Ecosystems and Human Well-being: Wetlands and Water

Synthesis

Millennium Ecosystem Assessment

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Ecosystems and Human Well-being: Wetlands and Water

Synthesis

A Report of the Millennium Ecosystem Assessment

This report has been prepared to provide Contracting Parties to the Convention on Wetlands (Ramsar, Iran, 1971), and all those responsible for and involved in implementation of the Convention and concerned with the future sustainability of wetlands and water, with a synthesis of the findings of the Millennium Ecosystem Assessment

Synthesis Team Co-chairs
C. Max Finlayson, Rebecca D'Cruz, Nick Davidson

Synthesis Team Members
Jacqueline Alder, Steve Cork, Rudolf de Groot, Christian Lévêque, G. Randy Milton, Garry Peterson, Dave Pritchard, Blake D. Ratner, Walter V. Reid, Carmen Revenga, María Rivera, Frederik Schutyser, Mark Siebentritt, Mishka Stuip, Rebecca Tharme

Contributing Authors
Stuart Butchart, Ellen Dieme-Amting, Habiba Gitay, Steve Raaymakers, Douglas Taylor

Extended Writing Team
MA Coordinating Lead Authors, Lead Authors, Contributing Authors, and Working Group Coordinators

Review Editors
José Sarukhán and Anne Whyte (Co-chairs) and MA Board of Review Editors

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Contents

Key Messages

- *Wetland ecosystems (including lakes, rivers, marshes, and coastal regions to a depth of 6 meters at low tide) are estimated to cover more than 1,280 million hectares, an area 33% larger than the United States and 50% larger than Brazil. However, this estimate is known to under-represent many wetland types, and further data are required for some geographic regions. More than 50% of specific types of wetlands in parts of North America, Europe, Australia, and New Zealand were destroyed during the twentieth century, and many others in many parts of the world degraded.*
- *Wetlands deliver a wide range of ecosystem services that contribute to human well-being, such as fish and fiber, water supply, water purification, climate regulation, flood regulation, coastal protection, recreational opportunities, and, increasingly, tourism.*
- *When both the marketed and nonmarketed economic benefits of wetlands are included, the total economic value of unconverted wetlands is often greater than that of converted wetlands.*
- *A priority when making decisions that directly or indirectly influence wetlands is to ensure that information about the full range of benefits and values provided by different wetland ecosystem services is considered.*
- *The degradation and loss of wetlands is more rapid than that of other ecosystems. Similarly, the status of both freshwater and coastal wetland species is deteriorating faster than those of other ecosystems.*
- *The primary indirect drivers of degradation and loss of inland and coastal wetlands have been population growth and increasing economic development. The primary direct drivers of degradation and loss include infrastructure development, land conversion, water withdrawal, eutrophication and pollution, overharvesting and overexploitation, and the introduction of invasive alien species.*
- *Global climate change is expected to exacerbate the loss and degradation of many wetlands and the loss or decline of their species and to increase the incidence of vector-borne and waterborne diseases in many regions. Excessive nutrient loading is expected to become a growing threat to rivers, lakes, marshes, coastal zones, and coral reefs. Growing pressures from multiple direct drivers increase the likelihood of potentially abrupt changes in wetland ecosystems, which can be large in magnitude and difficult, expensive, or impossible to reverse.*
- *The projected continued loss and degradation of wetlands will reduce the capacity of wetlands to mitigate impacts and result in further reduction in human well-being (including an increase in the prevalence of disease), especially for poorer people in lower-income countries, where technological solutions are not as readily available. At the same time, demand for many of these services (such as denitrification and flood and storm protection) will increase.*
- *Physical and economic water scarcity and limited or reduced access to water are major challenges facing society and are key factors limiting economic development in many countries. However, many water resource developments undertaken to increase access to water have not given adequate consideration to harmful trade-offs with other services provided by wetlands.*

- *Cross-sectoral and ecosystem-based approaches to wetland management—such as river (or lake or aquifer) basin-scale management, and integrated coastal zone management—that consider the trade-offs between different wetland ecosystem services are more likely to ensure sustainable development than many existing sectoral approaches and are critical in designing actions in support of the Millennium Development Goals.*

- *Many of the responses designed with a primary focus on wetlands and water resources will not be sustainable or sufficient unless other indirect and direct drivers of change are addressed. These include actions to eliminate production subsidies, sustainably intensify agriculture, slow climate change, slow nutrient loading, correct market failures, encourage stakeholder participation, and increase transparency and accountability of government and private-sector decision-making.*

- *Major policy decisions in the next decades will have to address trade-offs among current uses of wetland resources and between current and future uses. Particularly important trade-offs involve those between agricultural production and water quality, land use and biodiversity, water use and aquatic biodiversity, and current water use for irrigation and future agricultural production.*

- *The adverse effects of climate change, such as sea level rise, coral bleaching, and changes in hydrology and in the temperature of water bodies, will lead to a reduction in the services provided by wetlands. Removing the existing pressures on wetlands and improving their resiliency is the most effective method of coping with the adverse effects of climate change. Conserving, maintaining, or rehabilitating wetland ecosystems can be a viable element to an overall climate change mitigation strategy.*

- *The MA conceptual framework for ecosystems and human well-being provides a framework that supports the promotion and delivery of the Ramsar Convention's "wise use" concept. This enables the existing guidance provided by the Convention for the wise use of all wetlands to be expressed within the context of human well-being and poverty alleviation.*

Foreword

Since the inception of global assessments on ozone depletion and climate change, the global policy process has been better informed, and decision-makers are able to take more effective and timely decisions. The Millennium Ecosystem Assessment followed in the footsteps of these assessments and was designed to meet the need for information about the consequences of ecosystem change for human well-being. It sought in particular to strengthen the link between scientific knowledge and decision-making.

It provided an assessment, not just a review of existing knowledge and understanding, of the current state of our ecosystems and the many services they support and provide to people. It significantly enhanced our understanding of the direct drivers of change to wetlands and showed how they would fare under a range of future scenarios. It analyzed future challenges and response options that could allow us to maintain, to the greatest extent possible, the ecosystem services on which we all depend.

The Convention on Wetlands (Ramsar, I.R. Iran, 1971) has recognized from the start that the MA can and should provide the Contracting Parties to the Convention, and all involved in the conservation and wise use of wetlands, with new understanding and insights into how best they can meet the objectives of the Convention. The Convention's Standing Committee, Secretariat, and Scientific and Technical Review Panel have supported and contributed to the work of the MA throughout.

This report, synthesizing the findings of the MA on inland, coastal, and near-shore marine wetlands, is the key product of the MA for the Ramsar Convention. It draws on the work of approximately 1,360 experts who compiled the many chapters of the MA reports. The synthesis stresses the link between wetlands and water and will help us set the future agenda for Ramsar.

During its work, the MA made a significant contribution to the work of the Convention's STRP. Several of the MA's authors contributed to the STRP's work that will be considered by the Convention's COP9 in November 2005. Through this "cross-fertilization" of ideas it became apparent that the MA's conceptual framework provides a structure for the delivery of the Convention's central concept of "wise use" of all wetlands. Furthermore, the STRP has recognized that the ecosystem terminologies adopted by the MA provide a valuable approach to its work of updating and harmonizing the terms and definitions used by the Convention, notably those concerning ecological character and wise use. Finally, the existing Ramsar "Toolkit" of Wise Use Handbooks is enhanced and supported by the MA's advice on response options.

We therefore commend this synthesis report to you, and urge all those concerned with the Ramsar Convention and with securing the wise use of wetlands to read it and use its findings to raise awareness of the role of wetlands in securing sustainable water supplies as well as providing a range of other vital ecosystem services.

Peter Bridgewater
Secretary General
Ramsar Convention on Wetlands

Gordana Beltram
Chair, Standing Committee
Ramsar Convention on Wetlands

Reader's Guide and Acknowledgments

This report uses the Ramsar Convention definitions of several key terms related to wetlands. (See Box on Key Terms.) All of the MA authors and Review Editors have contributed to this draft through their contributions to the underlying assessment chapters on which this material is based.

Five additional synthesis reports were prepared for ease of use by other audiences: general overview, UNCCD (desertification), CBD (biodiversity), business, and the health sector. Each MA sub-global assessment will also produce additional reports to meet the needs of its own audience. The full technical assessment reports of the four MA Working Groups will be published in 2005 by Island Press. All printed materials of the assessment, along with core data and a glossary of terminology used in the technical reports, will be available on the Internet at www.millenniumassessment.org. Appendix A lists the acronyms and abbrevia-tions used in this report and includes additional information on sources for some of the Figures.

References that appear in parentheses in the body of this report are to the underlying chapters in the full technical assessment reports of each Working Group. (A list of the assessment report chapters is provided in Appendix B.) To assist the reader, citations to the technical volumes generally specify sections of chapters or specific Boxes, Tables, or Figures, based on final drafts of the chapter. Some chapter subsection numbers may change during final copyediting, however, after this report has been printed.

In this report, the following words have been used where appropriate to indicate judgmental estimates of certainty, based on the collective judgment of the authors, using the observational evidence, modeling results, and theory that they have examined: very certain (98% or greater probability), high certainty (85–98% probability), medium certainty (65–85% probability), low certainty (52–65% probability), and very uncertain (50–52% probability). In other instances, a qualitative scale to gauge the level of scientific understanding is used:

Box. Key Terms Used in This Report

Wetlands: As defined by the Ramsar Convention on Wetlands, wetlands are "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres" (Article 1.1 of the Convention text).

Ecological character of wetlands: As defined by the Ramsar Convention, this is "the sum of the biological, physical and chemical components of the wetland ecosystem, and their interactions, which maintain the wetland and its products, functions and attributes" (Ramsar COP7, 1999). In February 2005, the STRP proposed updating the definition of ecological character, drawing on the MA's ecosystem terminology: "Ecological character is the combination of the ecosystem components, processes and services that characterise the wetland at a given point in time." This includes replacing "products, functions and attributes" with "services." This proposal will be formally considered by the Ramsar Convention's Contracting Parties in November 2005.

