,000	2,500	500	50%	42%	8%
Hawaii	1,200	650	450	100	54%	38%	8%

Source: Bryant et al. 1998.
Notes: Reef area estimates are based on UNEP-WCMC (1999a) and Spalding and Grenfell (1997). Estimates of shallow reef area for Australia, Indonesia and the Philippines are significantly smaller than other published estimates.

Threats to Coral Reefs

In recent years, considerable concern has been raised over the increasing number of threats facing the world's coral reefs. Immediate threats fall under five broad categories: climate change, pollution (from both terrestrial and marine sources), sedimentation, overexploitation, and destructive fishing practices.

The impacts of these threats are typically those of reef degradation, rather than absolute loss, and are not shown on habitat extent maps. Some understanding of the extent and distribution of damage caused by such events can be gauged from direct records of these activities or from records of reef degradation. Since 1994, the International Center for Living Aquatic Resources Management (ICLARM) has been developing ReefBase—a global database on coral reefs. This database now contains many records of observed threats to coral reefs, including pollution events, sedimentation, and destructive fishing practices. These are presented in Map 16.

Although this map indicates known events, it is restricted by the availability of information. In addition, the data do not show the extent or degree of impact. One alternative method has been to model the potential areas where these impacts may be occurring. Bryant et al. (1998) undertook an exercise to model these potential areas at risk. Using a number of indicators and predictions of sediment, marine and terrestrial sources of pollution, and overfishing, they modeled the level of threats to coral reefs around the world and tested the results against the known data holdings of ReefBase and through expert verification. A summary of these findings is presented in Table 14.

THREATS TO ECOSYSTEM STRUCTURE

Species assemblage is an important element of biodiversity that can be measured to assess an ecosystem's condition. Community structure can be dramatically and irreversibly changed by various anthropogenic pressures, such as introducing exotic species or removing dominant species or top predators through overfishing. Change in community structure over long periods can be inferred from the shift in predominant species within a geographic area. Given the limited availability of marine species population data, we can only discuss this as a potential area of new indicator development.

Fishing Practices

One way to assess the structure of marine ecosystems is to look at changes in species assemblages in terms of trophic levels. The change in the relative abundance of top predators affects the lower trophic level species, leading to a shift in community structure. This approach to analyzing the FAO fisheries dataset was introduced by Pauly et al. (1998a), and further evaluated in the *Marine Fisheries* section of this report. The FAO data set primarily consists of commercially exploited species groups; therefore, it is inadequate in detecting a change in the overall structure of the marine ecosystem. In areas such as the North Atlantic and Northeast Pacific, however, significant transitions in the trophic level composition of catches seem to have occurred between the 1950s and 1990s, indicating dramatic changes in community structure and subsequent change in the exploitation pattern for those particular areas *(see Marine Fisheries section)*. Pauly et al. (1998b) also estimated trophic categories for 97 marine mammals based on literature about the diet composition, which, if combined with population studies, can be useful for assessing ecosystem change at the structural level.

Aside from the direct effects of fishing on the target species themselves, there are considerable indirect effects caused by destructive fishing practices, which are less well documented. Bycatch is a widespread problem *(see a more detailed discussion in the Marine Fisheries section)*. Early attention was drawn to this problem, focussing on high profile species, such as dolphins being captured in tuna fisheries. More recently, the massive and indiscriminate catches of large driftnets have received similar attention and resulted in a U.N. ban on high-seas driftnet fisheries. Apart from the impact on the bycatch species themselves, discards affect the wider marine commuunity, presenting a considerable input of fish protein to scavenging species. Removing large numbers of target species and unwanted bycatch can also have a significant bearing on biodiversity and on community structures, by altering patterns of competition or predator-prey relations. A number of fish and invertebrate species have high mortality rates following discard. Bottom trawling is another fishing method that has gained increasing attention because of its adverse impact on benthic communities. *(See Box 2 in Coastal Zone: Extent and Change section.)*

Invasive Species

One of the most underreported and globally pervasive threats to natural ecosystems worldwide is the arrival of invasive species. Although some movement of species from region to region around the globe can be regarded as a natural process, human vectors have greatly exacerbated the rates of these movements and the distances covered. Proliferation of introduced algae species is sometimes attributed as a cause of Harmful Algal Blooms (HABs), posing direct threats to biodiversity as well as public health. *(See section on Water Quality for a discussion on HABs.)*

In the marine environment, one of the most significant and problematic sources of biological invasion is from the ballast water of ships. On any given day, it is estimated that perhaps 3,000 different species are carried alive in the ballast water of the world's ocean fleets (Bright 1999:156). One of the worst examples is the introduction of the so-called Leidy's comb jelly *(Mnemiopsis leidyi)* from the American Atlantic into the waters of the Black Sea in 1982. Unchallenged by natural predators, this species proliferated to peak numbers in 1989, 1994, and 1995 comprising about 95 percent of the entire wet weight biomass in the Black Sea (Shiganova 1997, 1998, and 2000). These animals devastated the natural zooplankton stocks, driving massive algal blooms and disrupting the natural food chains. This, subsequently, contributed to the collapse of the important anchovy fishing industry in the Black Sea (Bright 1999:157). This invasive also migrated from the Black Sea to adjacent basins, such as the Sea of Marmara and the eastern Mediterranean, in the early 1990s (Shiganova 1998:306). In addition, increased abundance of invasive *Mnemiopsis* has recently been observed in the Caspian Sea. The origin and cause of this introduction are still unknown, although it is most likely to be through ballast water (Shiganova 2000).

Other causes of biological invasion include the intentional introduction of nonnative species for fisheries stocking or ornamental purposes, and the accidental introduction associated with aquaculture. One final mechanism is that of Lessepsian migration, where species move through artificial canals, most notably through the Suez Canal from the Red Sea into the Mediterranean and vice versa.

There are no global data sets on introduced species, although comprehensive data are available for some countries and regions. A number of these have been gathered together for this report and Table 15 presents summary data for the waters where such data are available. The marine ecosystems in the Mediterranean now contain 480 invasive species, the Baltic Sea contains 89, while Australian waters contain 124 species.

Capacity of Coastal Ecosystems to Sustain Biodiversity

The condition indicators presented above do not provide a complete picture of how well biological systems are functioning globally in terms of maintaining biodiversity. From the evidence of habitat loss and the increasing level of threats, however, the capacity to maintain biodiversity seems to be declining in many parts of the world. Because of the lack of directly measured

Table 15
Number of Invasive Species in Baltic Sea, Mediterranean, and Australian Waters

	Baltic	Mediterranean	Australia
SPECIES GROUP			
Algae	16	25	17
Angiospermae	X	1	X
Annelida	8	28	7
Bryozoa	1	7	9
Chaetognatha	X	1	X
Chelicerata	X	1	X
Ascidea	1	9	3
Pisces	20	115	16
Aves	1	X	X
Mammalia	2	1	X
Cnidaria	4	7	5
Crustacea	23	104	27
Ctenophora	X	1	X
Echinodermata	X	5	3
Entoprocta		X	1
Mollusca	12	164	36
Nematoda	1	X	X
Porifera	X	9	X
Protozoa	X	1	X
Sipunculida	X	1	X
PLACE OF ORIGIN			
Black Sea	22	1	X
North Atlantic	29	22	X
Tropical Atlantic	X	33	X
Southern Africa	1	X	X
Red Sea	X	337	X
Indian Ocean	X	2	X
Indo-Pacific	8	42	X
North Pacific	15	3	X
Pacific Ocean	4	3	X
New Zealand	1	X	X
Eastern Pacific	X	1	X
China Seas	1	X	X
Circumtropical	X	1	X
Siberia	2	X	X
North America	2	X	X

Sources: Olenin and Leppäkoski 1999; Madl 1999; CSIRO-CRIMP 1999; FishBase 1998.

condition information over sufficient time-scales, it is impossible to estimate the degree to which this capacity has changed or is changing for many marine ecosystems.

As described earlier in the section on *Water Quality*, mass mortality and morbidity of marine organisms are a clear evidence of deteriorated ecosystem function caused primarily by pollution. Because changes at such high levels are generally complex and often are manifestations of multiple damages to the ecosystems, they are not useful as predictive indicators of particular stresses. Detection of changes at finer scales or closer proximity to the individual pressures, such as habitat loss or water pollution, that underlie the loss of biodiversity would provide better early warning signals.

Information Status and Needs

Given the poor state of knowledge of the extent and distribution of coastal ecosystems, information on the current status of its biodiversity is also limited. Identifying and describing areas of high conservation importance at genetic, species, and ecosystem levels, or areas of high natural productivity, would help improve the effectiveness of conservation activities with limited resources. Basic taxonomic inventory of coastal and marine ecosystems requires special efforts (Convention on Biological Diversity 1998:21) to support subsequent biogeographic research. Information on species distribution is widely available for many groups, but there remains a need to bring such data together into more broadly based data sets from which maps of species richness can be drawn (especially for groups other than fishes, corals, mangroves, and seagrasses). The species distribution information that exists is quite general, but combining such data with knowledge of available habitat can greatly refine distribution maps.

The threat status of particular species represents a potentially important indicator; however, the list of such species to date, particularly for fishes and invertebrates, is not comprehensive. A clearer approach to the application of threat categories is needed, ideally fully supported by better documented scientific evidence, followed by a concerted effort to apply these categories. Along with the species-level condition indicators, further research needs to be explored in the area of indicators for community structure and ecosystem function. Symptoms of ecosystem degradation, such as mass mortality and morbidity events, should be more extensively and systematically monitored, in order to assess the condition of biodiversity.

Data presented on the extent of major threats provide only a partial picture. For example, the impacts of trawling are considerable and several local studies exist to assess the impacts (Poiner et al. 1998; Kaiser 1998). Further work is needed, however, to ascertain in sufficient detail the extent and intensity of its impact on global biodiversity. Using field records of impacts on biodiversity, such as those presented here on coral reefs, is one other useful tool, although caution is needed. It is important to try to distinguish between major and minor events, and between data holes and true areas of low impact.

Similarly, although current databases can give some impression of the distribution of protected areas, it is not possible with current data holdings to identify the proportion of coasts and oceans that are protected, nor the proportion of different habitats. There is an urgent need to improve the amount of data available describing MPAs worldwide and the effectiveness of this network. The existing MPA data also need to be expanded to include other management regimes, such as fisheries controlled areas.