Ecosystem services: As defined by the MA, ecosystem services are "the benefits people obtain from ecosystems. These include provisioning services such as food and water; regulating services such as regulation of floods, drought, land degradation, and disease; supporting services such as soil formation and nutrient cycling; and cultural services such as recreational, spiritual, religious, and other nonmaterial benefits." This term corresponds with the usage by the Convention of the terms "products, functions and attributes" (as shown in the definition of ecological character). The classification of water as a provisioning service rather than a regulating service is debated, but this does not affect its general meaning within the context of this report.

Wise use of wetlands: This involves "their sustainable utilisation for the benefit of humankind in a way compatible with the maintenance of the natural properties of the ecosystem" (Ramsar COP3, 1987). The STRP has proposed updating the definition to: "the maintenance of their ecological character within the context of sustainable development, and achieved through the implementation of ecosystem approaches." This proposal will be formally considered by the Ramsar Convention's Contracting Parties in November 2005.

Waterbirds: These are "birds ecologically dependent on wetlands" (Article 1.2 of the Ramsar Convention text). This includes any wetland-dependent bird species and at the broad level includes penguins; divers; grebes; wetland-related pelicans; cormorants; darters and allies; herons; bitterns; storks; ibises and spoonbills; flamingos; screamers; swans, geese, and ducks (wildfowl); wetland-related raptors; wetland-related cranes; rails and allies; Hoatzin; wetland-related jacanas; waders (or shorebirds); gulls, skimmers, and terns; coucals; and wetland-related owls.

well established, established but incomplete, competing explanations, and speculative. Each time these terms are used they appear in italics.

Throughout this report, dollar signs indicate U.S. dollars and tons mean metric tons.

This report would not have been possible without the extraordinary commitment of the more than 2,000 authors and reviewers worldwide who contributed their knowledge, creativity, time, and enthusiasm to the development of the assessment. Thanks are due to the MA Assessment Panel, Coordinating Lead Authors, Lead Authors, Contributing Authors, Board of Review Editors, Expert Reviewers, and the members of the Scientific and Technical Review Panel of the Ramsar Wetlands Convention who contributed to this process and to the institutions that provided in-kind support enabling their participation. The current and past members of the MA Board (and their alternates), the members of the MA Exploratory Steering Committee, the Convention on Wetlands secretariat staff, and the MA secretariat staff, interns, and volunteers all contributed significantly to the success of this process.

The MA received major financial support from the Global Environment Facility; United Nations Foundation; David and Lucile Packard Foundation; World Bank; Consultative Group on International Agricultural Research; United Nations Environment Programme; Government of China; Ministry of Foreign Affairs of the Government of Norway; Kingdom of Saudi Arabia; and the Swedish International Biodiversity Programme. The full list of organizations that provided financial support to the MA is available at www.millenniumassessment.org.

Summary for Decision-makers

This report covers the range of wetlands as defined by the Ramsar Convention on Wetlands. These include inland wetlands (such as swamps, marshes, lakes, rivers, peatlands, and underground water habitats); coastal and near-shore marine wetlands (such as coral reefs, mangroves, seagrass beds, and estuaries); and human-made wetlands (such as rice fields (paddies), dams, reservoirs, and fish ponds).

For over 30 years, the Ramsar Convention has recognized the interdependence of people and their environment and is the only global intergovernmental convention addressing the interactions between water and wetland ecosystems. It has promoted the wise use of wetlands as a means of maintaining their "ecological character"—the ecosystem components and processes that comprise the wetland and that underpin the delivery of ecosystem services, such as fresh water and food.

Wetland Services and Human Well-being

Wetland ecosystems, including rivers, lakes, marshes, rice fields, and coastal areas, provide many services that contribute to human well-being and poverty alleviation. (See Table 1.) Some groups of people, particularly those living near wetlands, are highly dependent on these services and are directly harmed by their degradation. Two of the most important wetland ecosystem services affecting human well-being involve fish supply and water availability. Inland fisheries are of particular importance in developing countries, and they are sometimes the primary source of animal protein to which rural communities have access. For example, people in Cambodia obtain about 60–80% of their total animal protein from the fishery in Tonle Sap and associated floodplains. Wetland-related fisheries also make important contributions to local and national economies. Capture fisheries in coastal waters alone contribute $34 billion to gross world product annually.

The principal supply of renewable fresh water for human use comes from an array of inland wetlands, including lakes, rivers, swamps, and shallow groundwater aquifers. Groundwater, often recharged through wetlands, plays an important role in water supply, with an estimated 1.5–3 billion people dependent on it as a source of drinking water. Rivers have been substantially modified around the world to increase the water available for human consumption. Recent estimates place the volume of water trapped behind (documented) dams at 6,000–7,000 cubic kilometers.

Other wetland services with strong linkages to human well-being include:

- *Water purification and detoxification of wastes.* Wetlands, and in particular marshes, play a major role in treating and detoxifying a variety of waste products. Some wetlands have been found to reduce the concentration of nitrate by more than 80%.
- *Climate regulation.* One of the most important roles of wetlands may be in the regulation of global climate change through sequestering and releasing a major proportion of fixed carbon in the biosphere. For example, although covering only an estimated 3–4% of the world's land area, peatlands are estimated to hold 540 gigatons of carbon, representing about 1.5% of the total estimated global carbon storage and about 25–30% of that contained in terrestrial vegetation and soils.
- *Mitigation of climate change.* Sea level rise and increases in storm surges associated with climate change will result in the erosion of shores and habitat, increased salinity of estuaries and freshwater aquifers, altered tidal ranges in rivers and bays, changes in sediment and nutrient transport, and increased coastal flooding and, in turn, could increase the vulnerability of some coastal populations. Wetlands, such as mangroves and floodplains, can play a critical role in the physical buffering of climate change impacts.

Table 1. Ecosystem Services Provided by or Derived from Wetlands

Services	Comments and Examples
Provisioning	
Food	production of fish, wild game, fruits, and grains
Fresh water[a]	storage and retention of water for domestic, industrial, and agricultural use
Fiber and fuel	production of logs, fuelwood, peat, fodder
Biochemical	extraction of medicines and other materials from biota
Genetic materials	genes for resistance to plant pathogens, ornamental species, and so on
Regulating	
Climate regulation	source of and sink for greenhouse gases; influence local and regional temperature, precipitation, and other climatic processes
Water regulation (hydrological flows)	groundwater recharge/discharge
Water purification and waste treatment	retention, recovery, and removal of excess nutrients and other pollutants
Erosion regulation	retention of soils and sediments
Natural hazard regulation	flood control, storm protection
Pollination	habitat for pollinators
Cultural	
Spiritual and inspirational	source of inspiration; many religions attach spiritual and religious values to aspects of wetland ecosystems
Recreational	opportunities for recreational activities
Aesthetic	many people find beauty or aesthetic value in aspects of wetland ecosystems
Educational	opportunities for formal and informal education and training
Supporting	
Soil formation	sediment retention and accumulation of organic matter
Nutrient cycling	storage, recycling, processing, and acquisition of nutrients

[a] While fresh water was treated as a provisioning service within the MA, it is also regarded as a regulating service by various sectors.

■ *Cultural services.* Wetlands provide significant aesthetic, educational, cultural, and spiritual benefits, as well as a vast array of opportunities for recreation and tourism. Recreational fishing can generate considerable income: 35–45 million people take part in recreational fishing (inland and saltwater) in the United States, spending a total of $24–37 billion each year on their hobby. Much of the economic value of coral reefs—with net benefits estimated at nearly $30 billion each year—is generated from nature-based tourism, including scuba diving and snorkeling.

Wetlands provide many nonmarketed and marketed benefits to people, and the total economic value of unconverted wetlands is often greater than converted wetlands (*high certainty*). There are many examples of the economic value of intact wetlands exceeding that of converted or otherwise altered wetlands. For instance, areas of intact mangroves in Thailand have a total net present economic value—calculated based on the economic contribution of both marketed products such as fish and nonmarketed services such as protection from storm damage and carbon sequestration—of at least $1,000 per hectare (and possibly as high as $36,000 per hectare) compared with about $200 per hectare when converted to shrimp farms. In Canada, areas of intact freshwater marshes have a total economic value of about $5,800 per hectare compared with $2,400 when drained marshes are used for agriculture. This does not mean that conversion of wetlands is never economically justified, but it illustrates the fact that many of the economic and social benefits of wetlands have not been taken into account by decision-makers.

Both inland and coastal wetlands significantly influence the nature of the hydrological cycle and hence the supply of water for people and the many uses they make of water, such as for irrigation, energy, and transport. Changes in hydrology, in turn, affect wetlands.

■ Wetlands deliver a wide array of hydrological services—for instance, swamps, lakes, and marshes assist with flood mitigation, promote groundwater recharge, and regulate river flows—but the nature and value of these services differs across wetland types.

■ Flooding is a natural phenomenon that is important for maintaining the ecological functioning of wetlands (for example, by serving as a means for the natural transport of dissolved or suspended materials and nutrients into wetlands) and in particular for sustaining the delivery of many of the services they provide to millions of people, particularly to those whose livelihoods depend on floodplains for flood-recession agriculture and pasturage and for fish production.

■ Many wetlands diminish the destructive nature of flooding, and the loss of these wetlands increases the risks of floods occurring. Wetlands, such as floodplains, lakes, and reservoirs, are the main providers of flood attenuation potential in inland water systems. Nearly 2 billion people live in areas of high flood risk—a risk that will be increased if wetlands are lost or degraded. Coastal wetlands, including coastal barrier islands, coastal river floodplains, and coastal vegetation, all play an important role in reducing the impacts of floodwaters produced by coastal storm events.

Physical and economic water scarcity and limited or reduced access to water are major challenges facing human society and are key factors limiting economic development in many countries. Water scarcity and declining access to fresh water are a globally significant and accelerating problem for 1–2 billion people worldwide, hindering growth in food production and harming human health and economic development.

The continued degradation of water quality will increase the prevalence of disease, especially for vulnerable people in developing countries, where technological fixes and alternatives are not readily available (*high certainty*). The burden of disease from inadequate water, sanitation, and hygiene totals 1.7 million deaths and results in the loss of at least 54 million healthy life years annually. Although largely eliminated in wealthier nations, water-related diseases (malarial and diarrheal diseases, for instance) are among the most common causes of illness and death in developing countries, affecting particularly the poor. Some waterborne chemical and microbiological pollutants also harm human health—sometimes, in the case of chemical pollutants, through biomagnification through the food chain. Water quality degradation also affects people indirectly by degrading the resource base on which they depend. Present institutional structures tend to promote a narrow, sectoral approach to intervention for individual diseases, providing little opportunity to consider broader approaches to ecosystem management as a tool for enhancing human health. Actions to overcome intersectoral divides would help promote the use of ecosystem assessments or eco-health approaches to address human health concerns.

Status and Trends of Wetlands

The global extent of wetlands is estimated to be in excess of 1,280 million hectares (1.2 million square kilometers) but it is *well established* that this is an underestimate. This estimate includes inland and coastal wetlands (including lakes, rivers, and marshes), near-shore marine areas (to a depth of 6 meters below low tide), and human-made wetlands such as reservoirs and rice fields and was derived from multiple information sources. However, these sources were known to under-represent many wetland types, and further data are required for some geographic regions.

More than 50% of specific types of wetlands in parts of North America, Europe, Australia, and New Zealand were converted during the twentieth century (*medium to high certainty*). Extrapolation of this estimate to wider geographic areas or to other wetland types, as has been done in some studies, is *speculative* only. For North America, the estimates refer to inland water and coastal marshes and emergent estuarine wetlands; the estimates for Europe include the loss of peatlands; those for Northern Australia are of freshwater marshes, while estimates for New Zealand are of inland and coastal marshes.

There is insufficient information on the extent of all wetland types being considered in this report—such as inland wetlands that are seasonally or intermittently flooded and some coastal wetlands—to document the extent of wetland loss globally. There is, however, ample evidence of the dramatic loss and degradation of many individual wetlands. For example, the surface area of the Mesopotamian marshes (located between the Tigris and Euphrates Rivers in southern Iraq) decreased from an area of 15,000–20,000 square kilometers in the 1950s to less than 400 square kilometers today due to excessive water withdrawals, dams, and industrial development. Similarly, the volume of water in the Aral Sea basin has been reduced by 75% since 1960 due mainly to large-scale upstream diversions of the Amu Darya and Syr Darya river flow for irrigation of close to 7 million hectares.

Coastal ecosystems are among the most productive yet highly threatened systems in the world. These ecosystems produce disproportionately more services relating to human well-being than most other systems, even those covering larger total areas, but are experiencing some of the most rapid degradation and loss:

■ About 35% of mangroves (from countries with available multiyear data, representing 54% of total mangrove area at present) have been lost over the last two decades, driven primarily by aquaculture development, deforestation, and freshwater diversion.

■ Some 20% of coral reefs were lost and more than a further 20% degraded in the last several decades of the twentieth century through overexploitation, destructive fishing practices, pollution and siltation, and changes in storm frequency and intensity.

There is *established but incomplete* evidence that the changes being made are increasing the likelihood of nonlinear and potentially abrupt changes in ecosystems, with important consequences for human well-being. These nonlinear changes can be large in magnitude and difficult, expensive, or impossible to reverse. For example, once a threshold of nutrient loading is crossed, changes in freshwater and coastal ecosystems can be abrupt and extensive, creating harmful algal blooms (including blooms of toxic species) and sometimes leading to the formation of oxygen-depleted zones, killing all animal life. Capabilities for predicting some nonlinear changes are improving, but on the whole scientists cannot predict the thresholds at which change will be encountered. The increased likelihood of these nonlinear changes stems from the loss of biodiversity and growing pressures from multiple direct drivers of ecosystem change. The loss of species and genetic diversity decreases the resilience of ecosystems —their ability to maintain particular ecosystem services as conditions change. In addition, growing pressures from drivers such as overharvesting, climate change, invasive species, and nutrient loading push ecosystems toward thresholds that they might otherwise not encounter.

Many wetland-dependent species in many parts of the world are in decline; the status of species dependent on inland waters and of waterbirds dependent on coastal wetlands is of particular concern. Although the evidence has geographical limitations and is chiefly from species already globally threatened with extinction, this pattern is consistent for different groups of species, with *medium certainty* in the underlying data. (See Table 2.) Between 1970 and 2000, populations of freshwater species included in the Living Planet Index declined on average by 50%, compared with 30% for marine and other terrestrial species (*medium certainty*). The status of globally threatened birds dependent on freshwater wetlands, and even more so that of coastal seabirds, has deteriorated faster since 1988 than the status of birds dependent on other (terrestrial) ecosystems.

Causes of Wetland Loss and Degradation

The primary indirect drivers of degradation and loss of rivers, lakes, freshwater marshes, and other inland wetlands (including loss of species or reductions of populations in these systems) have been population growth and increasing economic development. The primary direct drivers of degradation and loss include infrastructure development, land conversion, water withdrawal, pollution, overharvesting and overexploitation, and the introduction of invasive alien species. (See Figure 1.)

- Clearing and drainage, often for agricultural expansion, and increased withdrawal of fresh water are the main reasons for the loss and degradation of inland wetlands such as swamps,

Table 2. Status and Trends of Major Groups of Wetland-dependent Species

Species Group	Status and Trends
Waterbirds	Of the 1,138 waterbird biogeographic populations whose trends are known, 41% are in decline. Of the 964 bird species that are predominantly wetland-dependent, 203 (21% of total) are extinct or globally threatened, with higher percentages of species dependent on coastal systems being globally threatened than are those dependent only on inland wetlands. The status of globally threatened birds dependent on freshwater wetlands and, even more so, that of coastal seabirds has deteriorated faster since 1988 than the status of birds dependent on other (terrestrial) ecosystems.
Wetland-dependent mammals	Over one third (37%) of the freshwater-dependent species that were assessed for the *IUCN Red List* are globally threatened; these include groups such as manatees, river dolphins, and porpoises, in which all species assessed are listed as threatened. Almost a quarter of all seals, sea lions, and walruses are listed in the *IUCN Red List* as threatened, and worldwide estimated mortalities across all cetacean species add up to several hundred thousand every year.
Freshwater fish	Approximately 20% of the world's 10,000 described freshwater fish species have been listed as threatened, endangered, or extinct in the last few decades.
Amphibians	Nearly one third (1,856 species) of the world's amphibian species are threatened with extinction, a large portion of which (964 species) are from fresh water, especially flowing freshwater habitats. In addition, the population sizes of at least 43% of all amphibian species are declining, indicating that the number of threatened species can be expected to rise in the future. By comparison, just 12% of all bird species and 23% of all mammal species are threatened.
Turtles	At least 50% of the 200 species of freshwater turtles have been assessed in the *IUCN Red List* as globally threatened and more than 75% of freshwater turtle species in Asia are listed as globally threatened, including 18 that are critically endangered, with one being extinct. All 6 species of marine turtles that have been assessed that use coastal wetlands for feeding and breeding are listed as threatened in the *IUCN Red List.*
Crocodiles	Of the 23 species of crocodilians that inhabit a range of wetlands including marshes, swamps, rivers, lagoons, and estuaries, 4 are critically endangered, 3 endangered, and 3 vulnerable.

Figure 1. Main Direct Drivers of Change in Wetland Systems

The cell color indicates the impact of each driver on biodiversity in each type of ecosystem over the past 50–100 years. High impact means that over the last century the particular driver has significantly altered biodiversity in that ecosystem; low impact indicates that it has had little influence on biodiversity in the ecosystem. The arrows indicate the trend in the driver. Horizontal arrows indicate a continuation of the current level of impact; diagonal and vertical arrows indicate progressively stronger increasing trends in impact. Thus, for example, if an ecosystem had experienced a moderate impact of a particular driver in the past century (such as the impact of overexploitation in inland water systems), a horizontal arrow indicates that this moderate impact is likely to continue. This Figure is based on expert opinion consistent with and based on the analysis of drivers of change in the various chapters of the assessment report of the MA Condition and Trends Working Group. The Figure presents global impacts and trends that may be different from those in specific regions.

		Habitat change	Climate change	Invasive species	Over-exploitation	Pollution (nitrogen, phosphorus)
Inland water		Very high ↑	Low ↑	High ↑	Moderate →	Very high ↑
Coastal		Very high ↗	Moderate ↑	High ↗	High ↗	Very high ↑
Marine		Moderate ↑	Low ↑	Low →	Very high ↗	Low ↑
Forest	Boreal	Low ↗	Low ↑	Low ↗	Low →	Moderate ↑
	Temperate	High ↘	Low ↑	Low ↑	Moderate →	Moderate ↑
	Tropical	Very high ↑	Low ↑	Low ↑	High ↗	Low ↑
Dryland	Temperate grassland	Very high ↗	Low ↑	Moderate →	Low →	Very high ↑
	Mediterranean	High ↗	Low ↑	High ↑	Moderate →	Low ↑
	Tropical grassland and savanna	High ↗	Moderate ↑	Low ↑	Very high →	Moderate ↑
	Desert	Low →	Moderate ↑	Moderate →	Low →	Low ↑
Island		High →	Low ↑	Very high →	High →	Low ↑
Mountain		High →	Moderate ↑	Low →	Low →	Low ↑
Polar		Low ↗	High ↑	Low →	Moderate ↗	Moderate ↑

Driver's impact on biodiversity over the last century

Low

Moderate

High

Very high

Driver's current trends

Decreasing impact ↘

Continuing impact →

Increasing impact ↗

Very rapid increase of the impact ↑

Source: Millennium Ecosystem Assessment

marshes, rivers, and associated floodplain water bodies. By 1985, an estimated 56–65% of inland and coastal marshes (including small lakes and ponds) had been drained for intensive agriculture in Europe and North America, 27% in Asia, 6% in South America, and 2% in Africa. The amount of water impounded behind dams quadrupled since 1960, and three to six times as much water is held in reservoirs as in natural rivers. Changes in flow regime, transport of sediments and chemical pollutants, modification of inland wetlands, and disturbance of migration routes have endangered many species and resulted in the loss of others.