FOOD PRODUCTION – MARINE FISHERIES

Importance of Marine Fisheries Production

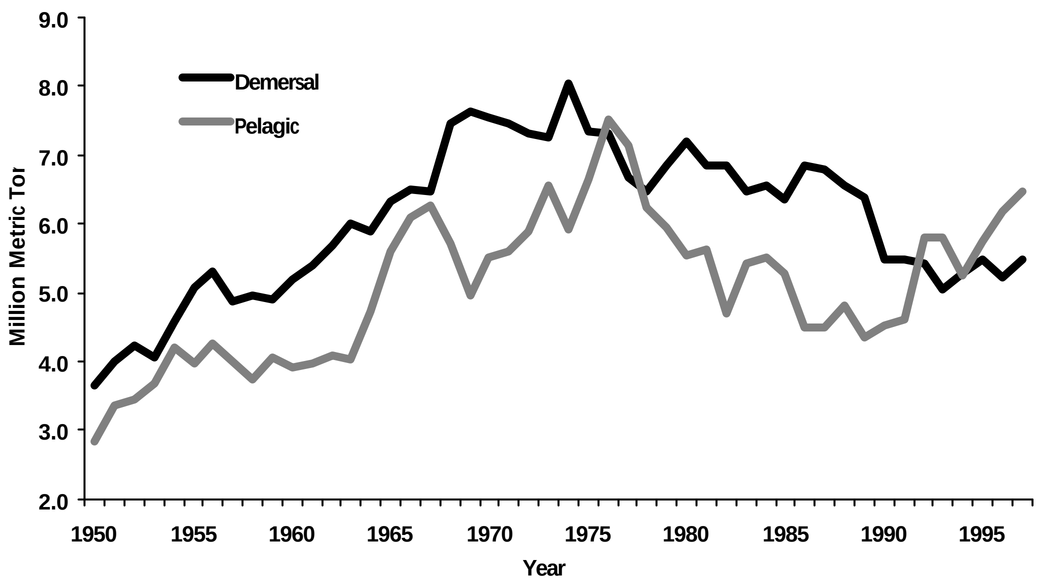
Fish and shellfish production is a vital element of the human food supply and one of the most important goods derived from coastal and marine ecosystems. More than 90 percent of the marine fish catch comes from these coastal ecosystems, whereas only a small percentage comes from the open ocean (Sherman 1993:3; Hinrichsen 1998:32). In 1997, fish provided 16.5 percent of the total animal protein or 6 percent of the total protein consumed by humans (Laureti 1999:41). Around 1 billion people—most of who live in developing countries—rely on fish as their primary animal protein source (Williams 1996:3). Of the 30 countries most dependent on fish, all but 4 are in the developing world (Laureti 1998:v). Indeed, in developing countries, fish production almost equals production of all major meat commodities (poultry, beef and veal, and sheep and pork), and globally, production is far greater than for any one of these commodities (Williams 1996:3). But the contribution of fish to the food supply is likely to decrease in the next two decades as demand increases and production flags (Williams 1996:13,27).

In 1997, some 93 million metric tons of fish and shellfish were available for direct human consumption (64 million metric tons from the oceans and inland waters, and 29 million from aquaculture), while another 29 million metric tons were processed for reduction to fish meal (FAO 1999b). The Food and Agriculture Organization of the United Nations (FAO) expects that quantities available for human consumption in 2010 will range between 74 million metric tons in a pessimistic scenario and 114 million metric tons in an optimistic scenario (FAO 1999c:1). According to their estimate, the optimistic scenario could only be satisfied if aquaculture production doubles and overfishing is brought under control so that ocean fish stocks can recover. But it is perhaps more likely that aquaculture growth will be more moderate, and the ocean catch will plateau at present levels or decline as overfishing continues to take its toll, leaving a substantial gap between supply and demand, raising fish prices, and threatening food security in some regions (Williams 1996:14-15, 25-26).

Any shortfall in fish supplies is likely to affect developing nations more than developed nations. As demand and prices rise, exports of fish products from developing nations to wealthy nations will tend to rise as well, leaving fewer fish for local con-

Figure 7

Pelagic and Demersal Fish Catch for the North Atlantic: 1950–1997



Source: FAOe 1999.

sumption and putting this protein increasingly out of reach for low-income families (Williams 1996:15, 27).

In addition to being a vital source of protein, fish and shellfish production is also an important factor in the global economy, particularly in developing countries where more than half of the export trade in fish products originates (FAO 1999a:21). Global earnings from fishery exports in 1996 were US$52.5 billion, which is equivalent to 11 percent of the value of total agricultural exports for that year (FAO 1999a:20). In 1990, all capture fisheries and aquaculture (marine and freshwater) employed more than 28.6 million people worldwide (FAO 1999a:64) of which 95 percent were in developing countries (FAO 1999d:1). If current trends continue, the pattern of employment within the fisheries sector is likely to shift dramatically in coming years, especially for small-scale fishers harvesting food for local markets and subsistence. Artisanal fishers have been losing ground over the last two decades as competition from commercial vessels has grown. For instance, surveys off the west coast of Africa show that fish stocks in the shallow inshore waters where these fishers ply their trade dropped by more than half from 1985 to 1990 because of increased fishing by commercial trawlers (FAO 1995:22). This trend is likely to intensify as fish stocks near the shore continue to decline under heavy fishing pressure.

Status and Trends in Marine Fisheries Production

World fisheries face a grim forecast. Forty-five years of increasing fishing pressure have left many major fish stocks depleted or in decline—a story well documented in recent years in the media and in government statistics. Global marine fish and shellfish production, both from capture fisheries and aquaculture (including the production of aquatic plants), has increased sixfold since 1950, from 17 million metric tons to 105 million metric tons in 1997 (FAO 1999e). However, a closer look at these numbers shows that the rate of increase for capture fisheries has slowed down from an average 6 percent increase per year during the 1950s and 1960s, to 1.5 percent from 1983-93, and to just 0.6 percent for the period 1995-96 (FAO 1999a:3).

The rapid increase in fish production has come partly from an increase in aquaculture, which now accounts for over a fifth of the total harvest—including inland and marine fish production (FAO 1999a:10). In marine and brackish environments alone, aquaculture production nearly tripled during the period from 1984 to 1997 and continues to expand rapidly (FAO 1999e).

Another reason for the global production increase is the change in the composition of the harvest. About 30 percent of the harvest consists of small, low-valued fish, such as anchovies, sardines, or pilchard, many of which are not used directly for food, but are reduced to fish oil or fish meal. These, in turn, are used as a protein supplement in livestock feeds and, ironically, in aquaculture feeds for high-valued products, such as shrimp, salmon, and other carnivorous species. Over time, the percentage of the global catch made up of these low-value species has risen as the harvest of high-value demersal species has plateaued or declined, partially masking the effects of overfishing (FAO 1997:3; Rothschild 1996:23). An example of this change in the composition of the fish catch can be seen in Figure 7 for the North Atlantic fisheries.

Overfishing is not a new phenomenon and was recognized as an international problem as far back as the early 1900s (FAO 1997:13). However, prior to the 1950s, the problem was much more confined, since only a few regions, such as the North Atlantic, the North Pacific, and the Mediterranean Sea, were heavily fished and most world fish stocks were not extensively exploited. Since then, the scale of the global fishing enterprise has grown rapidly and the exploitation of fish stocks has followed a predictable pattern, progressing from region to region across the world's oceans as each area in turn reaches its maximum productivity and then begins to decline (Grainger and Garcia 1996:8, 42-43). *(See Table 16.)*

Pressures on Marine Fishery Resources

Exploitation of marine fishery resources to provide food for the world's population takes a heavy toll on the sustainability of these ecosystems by disrupting key habitats and altering the species assemblages of many coastal areas. *(See section on Biodiversity.)* Although total fish production figures continue to increase, the adverse impacts of overfishing in combination with pollution and the effects of destructive fishing practices and fishing gears have become evident in different regions of the world.

One of the principal drivers of current overfishing is a critical overcapacity in the world fishing fleet. The level of effort put into fishing on a global basis has increased rapidly as the world fleet has grown and fishing technology has improved. During the 1970s and 1980s, the fleet grew at twice the rate that fish catches were increasing (FAO 1992). Globally capacity is now far in excess of what is needed to catch the maximum sustainable yield of fish. The problem of too many vessels with too much gear plagues both developed and developing nations, but is especially acute in developed nations, where a good deal of capital has been invested in building new boats without a concomitant effort to retire older vessels. A recent review of Europe's fisheries by the European Union indicates that the fishing fleet plying European waters would need to shrink by 40 percent to bring fleet size into balance with the remaining fish supply (FAO 1997:65). Worldwide, overcapacity is estimated at somewhere between 30 and 40 percent as well (Garcia and Grainger 1996:5).

Table 16

Comparison of Maximum Landings to 1997 Landings by Fishing Area

FAO Fishing Area	1997 Landings (10^3mt)	Max. Landings (10^3mt)	Year of Max. Landings	Percentage Decline
Northwest Atlantic	2,048	4,566	1968	55.1%
Northeast Atlantic	11,663	13,234	1976	11.9%
Western Central Atlantic	1,825	2,497	1984	26.9%
Eastern Central Atlantic	3,553	4,127	1990	13.9%
Mediterranean & Black Sea	1,493	1,990	1988	25.0%
Southwest Atlantic	2,651	2,651	1997	–
Southeast Atlantic	1,080	3,271	1978	67.0%
Western Indian Ocean	4,091	4,091	1997	–
Eastern Indian Ocean	3,875	3,875	1997	–
Northwest Pacific	24,565	24,565	1997	–
Northeast Pacific	2,790	3,407	1987	18.1%
Western Central Pacific	8,943	9,025	1995	0.9%
Eastern Central Pacific	1,668	1,925	1981	13.4%
Southwest Pacific	828	907	1992	8.7%
Southeast Pacific	14,414	20,160	1994	28.5%

Sources: FAO 1999e and 1999f.

Excessive harvests from too many boats are not the only factor in depleting world fish stocks. Modern trawling equipment that is dragged along the sea bottom in search of shrimp and bottom-dwelling fish, such as cod and flounder, for instance, can devastate the sea floor community of worms, sponges, urchins, and other nontarget species as it scoops through the sediment and scrapes over rocks. *(See Box 2 in the Coastal Zone: Extent and Change section.)* Studies show that the thick natural carpet of bottom dwelling animals and plants are important for the survival of groundfish's fry, such as cod, that find shelter and protection there. Some researchers believe this destruction of fish habitat is one of the principal factors in fish decline in some heavily trawled areas (Holmes 1997; Raloff 1996). Such habitat destruction is compounded by deteriorating environmental conditions from pollution and coastal development in

Table 17
State of Exploitation and Discards by Major Fishing Area

FAO Fishing Area	Status in 1995	Discards 1988–92
Northwest Atlantic	Overfished	27%
Northeast Atlantic	Overfished	19%
Western Central Atlantic	Overfished	14%
Eastern Central Atlantic	Overfished	10%
Mediterranean and Black Sea	Fully Fished	25%
Southwest Atlantic	Increasing	14%
Southeast Atlantic	Overfished	27%
Western Indian Ocean	Increasing	22%
Eastern Indian Ocean	Increasing	30%
Northwest Pacific	Increasing	22%
Northeast Pacific	Overfished	26%
Western Central Pacific	Increasing	33%
Eastern Central Pacific	Overfished	27%
Southwest Pacific	Overfished	15%
Southeast Pacific	Increasing	21%
Antarctic	Overfished	10%

Sources: Fisheries status from Grainger and Garcia 1996; Discards from Alverson et al. 1994 and FAO 1996.
Note: Discards are shown as a percentage of the overall catch (landings plus discards).

many of the inshore areas that are critical to fish spawning and rearing (Garcia and Newton 1997:14).

Additional pressures on fish populations and other marine animals are the high bycatch and discard rates and some regulation-driven practices, such as high grading, which accompany modern commercial fishing. Bycatch includes incidental catch—nontarget species that are caught during fishing operations and are either retained for sale or returned to sea—and discarded catch, which is the portion of target species' catch that is returned to the sea because of legal, economic, or other considerations (Alverson et al. 1994:6). High grading is a profit-driven practice used in controlled fisheries, where smaller fish of the target species that have been caught are discarded to make room for larger more valuable specimens caught later in the day. Discarded species have very low survival rates by the time they are returned to the sea. It is believed that the present levels of bycatch and discards are contributing to biological overfishing and changes in the species composition in the marine environment (Alverson et al. 1994:48). In 1994, Alverson et al. assessed the level of bycatch and discards in the world's commercial marine fisheries and calculated that the mean estimate of global discards amounted to 27 million metric tons. The highest discards were estimated to occur in the Northwest Pacific region (9 million mt), followed by the Northeast Atlantic (3 million mt), and the West Central Pacific and Southeast Pacific (2.7 and 2.6 million mt, respectively). Shrimp fisheries, particularly shrimp trawls, had by far the highest discard rate, accounting for more than a third of total global discards (Alverson et al. 1994:24). This assessment did not include data from inland, marine molluscs, or recreational fisheries. It also excluded bycatch of marine mammals, turtles, and birds. However, discard rates of some of these species continue to be high, with important consequences for biodiversity, especially for those already threatened species, such as marine turtles. A follow-up FAO meeting held in Tokyo at the end of 1996 (FAO 1996) reviewed the discard situation in seven FAO fishing areas and concluded that the 1994 estimate done by Alverson et al. may have overestimated the figures, and that in many important areas discarding had been reduced. As a consequence, FAO considers the present rough estimate to be more of the order of 20 million—the equivalent of about 25 percent of the reported annual production from marine capture fisheries (FAO 1999a:51). *(See Table 17.)*

Condition of Marine Fisheries Resources

Traditionally, the state of a particular fishery is assessed based on catch statistics and measures, such as Maximum Sustainable Yield (MSY)—the theoretical number of fish that can be harvested without causing a decline in the population in the long term. Even though these measures may indicate the condition of a particular species or group of species, they do not portray the ecosystem's condition. In addition, catch statistics provide limited understanding of the trends in commercial fish populations. Because of changes in fishing gear, technology, market demand, and the discovery of new fishing grounds, catch statistics do not tell the full story of the coastal and marine resources. The FAO database on fishery catches, however, is the most complete data set currently available at the global level and has been used as a diagnostic for the changes in marine ecosystems that have undoubtedly occurred, especially over the last half-century (Caddy et al. 1998a; FAO 1995, 1997, 1999a; Grainger and Garcia 1996).

The last 50 years has seen an unprecedented geographic expansion and increase in fishing intensity by industrial fleets from the core areas in the North Atlantic and North Pacific, to areas that were unexploited or underexploited in the 1950s. During recent decades, many world continental shelf areas have passed their peak in terms of productivity (metric tons/km2 continental shelf) with a subsequent decline in multispecies catches (Caddy et al. 1998a). *(See Map 17.)*

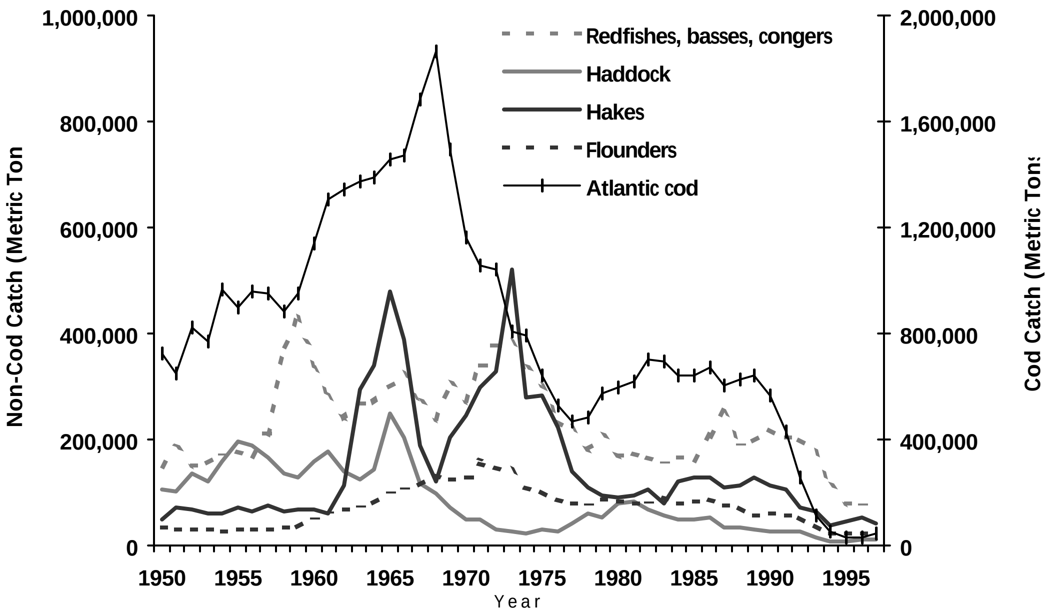
ASSESSING CONDITION THROUGH STOCK ASSESSMENTS

Two analyses, lead by scientists at FAO, provide an idea of the current state of world fish stocks.

A recent analysis based on records of fish landings from 1950 to 1994, shows that 35 percent of the most important commercial fish stocks exhibit a pattern of declining yields and require

Figure 8

Commercial Harvest of Important Fish Stocks in the Northwest Atlantic



Source: FAO 1999e.

immediate action to halt overharvesting and allow them to recover (Grainger and Garcia 1996:31). The declines in the catch from overfishing have been quite dramatic: landings of all fish stocks that FAO classifies as "overexploited" fell from 14 million metric tons in 1985 to 8 million metric tons in 1994—a drop of 40 percent in only 9 years (Grainger and Garcia 1996:10). Actually, this masks more precipitous drops in certain fish stocks like Atlantic cod, haddock, and redfish, which have all but collapsed in some areas of the Northwest Atlantic as shown in Figure 8 (FAO 1999e; Grainger and Garcia 1996:11).

As of 1999, FAO reported that 75 percent of all fish stocks for which information is available are in urgent need of better management: 28 percent are either already depleted from past overfishing or in imminent danger of depletion due to current overharvesting; and 47 percent are being fished at their biological limit and therefore vulnerable to depletion if fishing intensity increases (Garcia and De Leiva Moreno 2000). According to this last assessment, 75 percent of the fish stocks will require "stringent management of fishing capacity" for these resources to stabilize or recover. So far, only a few countries have implemented this form of management, mostly in developed countries (Garcia and De Leiva Moreno 2000).

ASSESSING CONDITION THROUGH TROPHIC LEVEL ANALYSIS

Another indicator of the condition of coastal and marine ecosystems (from the standpoint of fisheries resources) is the ratio of fish stocks' abundance at different trophic levels. In many fisheries, the most prized fish are large predatory species high in the food web, such as tuna, cod, or hake. With time, the fishery will often shift to new target species, lower in the food web, when the original target population is depleted. If the decrease in the relative abundance of high trophic level species cannot be accounted for by changes in demand or technology, then scientists believe that the pattern may reflect a broad change in the relative abundance of different trophic levels.

One cause of this change is a pattern of exploitation known as "fishing down the food web," described by Pauly et al. (1998), whereby fisheries have targeted the top predators in the food web, allowing expansion of forage fish stocks, and thus reducing the mean trophic level of the fish community and the catches. As noted by Caddy et al. (1998b), reduction in trophic level could also result from "bottom-up" effects, such as nutrification in semienclosed seas (e.g., the Black and Baltic Seas), which favors small plankton feeders. In upwelling areas, long-term changes in upwelling strength, e.g., off the coast of Peru, may also lead to temporary peaks in production of small, plankton feeding fish—again reducing the mean trophic level of the catch.

Part of these apparent changes in trophic composition of catches, however, could also result from changes in market demand, environmental conditions (hence species dominance and availability to industrial fishing), capture technology, or fishing gear. For example, the invention of synthetic fibers in the 1950s

Box 4

Classification of Catch Data into Trophic Categories

FAO calculated the summed catches of each species over the entire 1950–97 period in each FAO Fishing Area and then sorted them in decreasing order. Starting with the species having the largest total catches, successive species were assigned to one of four trophic categories *(see Table 18)*, up to a total of five species in each category. Where this procedure resulted in one group of species (e.g., tunas or salmons) dominating a trophic category, the list of species was revised. For example, other species in the same category having a peculiar role in the ecosystem were chosen and substituted for one or more of the "dominant" group. This procedure for choosing key species is somewhat arbitrary but seems inevitable, given the large proportion of catches that cannot be assigned to a trophic category because they are reported to FAO at a level higher than species.

Species in the top category, which feed on fish, were referred to as "piscivores," (instead of the more correct, but less well known, term "nektivores"), but also includes species feeding on pelagic cephalopods (i.e., squids). Zooplanktivores comprise species feeding on "plankton." The major food items of zoobenthivores are invertebrates living on the sea bottom, but a few species that eat fish have also been included here (e.g., Pacific halibut). The herbivore category is made up of species feeding on phytoplankton, plants, and detritus. Commercial species in the herbivorous category are mostly bivalves in temperate areas and fishes in tropical areas.

Of the approximately 600 species reported in the FAO Fishery Statistics series, 212 were classified by trophic category. Catches of the selected species represent 62.3 percent of the 1950–97 total catch in the 15 FAO Fishing Areas analyzed. This percentage varies widely between fishing areas: the species selected represent more than 80 percent of the total catches in the Northwest Atlantic, Southeast Atlantic, Northeast Pacific, and Southeast Pacific (all temperate areas) and less than 30 percent in the Western Indian Ocean, Eastern Indian Ocean, and Western Central Pacific (all tropical areas where species diversity is generally higher).

Marine organisms change their feeding habits during the life cycle and, hence, the life stage considered is that at which the species is exploited (i.e., usually the adults). Most marine species are also opportunistic feeders and switch between food items, depending on seasonal availability; therefore, any trophic classification is, to some degree, arbitrary (Caddy and Sharp 1986). In this analysis, FAO classified fish species using mostly the information in FishBase (1998), in scientific articles, and by consulting the FAO Species Catalogues.

Table 18

Trophic Categories

Trophic category	Food Items
Piscivores	Finfish, pelagic cephalopods
Zooplanktivores	Zooplankton, fish early stage, jelly fish
Zoobenthivores	Benthic animal organisms
Herbivores/ Detritivores	Plants, phytoplankton, detritus, suspended organics

has facilitated large scale exploitation of small pelagic fish over the last three decades of the century (Caddy et al. 1998b).