- Agricultural systems and practices have exerted a wide range of mostly adverse impacts on inland and coastal wetlands globally. Both the extensive use of water for irrigation (some 70% of water use globally is for irrigation) and excessive nutrient loading associated with the use of nitrogen and phosphorus in fertilizers have resulted in a decline in the delivery of services such as fresh water and some fish species. On the other hand, the expansion of paddy rice cultivation has increased the area of human-made wetlands in some regions.
- The introduction of invasive alien species is now considered to be a major cause of local extinction of native freshwater species. Worldwide, two thirds of the freshwater species introduced into the tropics and more than half of those introduced to temperate regions have established self-sustaining populations.

The primary direct driver of the loss and degradation of coastal wetlands, including saltwater marshes, mangroves, seagrass meadows, and coral reefs, has been conversion to other land uses. Other direct drivers affecting coastal wetlands include diversion of freshwater flows, nitrogen loading, overharvesting, siltation, changes in water temperature, and species invasions. The primary indirect drivers of change have been the growth of human populations in coastal areas coupled with growing economic activity. Nearly half of the world's major cities are located within 50 kilometers of the coast, and coastal population densities are 2.6 times larger than that of inland areas. This population pressure leads to conversion of coastal wetlands as a result of urban and suburban expansion and increasing agricultural demand (such as the clearing of mangroves for aquaculture). Given the extensive changes in land use and cover that have occurred in many coastal areas, it is unlikely that many of the observed changes in habitat and species loss will be readily reversed. Other important drivers of change in coastal wetlands include:

- Freshwater diversion from estuaries has meant significant losses in the delivery of water and sediment to nursery areas and fishing grounds in the coastal zone (*high certainty*) and to floodplains, affecting the livelihood of millions of people who depend on these coastal areas and floodplains for flood-recession agriculture and pasturage and for fish production and capture fisheries. Worldwide, although human activities have increased sediment flows in rivers by about 20%, reservoirs and water diversions prevent about 30% of sediments from reaching the oceans, resulting in a net reduction of sediment delivery to estuaries of roughly 10%.
- Seagrass ecosystems are damaged by a wide range of human impacts, including dredging and anchoring in seagrass meadows, coastal development, eutrophication, hyper-salinization resulting from reduction in freshwater inflows, siltation, habitat conversion for the purposes of algae farming, and climate change. Major losses of seagrass habitat have been reported from the Mediterranean, Florida Bay in the United States, and parts of Australia, and current losses are expected to accelerate, especially in Southeast Asia and the Caribbean.
- Disruption and fragmentation of coastal wetlands important as migration routes have endangered many species and resulted in the loss of others. For example, the decline of certain long-distance East Atlantic flyway populations (while other populations on the same flyway are stable or increasing) has been attributed to their high dependence on deteriorating critically important spring staging areas, notably the international Wadden Sea, that have been affected by commercial shellfisheries.
- Estuarine systems are among the most invaded ecosystems in the world, with introduced species causing major ecological changes. For example, San Francisco Bay in California has over 210 invasive species, with one new species established every 14 weeks between 1961 and 1995, brought in by ballast water of large ships or occurring as a result of fishing activities. The ecological consequences of the invasions include habitat loss and alteration, altered water flow and food webs, the creation of novel and unnatural habitats subsequently colonized by other invasive alien species, abnormally effective filtration of the water column, hybridization with native species, highly destructive predators, and introductions of pathogens and disease.

Excessive nutrient loading is expected to become a growing threat to rivers, lakes, marshes, coastal zones, and coral reefs. Since 1950, nutrient loading—anthropogenic increases in nitrogen, phosphorus, sulfur, and other nutrient-associated pollutants—has emerged as one of the most important drivers of ecosystem change in freshwater and coastal ecosystems, and this driver is projected to substantially increase in the future (*high certainty*). Wetlands provide an important service by treating and detoxifying a variety of waste products, and some wetlands have been found to reduce the concentration of nitrate by more than 80% (C7.2.5, C12.2.3). However, excessive nutrient loading associated with the use of nitrogen and phosphorus in fertilizers has resulted in eutrophication (a process whereby excessive plant growth depletes oxygen in the water), acidification of freshwater and terrestrial ecosystems, large and at times toxic algal blooms, widescale deoxygentation (and hypoxia), and a decline in the delivery of services such as fresh water and some fish species.

The negative impacts of nutrient loading can extend hundreds of kilometers from the source of pollution (such as the creation of hypoxic "dead zones" in coastal areas). The flux of reactive (biologically available) nitrogen to the coasts and oceans increased by 80% from 1860 to 1990, with resulting eutrophication that has harmed coastal fisheries and contributed to coral

reef regime shifts that are effectively irreversible. Humans now produce more reactive (biologically available) nitrogen than is produced by all natural pathways combined, and some projections suggest that this may increase by roughly a further two thirds by 2050. Three out of four scenarios prepared during the MA project that the global flux of nitrogen to coastal ecosystems will increase by a further 10–20% by 2030 (*medium certainty*), with almost all of the increase occurring in developing countries.

Global climate change is expected to exacerbate the loss and degradation of many wetlands and the loss or decline of their species and to harm the human populations dependent on their services; however, projections about the extent of such loss and degradation or decline are not yet well established. Climate change is projected to lead to increased precipitation over more than half of Earth's surface, and this will make more water available to society and ecosystems. However, increases in precipitation will not be universal, and climate change will also cause substantial decrease in precipitation in other areas.

Despite the benefits that increased precipitation may provide to some freshwater wetlands, the projected changes in climate are likely to have pronounced harmful impacts on many wetland ecosystems. Specifically:

- Many coastal wetlands will change as a consequence of projected sea level rise, increased storm and tidal surges, changes in storm intensity and frequency, and subsequent changes in river flow regimes and sediment transport. There will be adverse consequences for wetland species, especially those that cannot relocate to suitable habitats, as well as migratory species that rely on a variety of wetland types during their life cycle.
- Of all the world's ecosystems, coral reefs may be the most vulnerable to the effects of climate change. Many coral reefs have undergone major, although often partially reversible, bleaching episodes when local sea surface temperatures have increased during one month by 0.5–1° Celsius above the average of the hottest month.
- Global climate change impacts will often exacerbate impacts of other drivers of degradation of wetlands. For example, decreased precipitation as a result of climate change will exacerbate problems associated with already growing demands for water. Higher sea surface temperatures will exacerbate threats to coral reefs associated with increased sedimentation. In limited cases, however, global climate change could lessen pressure on some wetlands, particularly in areas where precipitation increases.
- Specific adverse consequences of global climate change include already observed changes in the distribution of coastal wintering shorebirds in Western Europe associated with rising mid-winter temperatures. It is also anticipated that climate change will lead to population declines in high-Arctic breeding waterbird species as a result of habitat loss and that the distribution of many fish species will shift toward the poles, with cold-water fish being further restricted in their range, and cool- and warm-water fish expanding in range (*medium certainty*).
- The incidence of vector-borne diseases such as malaria and dengue and of waterborne diseases such as cholera is projected to increase in many regions (*medium to high certainty*).

There are a number of widely accepted reasons why many types of wetlands such as lakes, marshes, mangroves, tidal flats, and estuaries continue to be lost, converted, or degraded even though benefits gained from maintaining them often are greater than the benefits associated with their conversion:

- The individuals who benefit most from the conservation of wetlands are often local residents, including many who are likely to have been disenfranchised from decision-making processes. Decisions concerning the fate of wetlands, however, are often made through processes that are unsympathetic to local needs or that lack transparency and accountability.

■ Decision-makers at many levels are unaware of the connection between wetland condition and the provision of wetland services and the consequent benefits for people. In very few instances are decisions informed by estimates of the total economic value of both the marketed and nonmarketed services provided by wetlands.

■ Many services delivered by wetlands (such as flood mitigation, climate regulation, groundwater recharge, and prevention of erosion) are not marketed and accrue to society at large at local and global scales. More degradation of these "public goods" takes place than is in society's interests. Individuals often do not have incentives to maintain the services for the benefit of wider society. Further, when an action results in the degradation of a service that harms other individuals, market mechanisms do not exist (nor, in many cases, could they exist) to ensure that these individuals are compensated for the damages they suffer.

■ The private benefits of wetland conversion are often exaggerated by subsidies such as those that encourage the drainage of wetlands for agriculture or the large-scale replacement of coastal wetlands by intensive aquaculture or infrastructure, including for urban, industrial, and tourism development.

■ In some cases, the benefits of conversion exceed those of maintaining the wetland, such as in prime agricultural areas or on the borders of growing urban areas. As more and more wetlands are lost, however, the relative value of the conservation of the remaining wetlands increases, and these situations become increasingly rare.