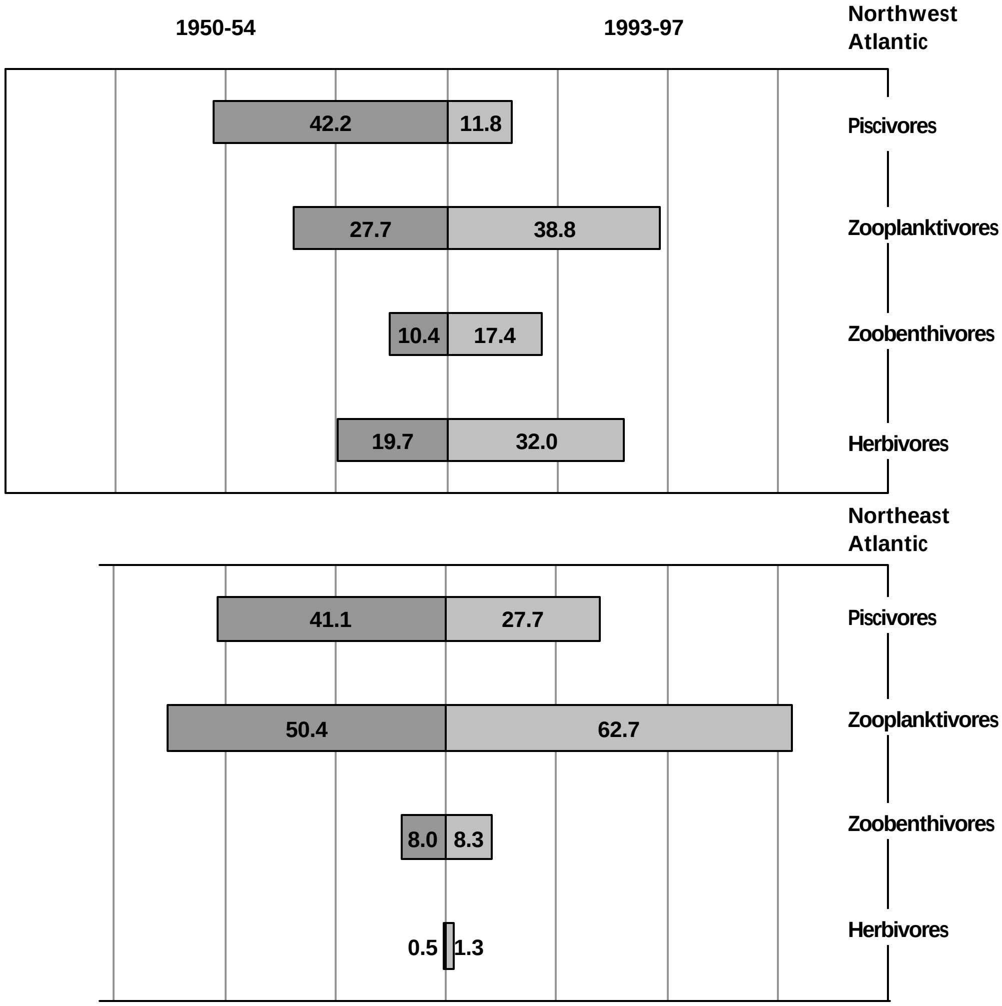
Presented below are the results of a simple trophic level analysis carried out by FAO for the PAGE study to develop a series of indicators that would help assess the condition of global fish resources. The FAO analysis developed three indicators, which are described below. For these three indicators, five species were selected for each of four trophic categories *(Table 18)* in each FAO Fishing Area, excluding the Arctic and Antarctic. These categories were used as rough indicators of ecosystem change. Box 4 presents a discussion of the methodology used to classify catch data into trophic level categories.

The three indicators developed by FAO from the catch statistics are listed below.

- Sum of catches for each FAO Fishing Area. Species catch in each category were summed and plotted over the entire 1950–97 period in each FAO Fishing Area separately. The sums of the piscivore and zooplanktivore catches (1950–97) for most of the FAO Fishing Areas assessed are presented in Map 18.
- Trend relationship between two of the four trophic categories: the piscivores and zooplanktivores. FAO calculated the ratio between the actual catches of the five piscivorous species and the five zooplanktivorous species. This indicator is considered a rough, but useful, way of monitoring ecosystem change. Declines in this ratio might either indicate "fishing down marine food webs" (Pauly et al. 1998) or increased productivity or nutrient availability (as in semienclosed seas; de Leiva et al., in press). Map 18 presents trend lines for piscivore and zooplanktivore catches (1950–97) for selected fishing areas analyzed by FAO. The map also lists the common names of the five species selected under each of the two categories for each fishing area.
- The third indicator was developed following a suggestion from Daniel Pauly. It compares the breakdown of catches of the different trophic levels early (1950–54) and late (l993–97) in the series, calculating the percentage of each category in each fishing area in the two periods. This indicator allows one to compare variations in the catch composition by trophic categories before and after forty years of fishing pressure.

Figure 9

Catches by Trophic Level for the Two Northern Atlantic Fishing Areas in 1950–54 and 1993–97



Source: Caddy et al. 1999.

The observed variations in these three indicators are discussed later in this section for each ocean.

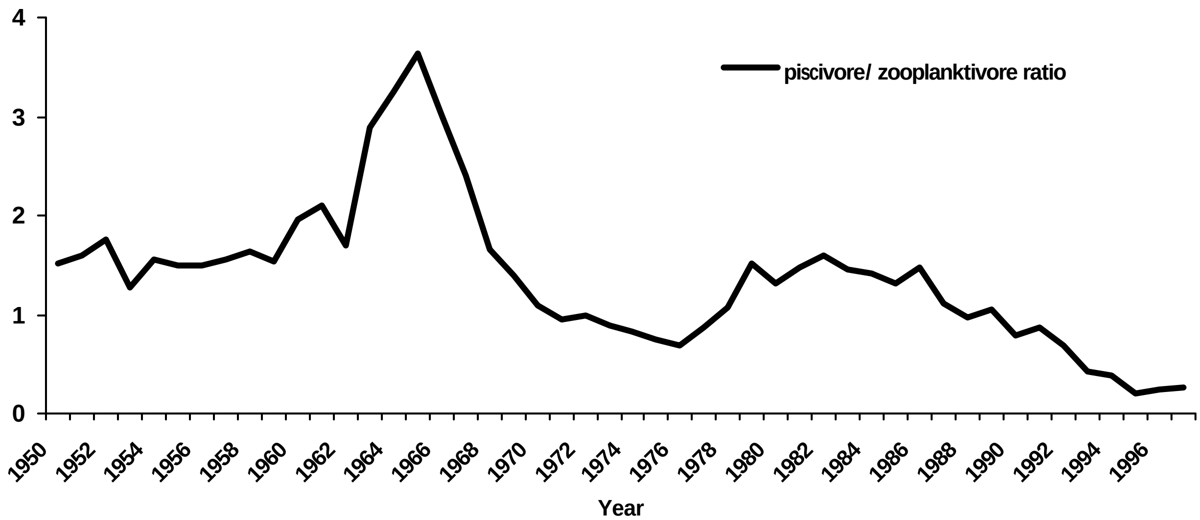
The results of the trophic level analysis show that notable changes have occurred over the last half century in the way humans have exploited food webs. In some cases, we see what appears to be "fishing down marine food webs," while other changes in exploitation patterns seem to come about through specific technological innovations. For some fishing areas, such as the Western Central Atlantic, the Southwest Atlantic, and the South Pacific, interpretation of possible ecosystem interactions from the developed indicators is difficult. In the Southeast Pacific, this difficulty is partly caused by the irregular pattern of landings in one of the major fisheries (i.e., anchoveta), which is correlated with El Niño events. The following is a summary of the results by ocean.

Atlantic Ocean

"Fishing down marine food webs" seems to be a reasonable hypothesis to account for major events in the northern Atlantic, where the mean trophic level appears to have declined as the large piscivores, such as cod and hakes, have been progressively depleted. This can be seen in Figure 9 which reflects the change in catch composition by trophic categories before and after 40 years of fishing pressure. In the Northeast Atlantic,

Figure 10

Piscivore/Zooplanktivore (PS/ZP) Ratio for the Northwest Atlantic



Source: Caddy et al. 1999.

results show an increase in the percentage of zooplanktivores in 1993–97 compared to 1950–54, which is concurrent with the decrease in piscivores.

In the Northwest Atlantic, a peak in overall fishery production occurred in the late 1960s and early 1970s. The piscivore-zooplanktivore (PS/ZP) ratio indicator, seen in Figure 10 shows a sharp drop for this area, reflecting the overfishing of demersal stocks after the mid-1960s, and the subsequent transition to landings dominated by small pelagics. *(See Northwest Atlantic graph in Map 18.)* Quota management of most fish stocks following extension of national fishing jurisdictions led to a recovery of demersal piscivore landings but these again declined in recent years with the collapse of the main groundfish stocks, especially cod. The fishery also showed a slight increase in landings of herbivore and zoobenthivore indicator species, which apparently reflects the growing share of invertebrates in the multispecies catch. The hypothesis of "fishing down marine food webs" seems generally supported as a key ecosystem change for this area.

In the Eastern Central Atlantic, fisheries for small pelagic fish dominated the early years before the international trawl fishery got underway, which was initially aimed at hake and other demersal fish before shifting toward high value zoobenthivores, such as octopus and shrimp. Interestingly enough, this area experiences upwellings—episodes that appear to show up as peaks in production of zooplanktivores (mainly sardine). The hypothesis that the shift in trawl fisheries to octopus in the late 1960s was partly because of a reduction in predatory cephalopod-eating species, such as sparids, has been postulated elsewhere (Caddy and Rodhouse 1998), but it is difficult to see from the sample species that an overall decline in piscivores has occurred. *(See Eastern Central Atlantic graph in Map 18.)*

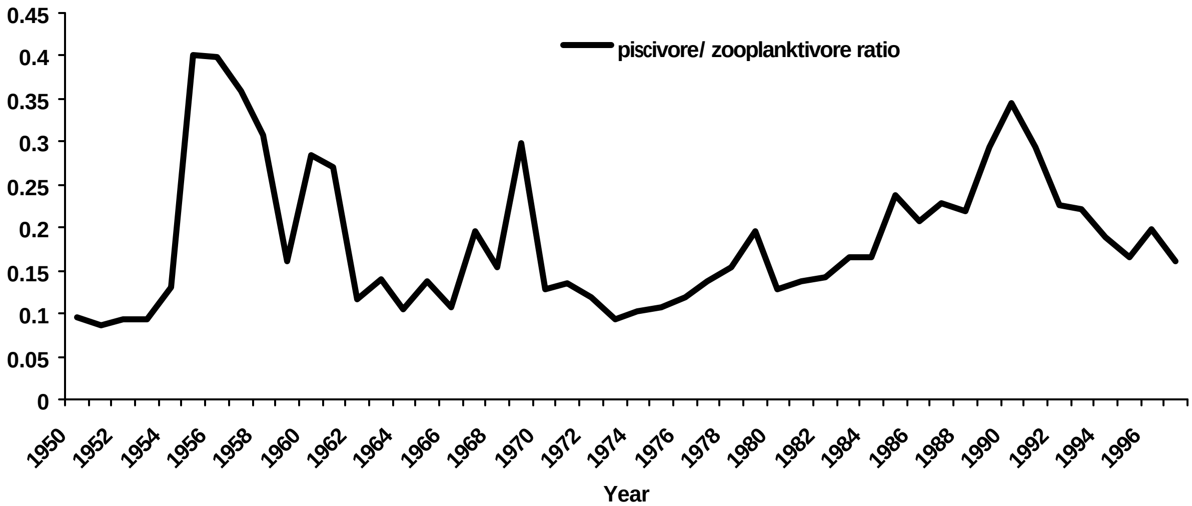
For the Southeast Atlantic, three of the four landing peaks in this area (in 1968, 1978, and 1987) coincide with peaks of the main zooplanktivores species, while the peak in 1973 is due to high catches of hakes. *(See Southeast Atlantic graph in Map 18.)* The PS/ZP ratio indicator for this area peaks in the early 1970s, which seems to reflect both the early dominance of fisheries for small to medium sized pelagics (mackerels fished by the international fleets, and pilchards by South Africa), and the increase of hake catches. The several peaks in small pelagic catches can be seen as a consequence of the upwelling regime, which varies in strength and dominates this area. This ecological instability as well as changes in preference of world markets, rather than just overfishing, may be reflected in the overall exploitation pattern of the area. "Fishing down marine food webs" is not supported as the dominant mechanism here.

Mediterranean and Black Sea

In the Mediterranean and other semienclosed seas, upward trends in fisheries landings occurred over much of the time series, despite a degree of early overfishing. *(See Mediterranean and Black Sea graph in Map 18.)* Events here seem to be driven in a bottom-up fashion as far as food web productivity is concerned, probably resulting from increased nutrient runoff from

Figure 11

PS/ZP Ratio for the Mediterranean and the Black Sea



Source: Caddy et al. 1999.

land-based sources (Caddy and Bakun 1994; Caddy et al. 1995). The sharp drop in total catches after 1988 reflects the collapse of the Black Sea anchovy stock from a combination of overfishing and the introduction of a jelly from the West Atlantic in ballast water (the ctenophore *Mnemiopsis leidyi*, a voracious predator on zooplankton, fish eggs, and larvae). This event led to a sharp decline in anchovy landings in 1989 and shows up as a peak in the PS/ZP ratio in Figure 11.

The trophic level analysis also shows an increase in piscivore landings in recent years and a relative drop in zooplanktivores. This and the increase in herbivore (mainly detritivore) landings in the recent period seem generally consistent with this bottom-up enrichment effect suggested by the above cited authors.

Indian Ocean

As noted by Grainger and Garcia (1996), the Indian Ocean was one of the latest areas to be exploited intensively. In the Map 18 graphs for the Western and Eastern Indian Ocean, overall landings have risen throughout the whole time series.

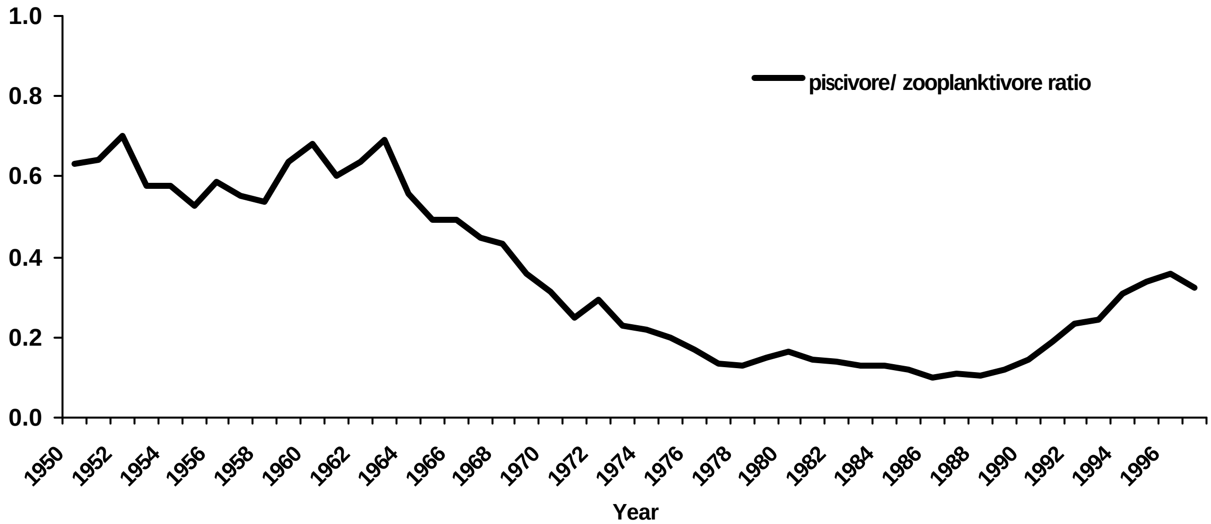
In the Western Indian Ocean, the analysis shows a rise in piscivores and a drop in planktivores. However, there is no indication of a drop in the PS/ZP ratio—which fluctuates widely—as might be expected in a situation where a number of small subregional fisheries are contributing to the overall indicator. As in other tropical areas, the observed change in catch composition is likely to be a function of increased fishing effort on tunas and tuna-like species, driven probably by market and technology changes, and is unrelated to changes in underlying food webs. In the Eastern Indian Ocean, for example, the overall fishery was dominated by the southern bluefin tuna fishery in the early years before stocks declined, while the rise in mackerel and sardinella fisheries occurred later in a different part of this large region. The recent depletion of southern bluefin tuna stocks probably explains the decline in piscivores that shows up in the analysis. *(See graph for Eastern Indian Ocean in Map 18.)* The observed increase in zoobenthivores and herbivore landings for the Eastern Indian Ocean is probably related to the development of shrimp fisheries in the area and recent rises in catches of shad and Indian oil sardine. In conclusion, while there have been changes in dominance by different trophic levels in Indian Ocean catches, ascribing this to any specific cause would require more careful studies at the local or subregional level.

Pacific Ocean

In the Northwest Pacific, total catch peaked in 1988 and more recently in 1997. Landings of piscivore indicator species have generally remained fairly steady over the whole period with recent increases in catches of largehead hairtail and Japanese flying squid, although the major catches for the latter species was in 1968. Zooplanktivore catches peaked in the period during the mid-1980s, after a constant rise in catches that started in the mid-1960s with the development of a major industrial fishery for Alaska pollock. *(See Northwest Pacific graph in Map 18.)* After the mid-1980s, a decline in catches of Alaska pollock and Japanese pilchard has been partially compensated by

Figure 12

PS/ZP Ratio for the Northwest Pacific



Source: Caddy et al. 1999.

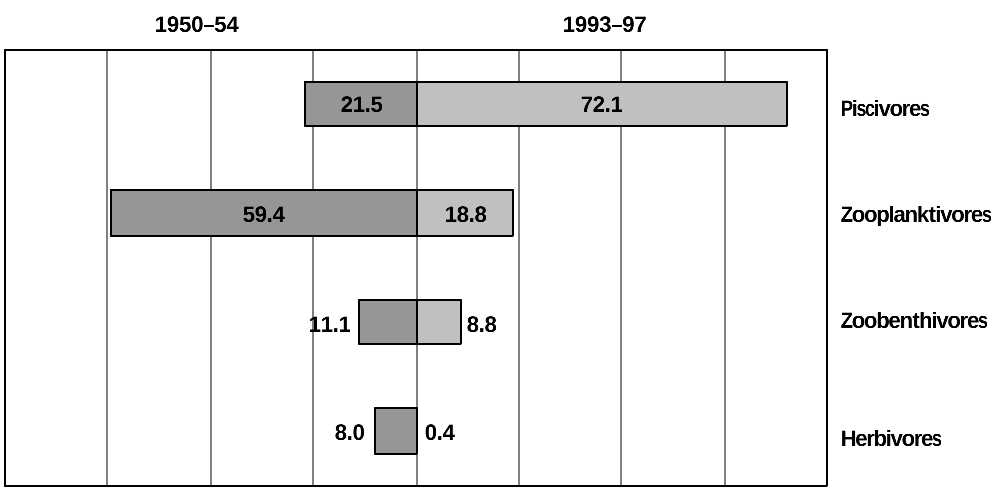
a strong increase in Japanese anchovy. Hence, the steady decline in the piscivore/zooplanktivore ratio does not seem to reflect "fishing down marine food webs," but is probably because of an increase in zooplanktivore catches. *(See Figure 12.)*

The ecosystems of the Northeast Pacific have experienced a number of changes in the trophic level of harvesting. Zooplanktivores, such as Pacific herring, and pink and sockeye salmon, dominated landings in the 1950s, but with the onset of commercial groundfish harvesting, namely the development of the Alaska pollock fishery in the mid-1960s, piscivores have dominated the catch as can be seen in Figure 13.

Figure 13 shows the dramatic contrast in catches of piscivores and zooplanktivores for the 1950-54 and 1993-97 periods. The strong reduction in zooplanktivores is mainly influenced by catches of Pacific herring, which halved in the 1993-97 period. The peak in overall landings in 1987 coincides with the highest

Figure 13

Catches by Trophic Level for the Northeast Pacific Fishing Areas in 1950–54 and 1993–97



Source: Caddy et al. 1999.

catches of Alaska pollock, which have been declining in recent years (1994-97).

In the Central Pacific, as in other tropical areas, overall landings show a steady upward trend. *(See the Central Pacific graphs from Map 18.)* In the western region, major increases in landings of the selected species started in the 1970s, with piscivores progressively becoming dominant. Among these, the tuna-like species are the most important with a peak in 1991, primarily because of skipjack tuna catches. Fisheries of zooplanktivore species remained undeveloped in the 1950s. In the Eastern Central Pacific, the overall landings peaked in 1981 and have subsequently declined somewhat. The zooplanktivores' peaks in 1981-82 and in 1989 are due to high catches of California pilchard in both periods and of California anchovy in the first period, with concomitant peaks of the piscivores—skipjack tuna in 1981, and yellowfin tuna in 1989. In 1995-97, a substantial increase in the landings of the jumbo flying squid, a piscivore, was registered and can be seen in the Eastern Central Pacific piscivore graph in Map 18.

Capacity of Coastal and Marine Ecosystems to Continue to Provide Fish

It is reasonable to conclude, at the beginning of the new millennium, that most shelf resources and most open ocean resources are fully exploited or overexploited. Although fishery regulations are now in place in many areas, management of shared, highly migratory, and straddling stocks still presents many loopholes, permitting overexploitation. This continues to occur, despite unprecedented agreements over the last few years, such as the Code of Conduct for Responsible Fisheries, and the U.N. Fish Stocks Agreement, which support proper management practices for aquatic resources. Expansion of oceanic fisheries still continues, with a movement toward exploiting deep-water resources, which are relatively unprotected by international agreements and regulations.

Although the use of FAO landing statistics for ecosystem changes has limitations for the reasons mentioned earlier, it provides some insights that supplement the conclusions drawn from existing analyses of simple catch trends such as in FAO (1995, 1997, and 1999a), Grainger and Garcia (1996), and Caddy et al. (1998a). The analysis of the catch species composition presented shows that notable changes have occurred over the last half century in some fishery areas, such as the northern Atlantic and Northeast Pacific. The piscivore/zooplanktivore ratio also provides some evidence for likely ecosystem change. These indicators do not point, however, to a single unambiguous cause for ecosystem change, although there seems no doubt that this is occurring in many marine ecosystems because of fisheries and other anthropogenic and natural environmental changes.