Scenarios for Wetlands

The MA developed four scenarios to explore plausible futures for ecosystems and human well-being. (See Box 1.) The scenarios explored two global development paths—one in which the world becomes increasingly globalized (*Global Orchestration* and *TechnoGarden*) and the other in which it becomes increasingly regionalized (*Adapting Mosaic* and *Order from Strength*)—as well as two different approaches to ecosystem management—one in which actions are reactive and most

Box 1. MA Scenarios

The MA developed four scenarios to explore plausible futures for ecosystems and human well-being based on different assumptions about driving forces of change and their possible interactions:

Globalized World	Description
Reactive ecosystem management (*Global Orchestration*)	This scenario depicts a globally connected society that focuses on global trade and economic liberalization and takes a reactive approach to ecosystem problems but that also takes strong steps to reduce poverty and inequality and to invest in public goods such as infrastructure and education. Economic growth in this scenario is the highest of the four scenarios, while the scenario is assumed to have the lowest population in 2050.
Proactive ecosystem management (*TechnoGarden*)	This scenario depicts a globally connected world relying strongly on environmentally sound technology, using highly managed, often engineered, ecosystems to deliver ecosystem services, and taking a proactive approach to the management of ecosystems in an effort to avoid problems. Economic growth is relatively high and accelerates, while population in 2050 is in the mid-range of the scenarios.
Regionalized World	
Reactive ecosystem management (*Order from Strength*)	This scenario represents a regionalized and fragmented world, concerned with security and protection, emphasizing primarily regional markets, paying little attention to public goods, and taking a reactive approach to ecosystem problems. Economic growth rates are the lowest of the scenarios (particularly low in developing countries) and decrease with time, while population growth is the highest.
Proactive ecosystem management (*Adapting Mosaic*)	In this scenario, regional watershed-scale ecosystems are the focus of political and economic activity. Local institutions are strengthened and local ecosystem management strategies are common; societies develop a strongly proactive approach to the management of ecosystems. Economic growth rates are somewhat low initially but increase with time, and population in 2050 is nearly as high as in *Order from Strength*.

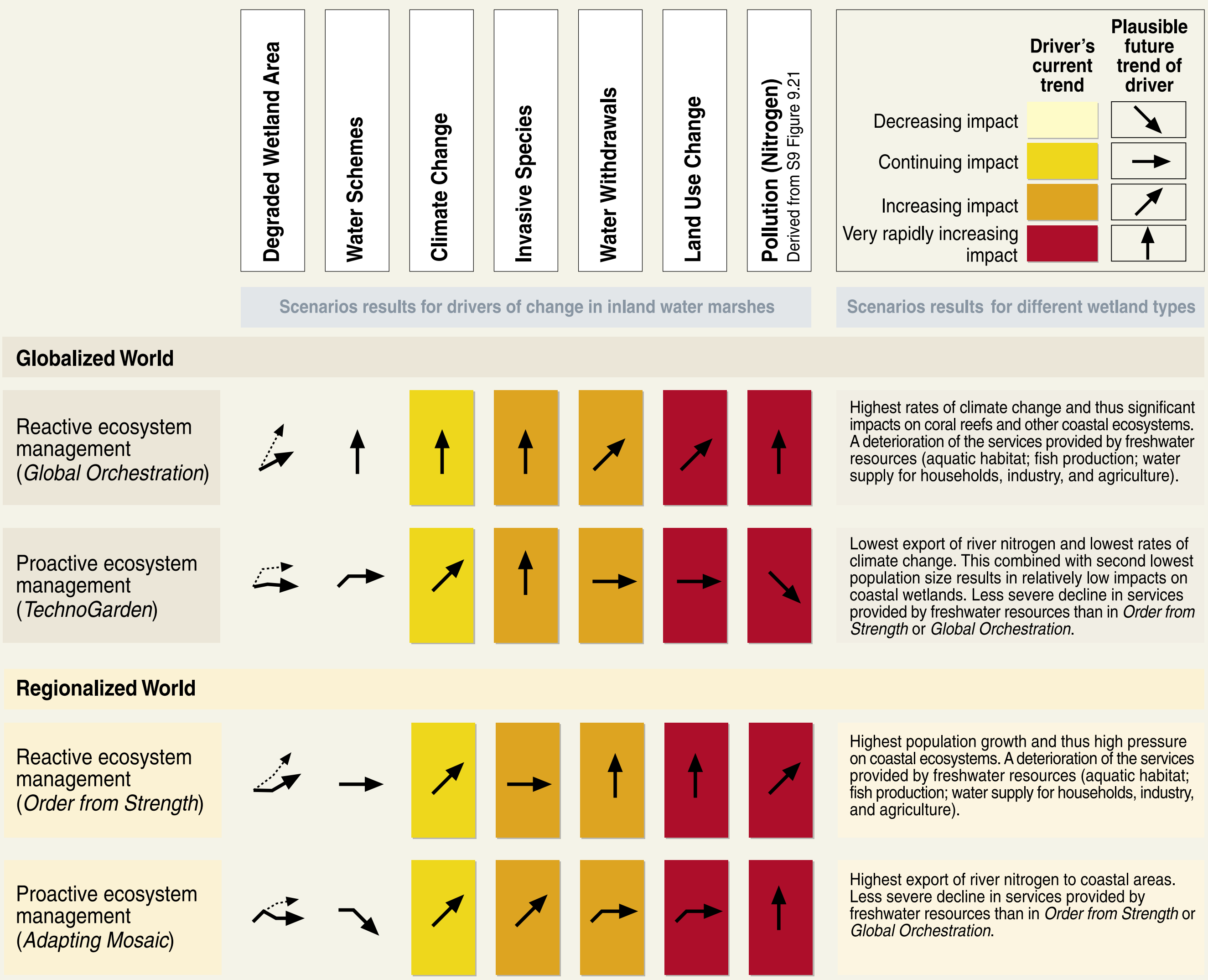
The scenarios are not predictions; instead they were developed to explore the unpredictable features of change in drivers and ecosystem services. No scenario represents business as usual, although all begin from current conditions and trends.

problems are addressed only after they become obvious (*Global Orchestration* and *Order from Strength*) and the other in which ecosystem management is proactive and policies deliberately seek to maintain ecosystem services for the long term (*TechnoGarden* and *Adapting Mosaic*).

The degradation of wetlands is expected to increase through 2050 under the reactive *Global Orchestration* and *Order from Strength* scenarios but to be relatively unchanged in 2050 (after initial increases in the early part of the century) under the proactive *TechnoGarden* and *Adapting Mosaic* scenarios. The degradation of wetlands is expected to increase (see Figure 2), and the global area of wetlands is expected to decrease with increases in human population, particularly in coastal zones, and with the expansion of agricultural land. Toward 2050, there is a long-term increase of conversion to agricultural land use in the scenarios with reactive ecosystem management. For the proactive *TechnoGarden* and *Adapting Mosaic* scenarios, however, the development of technologies and skills for agroecosystem management could lead to restoration of wetlands. Furthermore, toward 2050 climate change begins to have significant impacts on coastal wetlands such as estuaries, tidal flats, and deltas as a result of sea level rise.

Figure 2. Plausible Main Direct Drivers of Change in Wetland Area under Different MA Scenarios

For "Degraded Wetland Area," solid lines indicate the best case, and dashed lines the worst case, envisaged for each scenario. The cell color indicates the current trend in each driver (trends not available separately for water schemes). For the other cells, the arrows indicate the trend in the driver. Horizontal arrows indicate stabilization of the impact; diagonal and vertical arrows indicate progressively stronger increasing trends in impact. Thus a vertical arrow indicates that the likely effect of the driver on the degradation of wetlands in the future will grow much stronger.



Source: Millennium Ecosystem Assessment

The demand for provisioning services, such as food, fiber, and water, strongly increases in all four scenarios due to expected growth in population and economies and changing consumption patterns (*medium to high certainty*). Land use change is expected to continue to be a major driver of changes in the provision of ecosystem services up to 2050 (*medium to high certainty*). A deterioration of the services provided by freshwater resources—aquatic habitat, fish production, and water supply for households, industry, and agriculture—is expected under the two scenarios that adopt reactive approaches to environmental problems (*medium certainty*). A less severe decline is expected under the other two scenarios, which proactively increase efficiency in resource use through environmental policies and an emphasis on the application of technology for environmental benefits. After 2050, climate change and its impacts (such as sea level rise) have an increasing effect on the provision of ecosystem services (*medium certainty*).

The demand for regulating services provided by wetlands, such as denitrification and protection against floods and storms, will increase, while the provision of these services is likely to decrease. The use of nitrogen and other fertilizers is projected to increase in all scenarios, raising the demand for nutrient removal by wetlands. There is likely to be increased pressure on wetlands, such as mangroves and floodplains, to buffer the physical impacts of extreme events, such as sea level rise and increases in storm surges.

Increased loss of wetlands will lead to global extinctions as species numbers approach equilibrium with the remnant habitat. It is likely under most scenarios that large, costly, and even irreversible environmental changes will become more common in the future unless offset by anticipatory management that deliberately maintains the resilience of wetlands. However, time lags between habitat reduction and species extinction may provide an opportunity for humans to reverse past losses and avoid future ones.

Major policy decisions in the next 50–100 years will have to address trade-offs among current uses of wetland resources and between current and future uses. Particularly important trade-offs involve those between agricultural production and water quality, land use and biodiversity, water use and aquatic biodiversity, and current water use for irrigation and future agricultural production. Under all the MA scenarios, resource management decisions tend to give highest priority to increasing availability of provisioning services (such as food supply and water use), and this often leads to reductions in the provision of supporting, regulating, and cultural ecosystem services.

The MA scenarios differ significantly in their implications for the role of the Ramsar Convention in helping to protect wetlands. Some stresses to wetlands are stronger in the globalization scenarios, while others are stronger in the regional fragmentation scenarios. Under the *Adapting Mosaic* scenario, the focus on increasing knowledge of ecosystems through adaptive management could lead to high success in wetland protection, especially if the international cooperation frameworks help to empower regional managers and act as information-gathering and networking bases for regional and local management projects. The different futures projected by the MA scenarios imply somewhat different responsibilities for the Ramsar Convention. In the more regionalized scenarios, the Convention would likely need to carry a relatively greater part of the burden than at present for supporting actions at local and regional scales, whereas the globalization scenarios would tend to reinforce or amplify current Ramsar activities.

Responses

A conceptual shift among policy-makers and decision-makers is required to ensure that cross-sectoral approaches that incorporate the principles of consultation and transparency, address trade-offs, and ensure the long-term future of the services provided and supported by wetlands are adopted and implemented effectively. As these approaches place greater emphasis on the sustainable use of wetlands and their resources, they will better support sustainable development and improved human well-being. Rivers, lakes, marshes, mangroves, and other wetlands have often played central roles in development plans, but all too often these plans have been developed by single sectors and the resources have been used in ways that led to unnecessary harm to other sectors or that sacrificed long-term benefits for short-term gains. For example, rivers have been dammed to provide irrigation water, but these reservoirs have created health problems associated with infectious disease, while marshes drained to reduce malaria removed a critical source of food for local communities. As wetlands become scarcer and as we understand the benefits provided by the entire array of ecosystem services, the best options will increasingly involve managing wetlands for a broad array of services. This in turn requires the maintenance of the ecological character of the wetland—the goal of the "wise use" concepts advocated by the Ramsar Convention for more than 30 years.