The broad-brush trophic analysis presented in the preceding pages is not intended to be a substitute for more detailed local ecosystem analyses. These analyses are needed to illuminate the mechanisms influencing the major changes in fishing strategy. What is clear is that a number of key factors have been operating, often simultaneously. These include the development of new markets for fish; changes in the species composition because of fishing pressures; expansion in fish trade; environmentally driven fluctuations such as El Niño-type phenomena; and new technologies for capture, processing (often at sea), and storage.

Fisheries production relies on the condition of coastal habitats and other services provided by coastal ecosystems, namely biodiversity and water quality. As previously discussed, human modification and pollution are threatening important coastal habitats for many major fisheries. *(See sections on Coastal Zone: Extent and Change for habitat loss and modification, and Water Quality.)* Although available data are insufficient to detect clear trends for those parameters, there is evidence of increasing overall pressure on the ecosystems that sustain fishery resources.

Information Status and Needs

As stated earlier, FAO fisheries production statistics are limited to providing proximate information on commercial fish population trends and, therefore, are insufficient to assess the capacity of coastal and marine ecosystems to provide food. One of the limitations of production statistics is that the composition of the catch is not well known. Although 80-90 percent of the species caught from the North Atlantic are reported to FAO at the species level, the catch proportion misreported by individual stocks is higher. Between 50 and 70 percent reporting by species is typical of most other world areas, while for the Indian Ocean and West Central Pacific, only 20-30 percent of landings and harvests are reported by species; the rest being included in higher taxonomic categories or as mixed fish. Another limitation of production statistics is that they include biases from unreported discarding or misreporting of harvests by area and species, and exclude all information from illegal fishing, which is high for some species.

For some countries, including some developed countries, scientists believe that catch reporting systems are of dubious accuracy, especially with respect to landings and harvests of small vessels. The infrastructure for collecting and assembling data is often absent, and data on discards are fragmentary and missing in most fisheries. With respect to species identification, especially in tropical areas, high diversity poses a problem. The lack of emphasis placed on practical taxonomy over the last few decades has led to a dire shortage of top experts for identifying many taxonomic groups, so that accurate species identifications are not easily achieved.

In addition, there is a wide information gap in our understanding of marine fisheries ecosystems. For example, more extensive stock assessments are necessary to identify maximum sustainable yields (MSYs) for various commercially important species. In order to detect the decline in fish stock or imbalance in the ecosystems, collection of a few indicators, such as average fish size or species composition (trophic level ratio), need to be considered; however, monitoring of commercial landings for species, size, and age composition, is costly and labor-intensive.

The application of military technologies has improved direct and indirect fish population estimates and this could be further improved by the use of laser technologies or bottom-mounted sonar arrays. The requirement for fishing vessels to carry a black box that monitors vessel position, speed, and operation of fishing gear has helped collect more precise commercial data on when and where fish are caught and could make the measurement of fishing effort much more precise. For example, trawling areas could be tracked, and geographical and seasonal concessions of fishing grounds could be specified to reduce capture of protected species or juveniles. With complete remote coverage of fishing operations, closed areas might be more effectively monitored. In addition, areas with high discards, fragile bottom fauna, or vulnerable spawning concentrations might be largely avoided. The current situation is, however, that reporting of data to FAO on fishing effort or even of up-to-date fleet size is fragmentary. Databases on operations of smaller vessels are almost nonexistent, even at the national level, in many countries.

Regarding the fisheries manager's use of data, a key concern is how scientific data is used, if at all, in management. Better data collection is a praiseworthy and feasible goal, but it improves only one part of the management cycle. Given current information limitation and the inevitably high variance of fish population estimates, managers must use precautionary approaches in making decisions.

Tourism and Recreation

Growth of Global Tourism

Tourism has significant value and benefits to both local and global economies. Travel and tourism—encompassing transport, accommodation, catering, recreation, and services for travelers—is the world's largest industry and generator of quality jobs. Worldwide, analysts estimate travel and tourism to have generated US$3.5 trillion and almost 200 million jobs in 1999 (WTTC 1999:3). Tourism is the fastest growing sector of the global economy, and, in most countries, coastal tourism is the largest sector of this industry. In many countries, notably small island developing states, tourism contributes a significant and growing portion of GDP and is often the major source of foreign exchange. If properly managed, tourism and recreation activities in the coastal zone can promote conservation of ecosystems and economic development.

On a global basis, it is not possible to differentiate inland from coastal tourism. Most statistics related to tourism are aggregated by country, and agencies and organizations compiling statistics typically do not make this distinction. This section of the report will focus on the Caribbean, where tourism is mostly coastal or marine in nature. Additionally, because of the significant role that tourism plays in the region, relatively good and detailed statistics are available regarding this sector.

Status and Trends of Tourism in the Caribbean

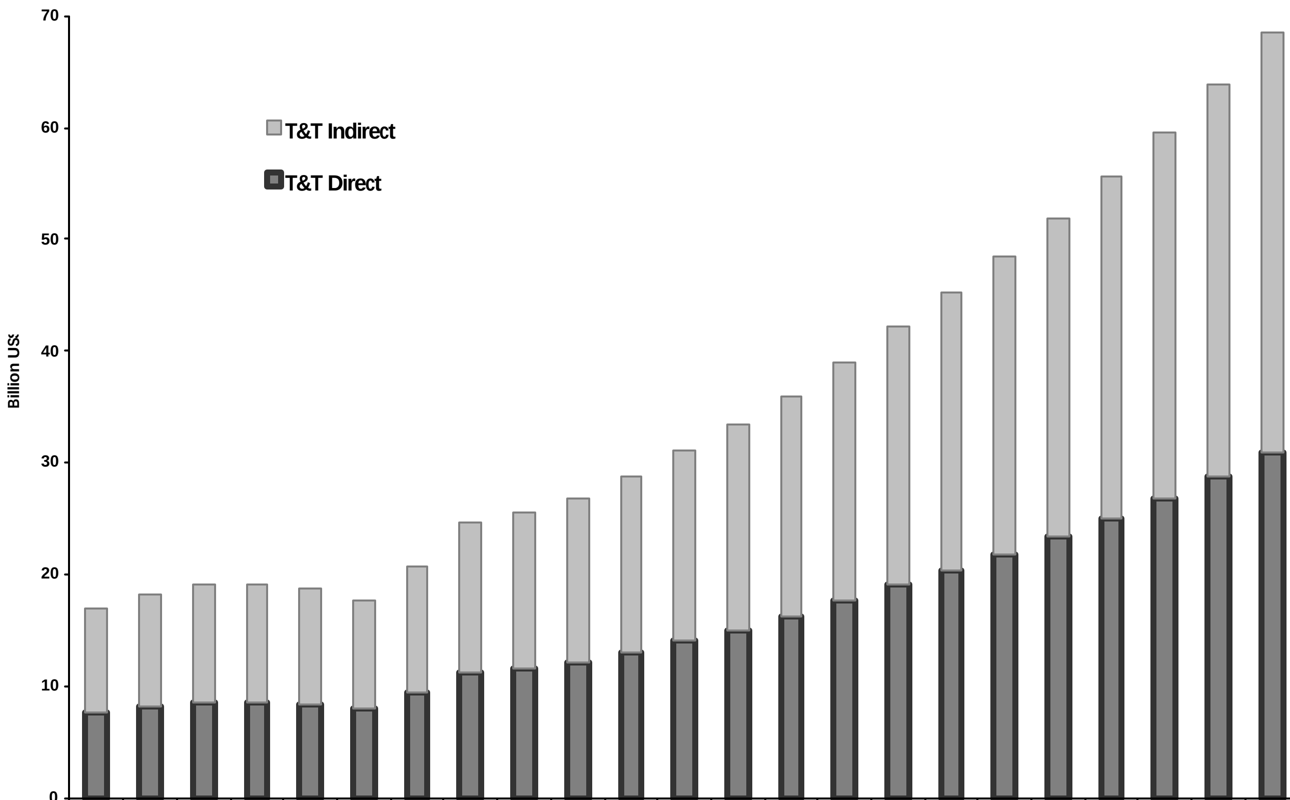
The Caribbean is a diverse region that includes 12 continental countries bordering on the basin, 14 island nations, and 7 dependent territories. The diversity of cultures, languages, and stages of economic development within the region makes generalization difficult. For most countries, tourism is the largest single source of foreign exchange earnings.

The World Travel and Tourism Council (WTTC 1999) compiles detailed accounts for the overall economy and travel and tourism sector, in addition to modeling future demand. In 1998, direct and indirect GDP from travel and tourism was over US$28 billion, accounting for about 25 percent of the region's total GDP. GDP from travel and tourism has risen from US$19 billion in 1990, and is expected to reach over US$48 billion by 2005 (WTTC and WEFA 1999). *(See Figure 14.)* The share of GDP coming from travel and tourism is expected to stay relatively constant within the Caribbean, at around 25 percent, and in real terms, to grow by 35 percent over the next decade (WTTC 1996:4).

The success of tourism in the Caribbean has been built upon the traditional appeal of excellent beaches, a high-class marine environment suitable for a range of recreational activities, and

Figure 14

Travel and Tourism GDP in the Caribbean



	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
T&T Indirect	9.27	10.03	10.44	10.51	10.30	9.66	11.41	13.58	14.07	14.69	15.81	17.13	18.32	19.75	21.44	23.19	24.86	26.64	28.55	30.59	32.79	35.13	37.65
T&T Direct	7.59	8.22	8.55	8.61	8.44	7.91	9.34	11.12	11.52	12.03	12.95	14.03	15.01	16.18	17.56	19.00	20.36	21.82	23.38	25.06	26.86	28.78	30.84

Source: WTTC and WEFA 1999.
Note: Figures for 1998-2010 are estimates.

Table 19

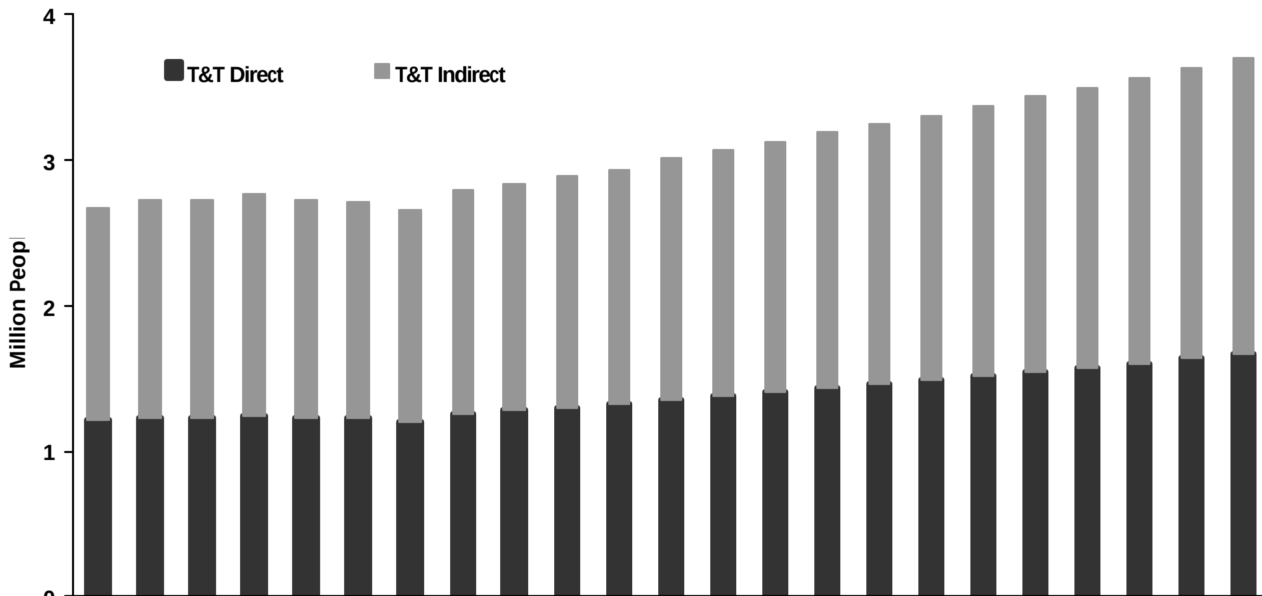
Tourist Arrivals in the Caribbean by Main Market (thousands)

Country of Origin	1993	1994	1995	1996	1997
United States	8,401.3	8,631.7	8,531.6	8,738.9	9,165.9
Canada	890.3	879.1	933.1	940.8	1,008.9
Europe	2,868.3	3,197.2	3,388.7	3,725.5	4,154.4
Caribbean	1,007.3	1,101.3	1,193.6	1,230.7	1,285.9
Other/Unspecified	2,442.6	2,674.1	2,900.6	2,880.2	3,258.2
Total	15,609.8	16,483.4	16,947.6	17,516.1	18,873.3

Source: CTO 1997a.

Figure 15

Travel and Tourism Employment in the Caribbean



	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
T&T Indirect	1.47	1.50	1.50	1.52	1.50	1.49	1.46	1.54	1.56	1.59	1.61	1.66	1.69	1.72	1.75	1.78	1.82	1.85	1.89	1.92	1.96	2.00	2.03
T&T Direct	1.21	1.22	1.22	1.25	1.22	1.22	1.20	1.26	1.28	1.30	1.32	1.36	1.38	1.41	1.44	1.46	1.49	1.52	1.55	1.58	1.60	1.63	1.66

Source: WTTC and WEFA 1999.
Note: Figures for 1998-2010 are estimates.

warm weather conditions year round. The attractiveness of the region makes it an "up market" high-spending destination. Average spending by tourists is US$861 per visit, which is 31 percent higher than the world average (CTO and CHA 1997).

Travel and tourism is human-resource intensive, creating quality jobs across the employment spectrum, many of them in small businesses and in urban or rural areas where structural unemployment is highest. As Figure 15 shows, in the Caribbean travel and tourism provided over 2.9 million jobs in 1998 (more than 25 percent of total employment); this number is expected to grow to over 3.3 million (27 percent of total) by 2005 (WTTC and WEFA 1999). These estimates include those jobs directly related to tourism (hotel and tour services) and those that indirectly support tourism (such as food production and housing construction).

The number of tourists arriving in the Caribbean is growing rapidly. *(See Table 19.)* In 1997, over 18.8 million tourists visited the region, the majority coming from the United States and Europe (CTO 1997a). Over the next decade, an estimated 36 percent increase in tourist arrivals is anticipated (CTO 1997b).

Although tourism is an important industry across the Caribbean, its significance varies by country. Figure 16 reflects tourism as a percentage of GDP for selected Caribbean countries, indicating the level of dependency of their economies on tourism revenues. Most of the countries with relatively high per capita GDP have a high percentage (more than 30 percent) of GDP derived from this industry.

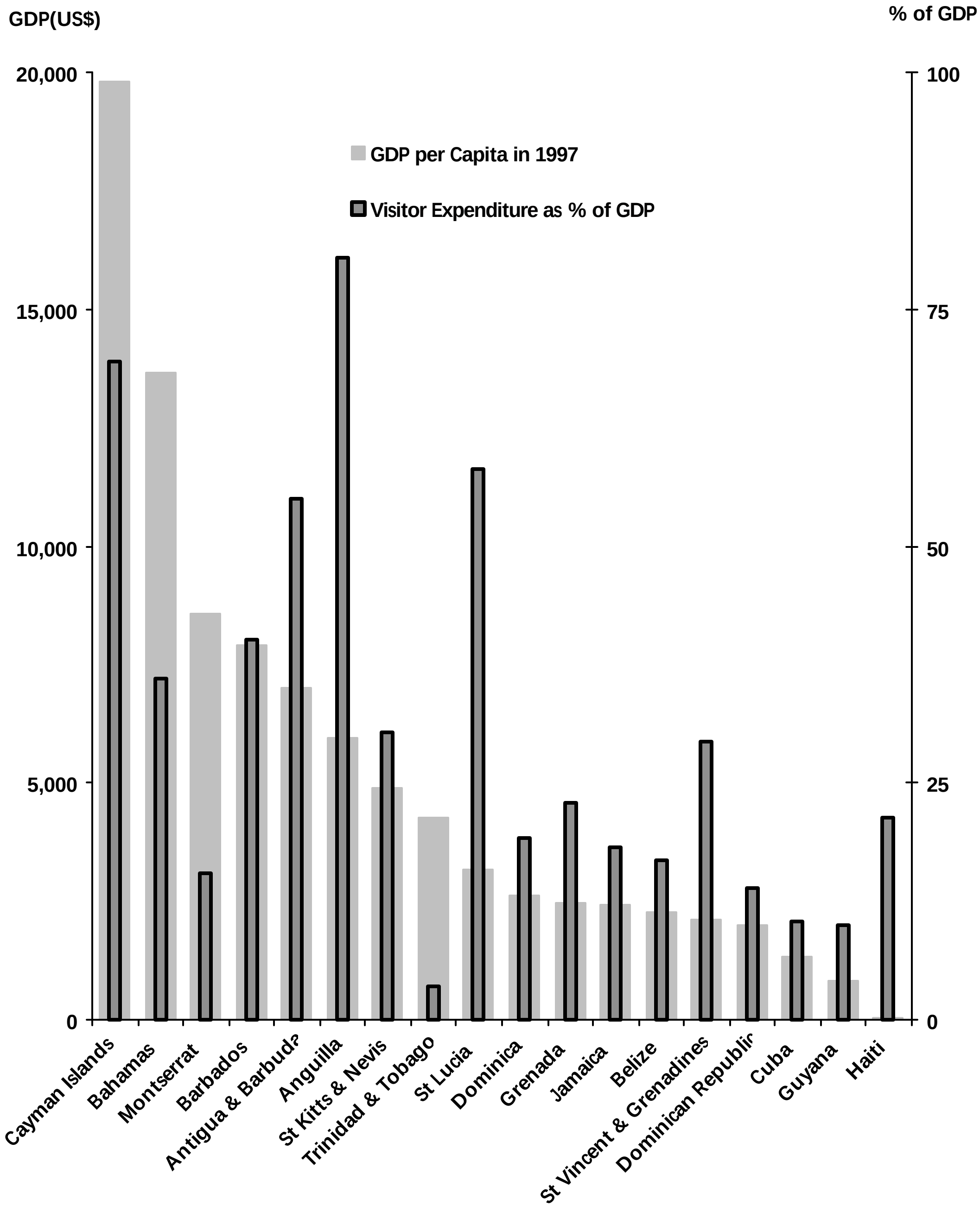
Impacts of Tourism on the Environment and the Economy

The natural beauty and environmental quality of vacation areas has a positive influence on tourists. A survey of tourists in Spain revealed beautiful landscape (51 percent), water quality (27 percent), unspoiled nature (23 percent), and air quality (22 percent) as the four environmental factors that most influence their choice of destination (Boers and Bosch 1994). A survey of Japanese tourists put enjoying nature (72 percent) as the primary purpose of the trip (WTTC et al. 1997).

As much as the tourism industry benefits from a pristine environment, uncontrolled expansion and mismanagement can harm the very resources on which it is based (WTTC et al. 1997). This is particularly true for more nature-based activities such as dive tourism. If a tourism-dependent economy suffers a loss of natural resources and environmental degradation, it may result in significant socioeconomic consequences, such as loss of

Figure 16

Per Capita GDP and Tourism as a Percentage of GDP for Selected Countries in the Caribbean



Source: CTO 1997a.

jobs, reduction in private sector and government revenues, and worsening balance of payment problems (UNEP 1997b).

TOURISM TYPES AND IMPACTS ON ECOSYSTEMS

The impacts of tourism in the Caribbean are extremely diverse, depending on differences among state economies, the relative and absolute size of the tourism sector, the rate of growth in tourism, and the nature of the tourism facilities involved (IRF 1996). Adverse impacts of the tourism industry on coastal resources are caused by all subsectors of the industry, primarily the construction and operation of facilities (UNEP 1997b). Tourism-related impacts include scarring of mountain faces with housing and road construction, filling in of wetlands and mangroves for resort properties, beach loss and lagoon pollution from sand mining, dredging, and sewage dumping, and damage to coral reefs from anchoring, sedimentation, and marina development (McElroy and de Albuquerque 1998a:146). These impacts have been, for the most part, documented only qualitatively.

A 1996 study by Island Resources Foundation (IRF) on tourism and coastal resource degradation concluded that "virtually every state of the Wider Caribbean suffers from sewage pollution of coastal waters, most suffer some contamination from oil spills and production leakages…and most of the low income states of the region report solid waste contamination of coastal areas. In addition, many states report inadequate monitoring and assessment systems to understand the causes, dimensions, and impacts of coastal pollution." Tourism directly contributes to sewage and solid waste pollution in virtually every country. In tourism-dependent countries, it is the prime contributor to coastal erosion and sedimentation (IRF 1996). Additionally, the industry contributes to coastal habitat degradation through anchor damage, boat groundings, clearing of natural habitat, dredging and sand removal, diver damage, and trampling of coral reefs. (Hoagland et al. 1995). Most tourism-related environmental degradation occurs locally. Marine debris aside, the major "international" environmental effect of coastal tourism in the Caribbean may be the impact of yachts, charter boats, and cruise ships in near-coastal and marine environments (IRF 1996).

INTENSITY OF TOURISM

Coastal degradation from tourism also depends upon the level of intensity, which is often expressed using a range of indicators, from number of tourists per arable land area to the rate of growth of the industry. For instance, tourism growth rates vary greatly even among Caribbean states, and this variety needs to be taken into account when developing the appropriate management plan for the region (IRF 1996). Concerning growth rates for 1990–94 (IRF 1996:Table 3), Dominican Republic, Jamaica, U.S. Virgin Islands, and Puerto Rico were at 15–19 percent, while Grenada, Aruba, Trinidad and Tobago, and the Caymans experienced 33–37 percent growth over that period, and Belize, St. Lucia, and Guadeloupe had 50–65 percent growth.