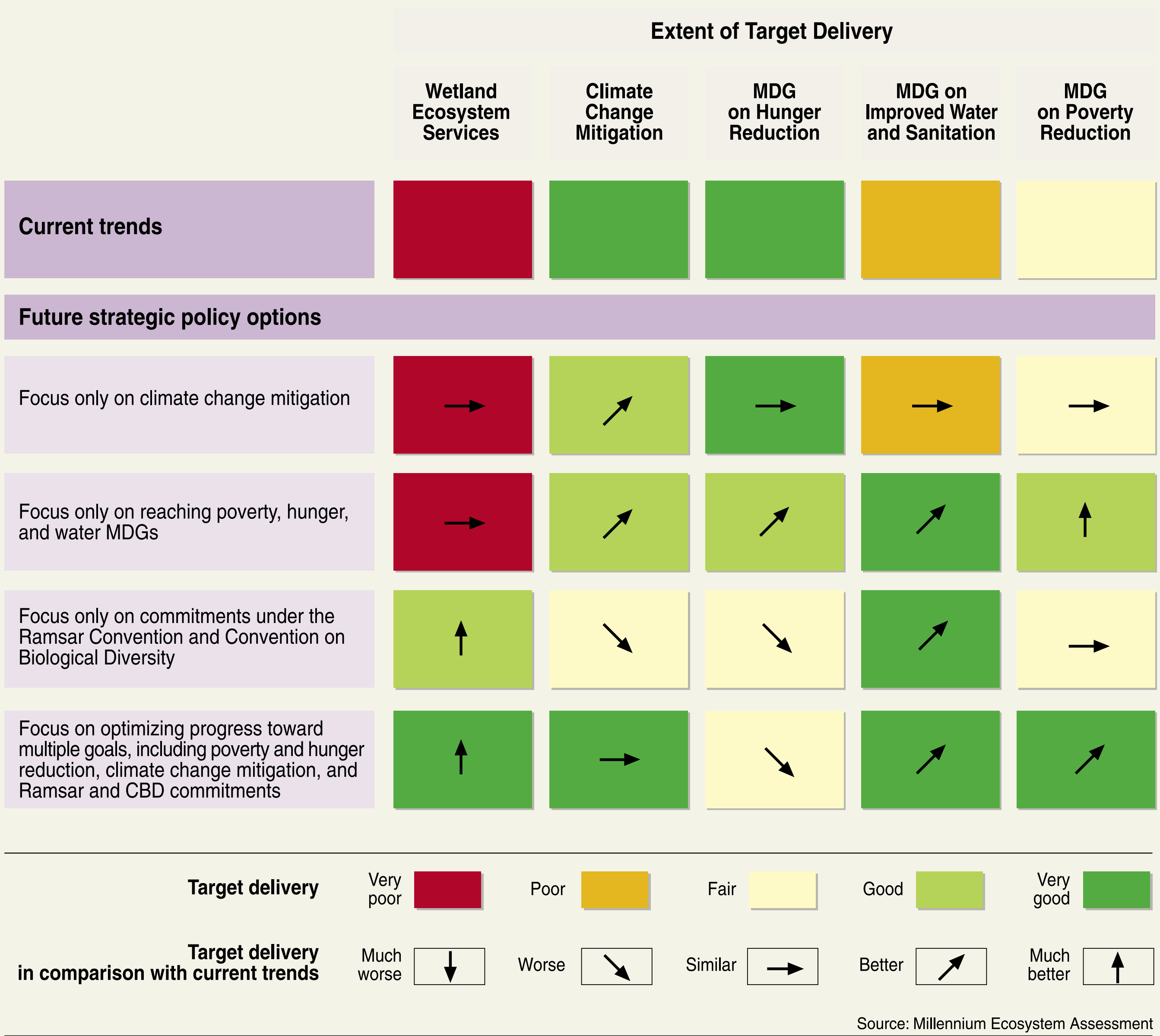
Many of the responses designed with a primary focus on wetlands and water resources will not be sustainable or sufficient unless other indirect and direct drivers of change are addressed. For example, the sustainability of protected areas for wetlands will be severely threatened by human-caused climate change. Similarly, the management of ecosystem services cannot be sustainable globally if the growth in consumption of services continues unabated. Responses also need to address the conditions that determine the effectiveness and degree of implementation of the wetland-focused actions.

In particular, changes in institutional and environmental governance frameworks are often required to create these conditions. Many of our institutions were not designed to take into account the threats associated with the loss and degradation of ecosystem services; nor were they well designed to deal with the management of common pool resources, a characteristic of many ecosystem services. Issues of ownership and access to resources, the right to participate in decision-making, and the regulation of particular types of resource use or discharge of wastes can strongly influence the sustainability of ecosystem management and are fundamental determinants of who wins and who loses from changes in ecosystems. Corruption, a major obstacle to effective management of ecosystems, also stems from weak systems of regulation and accountability.

Consideration of the trade-offs among different wetland ecosystem services and the need for cooperation across sectors will be critical in designing actions in support of the Millennium Development Goals. (See Figure 3.) For example, it is not uncommon for strategies aiming to increase food production and

Figure 3. Indicative Trade-offs Involved in Approaches to Achieve the MDGs (Derived from C7, C20, R13, R19)

The Figure shows the implications for the future delivery of wetland ecosystem services of different strategic policy options for the achievement of intergovernmental environmental commitments: carbon mitigation (Kyoto Protocol), the poverty and hunger Millennium Development Goals, and environmental conventions concerned with water and ecosystems (Ramsar and CBD). Each row provides a hypothetical case where actions are taken to achieve a particular goal (such as carbon mitigation, poverty or hunger reduction, or wetland service delivery) using strategies that maximize the short-term progress toward that goal without any consideration given to alternative goals. The colored boxes show the likely extent of achievement of the different global targets under each strategy. The arrows indicate the extent of improvement (or otherwise) of target delivery under each strategy option in comparison with current trends. Although the actual trade-offs may differ in specific locations, in general overall progress is likely to be less when the goals are addressed in isolation than when they are addressed jointly.



reduce poverty to propose the conversion of marshes to agriculture, conversion of mangroves to aquaculture, and significant increases in the use of fertilizers to increase crop production. This approach, however, will reduce habitat area (and hence the magnitude of services provided by the original habitat), increase the input of water pollutants, remove the natural water filtering service provided by wetlands, and remove ecosystem services provided by mangroves, such as timber and charcoal supply and fish habitat, on which the poor in particular rely. This will make the development goal of improved water and sanitation more difficult to achieve and may in fact increase poverty for some groups. In contrast, a development strategy that aims to safeguard the full range of benefits provided by wetlands might better achieve the set of development goals while minimizing future harm to the wetlands.

The MA conceptual framework for ecosystems and human well-being provides a valuable framework for the delivery of the Ramsar Convention's concept of "wise use" of wetlands. Figure 4 illustrates where interventions using each of the Ramsar Wise Use Handbooks can be applied in the framework. In the context of wetland ecosystem management, responses will involve a combination of approaches that may operate at local or micro, regional, national, or international level (or a combination of these) and at various time scales.

Economic valuation can provide a powerful tool for placing wetlands on the agendas of conservation and development decision-makers. The concept of total economic value has now become one of the most widely used frameworks for identifying and quantifying the contribution of ecosystem services to human well-being. Looking at the total economic value of a wetland essentially involves considering its full range of characteristics as an integrated system—its resource stocks or assets, flows of environmental services, and the attributes of the ecosystem as a whole. Such information enables wetlands to be considered as economically productive systems, alongside other possible uses of land, resources, and funds. It provides an analytical basis for considering trade-offs and making management decisions that better support public welfare and aspirations. A wide range of methods that move beyond the use of direct market prices are available and are increasingly used for valuing wetlands. These include approaches that elicit preferences directly (such as through contingent valuation methods) as well as those that use indirect methods to infer preferences from actions to purchase related services (for example, through production functions and replacement costs).