There is no single standard integrated measure of size, scale, and degree of overall impact of tourism in a given destination (McElroy and de Albuquerque 1998b). Measures of tourism intensity and impact are linked to the concept of tourism carrying capacity discussed below and, hence, need to encompass environmental as well as sociocultural consequences of tourism development.

Commonly used indicators, such as visitor density or average length of stay tend to correlate with the economic indicators and fail to capture tourism's range of adverse impacts on the environment through different types of tourism activities. There is also a need to measure social impacts, some of which are difficult to quantify: crime rate, real estate inflation, erosion of cultural traditions, and level of frustration felt by local residents (McElroy and de Albuquerque 1998a).

Table 20

Leakages of Gross Tourism Expenditures

Country	Leakage (% of gross tourism receipts)	Year of estimate
Antigua	25%	1978
Aruba	41%	1980
Jamaica	40%	1991
St. Lucia	45%	1978
US Virgin Islands	36%	1979

Source: Smith and Jenner 1992, reproduced in Wells 1997.

DISTRIBUTION OF TOURISM BENEFITS AND ENVIRONMENTAL COSTS

Different types of tourism operations have varying levels of socioeconomic and environmental impacts on local populations. While large-scale commercial tourism operators from abroad or from larger cities often capture much of the economic benefit, environmental degradation is more likely be felt locally. In such cases, the consequences of the trade-offs are not fairly distributed among all the stakeholders.

Relatively few local communities have realized significant benefits from nature tourism on their own lands or in nearby protected areas. Their participation in nature tourism has been constrained by a lack of relevant knowledge and experience, lack of access to capital for investment, inability to compete with well-established commercial operations, and simple lack of ownership rights over the tourism destinations (Wells 1997).

One way of looking at the tourism benefit that reflects the true contribution to the local economy is to examine "tourism leakages." Leakages are the proportion of foreign exchange revenue derived from tourism, which is collected by nonlocal service providers. The items commonly included in analyses of leakages are imported materials and capital goods for the tourism industry, imported consumables, the employment of foreigners, and the repatriation of benefit by foreign companies. The rate of leakage is often higher in relatively underdeveloped locations where those services are not available locally (Wells 1997). Estimates of leakage are presented in Table 20 for a limited number of Caribbean islands for which statistics are available.

Tourism Carrying Capacity

"Carrying capacity" in tourism is a term used often to measure the level of tourism development an area can accommodate without adverse effects on the resident community, the natural environment, or the quality of visitor experience (UNEP and WTO 1992). This concept can be broken down into types of limits, such as ecological or environmental, physical (threshold limit for space or accommodation), and social (level of tolerance of the host population to the presence of tourists) (Lim 1998:3).

Tourism is growing rapidly, but the local capacity to deal with it does not grow as fast. When local capacity to deal with the level of tourism intensity is saturated, negative consequences occur. The threshold of the capacity can depend on the level of physical infrastructure, such as waste treatment, as well as social infrastructure, such as regulations or codes of conduct, that make tourism activities less harmful to the natural environment and local culture.

The measure of carrying capacity has been examined with limited success. Important factors include land area, soil and habitat types, and availability of freshwater, in addition to a range of cultural and socioeconomic factors. Perhaps there is no simple indicator of tourism carrying capacity in terms of number of tourists, but rather it is the type of tourism and nature of tourist consumption and activities that really matter.

There have been some attempts to develop carrying capacity indicators by combining the type of tourism impact indicators discussed above. It is difficult to establish the threshold at which carrying capacity is exceeded because different natural and sociocultural settings can sustain vastly different levels of visitation (McElroy and de Albuquerque 1998a).

Sustainable Tourism

Current efforts to develop indicators in this area are important, as are certification programs that encourage tourist facilities to adopt more efficient and environmentally sound practices.

"Sustainable tourism" has the potential for longer-term economic benefits for a community and serves to limit environmental degradation. According to the definition by WTTC, World Tourism Organization (WTO), and Earth Council, "sustainable tourism development is envisaged as leading to management of all resources in such a way that economic, social and aesthetic needs can be fulfilled while maintaining cultural integrity, essential ecological processes, biological diversity, and life support systems." (WTTC et al. 1997:30).

The tourism industry recognizes the importance of maintaining the quality of the natural environment and the cultural integrity of a local community as a resource base of tourism attractions. Some certification of "best practices" or "ecolabeling" schemes has been developed as self-regulatory and voluntary measures to promote sustainable tourism. The certification criteria vary depending on the focus area of each scheme: from energy efficiency and waste treatment, to staff training and education (UNEP 1998). The following are examples of the criteria used by the schemes particularly relevant to coastal tourism.

In 1994, the WTTC launched Green Globe, a worldwide environmental management and awareness program for the travel and tourism industry. The program includes a series of packages designed to help staff at all levels bring about environmental improvements. A number of national tourist associations and businesses are participating in this program, which provides standards and mechanisms for "green" certification of hotels and resorts (UNEP 1998; Green Globe Website: http://www.greenglobe.org/).

Foundation for Environmental Education in Europe (FEEE) manages the Blue Flag Campaign, currently in 21 European countries, focusing on environmental management performance of beaches and marinas (FEEE Website: http://www.blueflag.org). In 2000, 1,873 beaches and 652 marinas were awarded the Blue Flag, a dramatic increase from 244 beaches and 208 marinas in 1987 (FEEE 2000), indicating increased interest by beaches and marinas in participating in the campaign. *(See Box 5 for an example of voluntary guidelines for sustainable tourism.)*

The Role of Protected Areas

Ecotourism, or nature-based tourism, although accounting for a small fraction of the fast-growing tourism industry, has a high potential to generate revenue and employment for local populations, and provide incentives for protecting natural ecosystems. Protected areas are often a desirable aspect of a tourist destination and, therefore, a valuable component of nature-based tourism.

Although often thought of as areas protected from tourism and other intrusions, parks and protected areas throughout the Wider Caribbean are major factors in attracting and managing tourists and tourism. Throughout the eastern Caribbean, cruise ship visitor surveys indicate that 30 percent of passengers who go ashore want to visit natural areas and parks (OAS and CTRDC 1988, cited in IRF 1996). The negative environmental effects of tourism in parks and protected areas tend to be small, but the ability to tolerate such impacts is also small (IRF 1996).

However, some marine protected areas (MPAs) have failed to capture their share of the growing tourism revenue. Some often lack sufficient funding to enforce protection of the areas and monitor environmental quality. A World Bank report examining nature tourism and economic development concluded that many protected areas that often supply the most valuable part of the nature tourism experience, charge relatively low entry fees and therefore capture little of the economic value of tourism. Although many governments have successfully increased tourist numbers by marketing their country's nature tourism destinations, most have not invested sufficiently in managing

Box 5

Voluntary Guidelines for Sustainable Coastal Tourism Development in Quintana Roo, Mexico

Tourism represents one of the most important sources of revenue and foreign exchange for Mexico: it is the driving force for economic development in the state of Quintana Roo. For example, 25 years ago the small fishing village of Cancun in Quintana Roo was transformed into a popular international tourist destination, which today hosts over 2 million visitors annually and over 300,000 residents. Although Cancun's development has resulted in environmental problems for the area, the economic importance of tourism makes further development desirable, but necessitates development in a more environmentally sustainable manner—where environmental impact is limited and economic benefits are derived locally.

Invariably, there are trade-offs between the economic benefits of tourism development and the negative impacts to cultural amenities and environmental services. The new frontier for tourism development in Quintana Roo is now Costa Maya along the southern coast, a region of high biodiversity and rich coastal ecosystems. The region is bordered by the Sian Ka'an Biosphere Reserve, Belize's Hol Chan Marine Reserve, and the Mesoamerican reef system. With tourism development investment rapidly increasing, the state is working to improve the balance of costs and benefits by promoting "low-impact" tourism development that both protects the long-term sustainability of tourism investment and preserves the coastal environment.

Quintana Roo has an extensive regulatory system of legal instruments for resource management and development which is aimed at limiting inappropriate development, but needs to be more consistently implemented to be truly effective. The state is on the "vanguard" with its system of protected areas and the first ecological land zoning plans adopted in Mexico. The strategy for promoting low-impact tourism development complements these regulatory approaches—which often lack adequate resources for effective implementation and enforcement—with a voluntary approach. A proven-effective tool of the voluntary initiative is a practitioner's manual of guidelines for low-impact tourism development practices.

The guidelines address issues concerning management of beaches, dunes, wetlands, vegetation, wastewater, solid waste, and use of energy and water resources. They are based on a comprehensive assessment of the coastal resource base and ecosystem dynamics, incorporating design and management techniques that have proven effective in other regions around the world. One of the key messages is the benefit to both industry and society of mitigating damage from natural hazards through low-cost and straightforward preconstruction practices, such as use of construction setbacks, incorporating vegetated dunes with native vegetation, and taking into account previous hurricane and erosion history in development planning.

The guidelines have reached a constituency of private sector developers and government officials in Costa Maya and have initiated a constructive dialogue on local coastal stewardship and resource conservation. Government, nongovernmental organizations, and the private sector are using these guidelines in workshops and field demonstrations to define and incorporate specific techniques into development practices, environmental impact assessments, land zoning ordinances, and urban plans at both the site and regional levels. In the future, they may be used as part of industry-based incentive programs, as well as criteria to guide public land development.

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the natural assets that attract tourists or in the infrastructure needed to support nature tourism. This has exposed ecologically or culturally sensitive sites to the risk of degradation by unregulated development, too many visitors, and the impact of rapid immigration linked to new jobs and business opportunities (Wells 1997).

On the other hand, there are parks where tourism has proven a valuable means of preserving biological diversity. Protected areas, such as the Great Barrier Reef Marine Park, in Australia, and Antarctica, have long been used to bring in income from tourism, while protecting the environment (WTTC et al. 1997).

Information Status and Needs

Conventional economic statistics do not properly capture the contribution of a pristine environment to the growth of coastal tourism. The relative importance of nature-based tourism to the whole tourism sector needs to be measured not only in terms of total foreign exchange revenue but also in nonmonetary indicators, such as local employment. Currently, basic statistics, such as GDP and employment, are not collected specifically for coastal tourism. Because diverse types of businesses constitute the industry, it is not easy to differentiate tourism as an economic sector. Moreover, the value of ecosystems to sustain the tourism industry has been underappreciated because of information limitations.

Although tourism plays a vital role in the economies of many countries, the existing information does not provide a comprehensive view of the full costs and benefits of the industry. This is due to a lack of information on both sides of this equation: *benefits* from income and employment generation; and environmental and sociocultural *costs* from adverse impacts of rapid, uncontrolled tourism development. Reliable data or an adequate framework to measure the actual benefits of tourism to the local economy and people are currently lacking. Many of the benefits often go to foreign investors and outside service providers. Identifying who benefits from tourism development and who bears the environmental cost would lead to more rational and conscious decisions on the trade-offs involved in tourism development, which are key to more equitable and sustainable management of the ecosystems.

One can only assess the effectiveness of existing sustainable tourism initiatives and certification programs if one develops the criteria and the indicators of "sustainability." Since each program has its own concerns about what to "sustain," such criteria and measures can also vary. Although some useful concepts such as carrying capacity have been developed, there are critical gaps in the type of information that is necessary to quantify them.

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