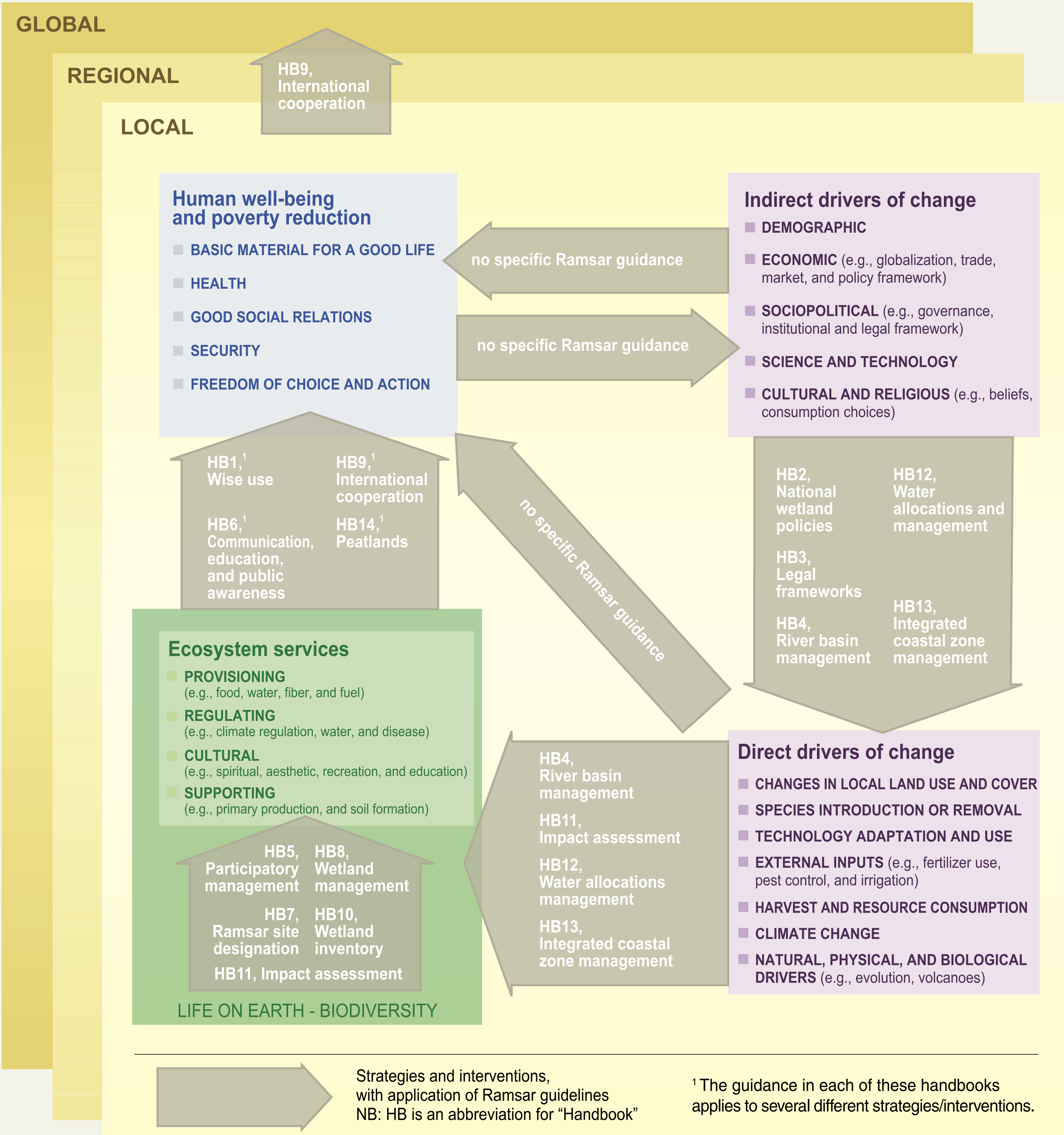
The effective management of inland wetlands and water resources will require improved arrangements for river (or lake or aquifer) basin-scale management and integrated coastal zone management. Actions taken upstream or upcurrent can have profound impacts on wetland resources downstream or down current. Regional approaches such as IRBM and ICZM are examples of "ecosystem approaches." Ecosystem approaches have been developed as an overall strategy for integrated environmental management promoting conservation and sustainable use in an equitable way. They focus on managing environmental resources and human needs across landscapes and are a response to the tendency to manage ecosystems for a single good or service, by trying to balance trade-offs to both human well-being and ecosystem services.

An ecosystem approach to water resources management is recognized as a key strategy for meeting the objectives of poverty alleviation. To date, however, few efforts at implementing IRBM have actually succeeded in achieving social, economic, and environmental objectives simultaneously. One of the key lessons emerging from ICZM experiences is that more integration per se does not guarantee better outcomes. Adopting an incremental approach—focusing on a few issues initially and then gradually addressing additional ones as the capacity increases—is often more feasible and effective. In addition, these approaches can only succeed if appropriate institutional and governance arrangements are in place and, in particular, if the authority and resources of the management mechanisms are consistent with their responsibilities.

For international transboundary wetlands, including river systems, lakes, and aquifers, sovereignty is an important issue, making it more challenging to establish a basin-scale organization supported by appropriate governance arrangements. Alternatives such as intergovernmental agreements that mandate development of management arrangements at the basin scale may need to be explored. An important tool for public involvement is the development of a process for transboundary environmental impact assessment.

A key approach for ensuring the future of wetlands and their services is to maintain the quantity and quality of the natural water regimes on which they depend, including the frequency and timing of flows. A variety of methods and tools are available

Figure 4. Places within the MA Conceptual Framework Where Interventions Using Each Ramsar Wise Use Handbook Can Be Applied



Source: Millennium Ecosystem Assessment

both for assessing the "environmental flow" requirements of wetlands and for implementing, at a basin scale, the range of water allocations to meet policy and planning requirements that balance ecosystem maintenance with public well-being and economic development. These methods and tools provide a means to address the trade-offs for water allocation between different ecosystem services. They can also ensure that sufficient water is allocated to meet multiple objectives agreed to by the wider stakeholder community.

Wetland restoration is a broad response category to recover ecosystems that have been degraded or destroyed. A primary goal of wetland recovery projects is to restore and enhance wetland benefits by re-establishing natural ecological processes. Some wetland functions can be mimicked with engineered structures, but engineered methods typically do not provide the maximum ecological benefit. Restoration has become controversial in part because of the uncertainty about what set of actions leads to the establishment of a desired combination of wetland structure and function. Created wetlands rarely perform the same functions or house the same biodiversity as the original site, and for this reason they are unlikely to structurally and functionally completely replace destroyed wetlands. The key to success is the setting of well-stated goals that form part of a broader comprehensive and rigorous process for planning, developing, implementing, and evaluating the restoration projects and adopting an adaptive management approach.

Systems of protected areas are another important category of response in international, regional, sub-regional, and national frameworks. A regional or landscape approach is necessary especially for aquatic systems, which are not easily "fenced" from surrounding areas. Protected area networks at all levels, including the designation and management of Ramsar sites, play an important role, given the fact that individual sites are often functionally interconnected by reason of shared hydrology, migratory species, and so on.

Although information about the consequences of climate change on specific wetland types and river basins is lacking, it is generally understood that removing the existing pressures on wetlands and improving their resilience is the most effective method of coping with the adverse effects of climate change. Sea level rise, coral bleaching, and changes in hydrology and the temperature of water bodies will lead to a reduction in the goods and services provided by wetlands. Further, efforts to respond to climate change may have equally negative and compounding effects on freshwater and coastal zone ecosystems. Information about the consequences of climate change on specific wetland types and river basins is sorely needed to allow water resource and wetlands managers to integrate changes in climate into their planning and management efforts. Conserving, maintaining, or rehabilitating wetland ecosystems can be a viable element to an overall climate change mitigation strategy.

Greater coordination of actions among multilateral environmental agreements would result in more-effective implementation. The Ramsar Convention has been promoting cooperation and coordination with other treaties to achieve its objectives. For instance, the Ramsar and World Heritage Conventions have cooperated to identify and strengthen conservation of sites of international importance that are of mutual interest and benefit. Furthermore, cooperation between the Ramsar Convention and the Convention on Migratory Species has been in effect since 1997 in terms of joint conservation action; data collection, storage, and analysis; institutional cooperation; and new agreements on migratory species. The Ramsar Convention is implementing its third joint work plan with the Convention on Biological Diversity, covering the period 2002–06.

Responses addressing direct and indirect drivers and seeking to establish conditions that would be particularly important for biodiversity and ecosystem services include the following:

- *Elimination of subsidies that promote excessive use of ecosystem services (and, where possible, transfer of these subsidies to payments for nonmarketed ecosystem services).* Subsidies paid to the agricultural sectors of OECD countries between 2001 and 2003 averaged over $324 billion annually, or one third the global value of agricultural products in 2000. A significant proportion of this total involved production subsidies that led to overproduction, reduced the profitability of agriculture in developing countries, and promoted overuse of fertilizers and pesticides. Many countries outside the OECD also have inappropriate input and production subsidies. These subsidies could instead be directed to payments to farmers to produce nonmarketed ecosystem services through the maintenance of forest cover or wetlands or to protect biodiversity, thereby helping to establish economic incentives to provide these public goods. Similar problems are created by fishery subsidies, which amounted to approximately $6.2 billion in OECD countries in 2002, or about 20% of the gross value of production. Water use is also often subsidized—for example, by public water supply systems that do not charge consumers for the cost of the water supply infrastructure and maintenance or, as is often the case with groundwater pumping, indirectly through energy subsidies.

  Although removal of perverse subsidies will produce net benefits, it will not be without costs. Some of the people benefiting from production subsidies (through either the low prices of products that result from the subsidies or as direct recipients of subsidies) are poor and would be harmed by their removal. Compensatory mechanisms may be needed for these groups. Moreover, removal of agricultural subsidies within the OECD would need to be accompanied by actions designed to minimize adverse impacts on ecosystem services in developing countries.

- *Sustainable intensification of agriculture.* The expansion of agriculture will continue to be a major driver of wetland loss. In regions where agricultural expansion remains a large threat to wetlands, the development, assessment, and diffusion of technologies that could increase the production of food per

unit area sustainably, without harmful trade-offs related to excessive consumption of water or use of nutrients or pesticides, would lessen pressure on wetlands significantly. In many cases, appropriate technologies already exist that could be applied more widely, but countries lack the financial resources and institutional capabilities to gain and use these technologies.

■ *Slowing and adapting to climate change.* By the end of the century, climate change and its impacts may be the dominant direct driver of change of ecosystem services globally. Harm to ecosystems will grow with both increasing rates of change in climate and increasing absolute amounts of change. Some ecosystem services in some regions may initially benefit from increases in temperature or precipitation expected under climate scenarios, but the balance of evidence indicates that there will be a significant net harmful impact on ecosystem services worldwide if global mean surface temperature increases more than 2º Celsius above preindustrial levels or faster than 0.2º Celsius per decade (*medium certainty*). Given the inertia in the climate system, actions to facilitate the adaptation of biodiversity and ecosystems to climate change will be necessary to mitigate negative impacts. These may include the development of ecological corridors or networks.

■ *Slowing the global growth in nutrient loading even while increasing fertilizer application in regions where crop yields are constrained by the lack of fertilizers, such as parts of sub-Saharan Africa.* Technologies already exist for reducing nutrient pollution at reasonable costs, but new policies are needed for these tools to be applied on a sufficient scale to slow and ultimately reverse the increase in nutrient loading.

■ *Correction of market failures and internalization of environmental externalities that lead to the degradation of ecosystem services.* Because many ecosystem services are not traded in markets, markets fail to provide appropriate signals that might otherwise contribute to the efficient allocation and sustainable use of the services. In addition, many of the harmful trade-offs and costs associated with the management of one ecosystem service are borne by others and so are not weighed in sectoral decisions regarding the management of that service. In countries with supportive institutions in place, market-based tools could be more effectively applied to correct some market failures and internalize externalities, particularly with respect to provisioning ecosystem services.

■ *Economic interventions, including payments for services and markets, that have long existed for resources such as water that, in many contexts, have long been traded goods.* At the same time, water, and the wetlands it supports, has typically been undervalued and consequently underpriced, leading to the inefficient and ineffective management of water for people and ecosystems. Recent efforts have aimed at exploring the potential of water markets as a tool for reallocation of water to meet ecosystem needs as well as the traditional goal of improving resource efficiency for the provision of water to irrigation, hydropower, and drinking water supplies.

■ *Increased transparency and accountability of government and private-sector performance in decisions that affect wetlands, including greater involvement of concerned stakeholders in decision-making.* Laws, policies, institutions, and markets that have been shaped through public participation in decision-making are more likely to be effective and perceived as just. Stakeholder participation also contributes to the decision-making process because it allows for a better understanding of impacts and vulnerability, the distribution of costs and benefits associated with trade-offs, and the identification of a broader range of response options that are available in a specific context. Stakeholder involvement and transparency of decision-making can increase accountability and reduce corruption. Recognition of the importance of public participation and equity in decision-making is growing, and national policies are increasingly being used to support stakeholder participation. Increasing participation at relevant levels supports the concept of subsidiarity—assigning roles and responsibilities at the management level closest to where they will have effect.

Wetlands and Water: Ecosystems and Human Well-being

1. *Introduction*

This report has been prepared to provide Contracting Parties to the Convention on Wetlands (Ramsar, Iran, 1971) and all those concerned with the management of wetlands and water resources with a synthesis of the findings of the Millennium Ecosystem Assessment. (See Box 1.1.)

The Millennium Ecosystem Assessment

The Millennium Ecosystem Assessment was a four-year international process (2001–05) designed to meet the needs of decision-makers for information on the links between ecosystem change and human well-being. It focused on how changes in ecosystems and ecosystem services have affected human well-being, how ecosystem changes may affect people in future decades, and what types of responses can be adopted at local, national, regional, or global scales to improve ecosystem management and thereby contribute to human well-being. It also considered the extent of our current knowledge and information and how well this can assist in addressing the ambitious and innovative focus adopted.

The importance of and interest in the MA was illustrated by its launch in June 2001 by Secretary-General Kofi Annan and by the support offered to it by Contracting Parties to the Ramsar Convention as well as the Convention on Biological Diversity, the U.N. Convention to Combat Desertification, and the Convention on Migratory Species. Parties to these Conventions requested the MA to provide scientific information that could assist in the implementation of these important international treaties. The MA also addressed the needs of other stakeholders, including the private sector, civil society, and indigenous peoples' organizations.

The MA was conducted through four Working Groups: Condition and Trends, Scenarios, Responses, and Sub-global Assessments. A total of 1,360 leading scientists from 95 nations carried out the assessment under the direction of a Board that included representatives of the four international conventions, five United Nations agencies, international scientific organizations, and leaders from the private sector, NGOs, and indigenous groups.

Box 1.1. The Convention on Wetlands

The Convention on Wetlands, also known as the Ramsar Convention, is one of the oldest global environmental intergovernmental agreements. It was established in 1971 in the City of Ramsar, I.R. of Iran. The Convention's Mission is "the conservation and wise use of all wetlands through local, regional and national actions and international cooperation, as a contribution towards achieving sustainable development throughout the world."

The 146 Contracting Parties to the Ramsar Convention (as at July 2005) implement the Convention through three pillars of implementation:

- the "wise use" of all wetlands,
- special attention to internationally important wetlands, and
- international co-operation.

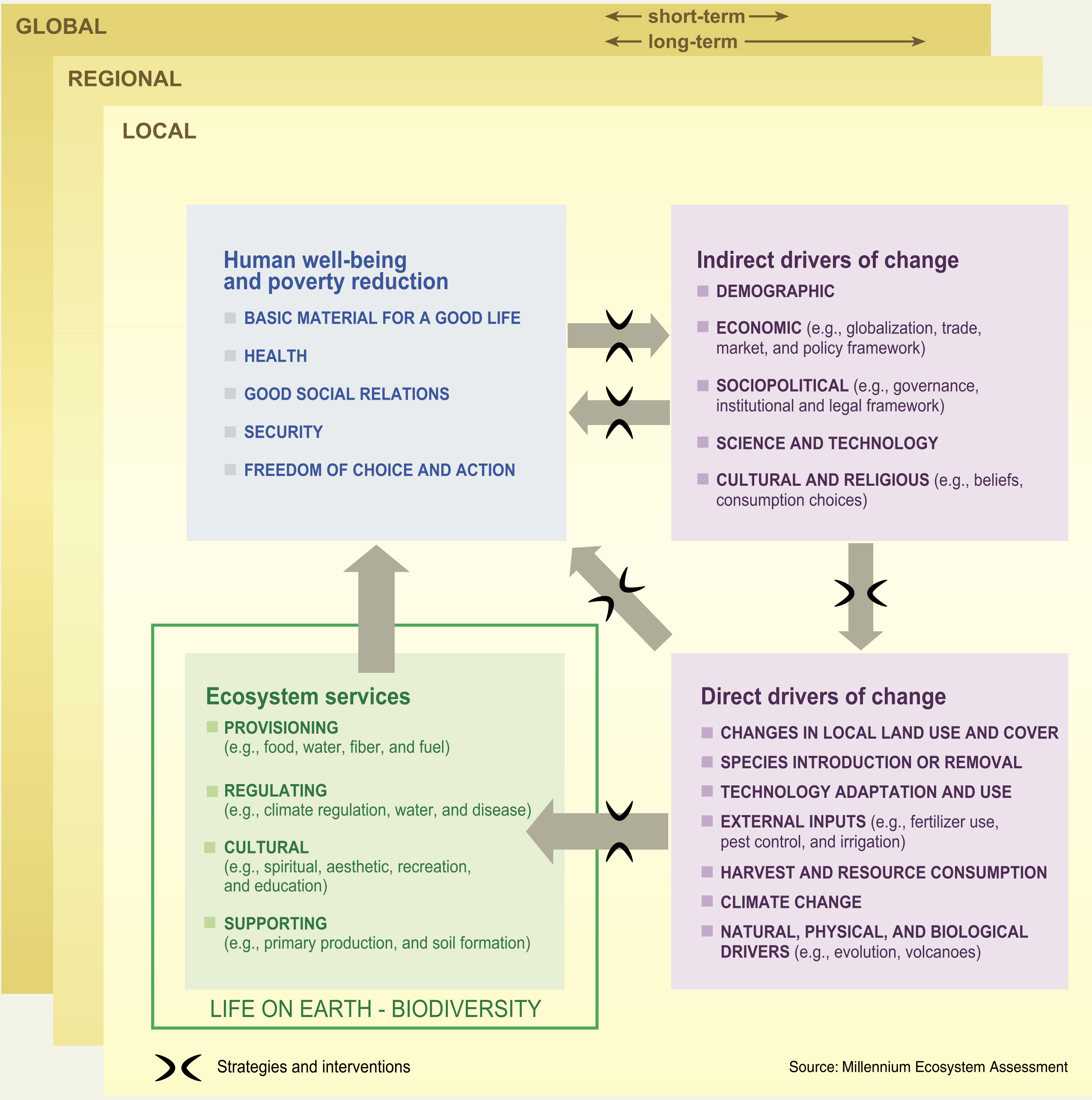
The Convention defines wetlands as "areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water the depth of which at low tide does not exceed six metres." This broad definition includes *inland* wetlands (such as marshes, lakes, rivers, peatlands, forests, karst, and caves), *coastal and near-shore marine* wetlands (such as mangroves, estuaries, and coral reefs), and *human-made* wetlands (such as rice fields (paddies), reservoirs, and fish ponds).

For more than 30 years the Convention has recognized the interdependence of people and their environment and the need to maintain the ecological character of wetlands, including the services they provide for people. It is the only global intergovernmental convention addressing the interactions between water and ecosystems (inland, coastal, and human-made wetlands).

The MA and the Ramsar Convention

The Ramsar Convention has been involved in the development and implementation of the MA. Parties to the Convention at its 8th Conference of the Parties in November 2002 welcomed and endorsed the MA as an initiative of significant relevance to the Convention. Representatives of the Convention (including those from Contracting Parties, the Scientific and Technical Review Panel, the Standing Committee, and the Secretariat) have been closely involved throughout the work of the assessment in guiding its development, design, and implementation and in the development of the MA's conceptual framework. (See Figure 1.1.) The STRP has in particular accepted the principles that

Figure 1.1. The Conceptual Framework of the Millennium Ecosystem Assessment



support this framework and through a series of iterative workshops and presentations linked it to the key Convention concepts of wise use and maintenance of the ecological character of wetlands. (See Box 1.2.)

The focus of this report is on the needs expressed by the Ramsar Convention as a user of the findings of the MA. These needs were expressed as a set of key questions prepared by the STRP early in the design of the MA. Subsequently, the Synthesis Team reviewed these in light of the further development of the Convention and the decisions of its Parties made at Ramsar COP8, in particular those concerning the role of the Convention in wetlands and water issues and those addressing the direct drivers of change to wetland ecosystems, such as water resource management and agriculture.

Information in this report is derived from the MA reports as well as from *Ecosystems and Human Well-being*, which in 2003 set out the MA's conceptual framework and the approach and method adopted for the assessment. It is noted that not all wetland types considered by the Ramsar Convention were assessed to the same degree in the MA reports, as individual MA reports adopted different emphases and balances between a plethora of important issues.

Based on the material provided in the MA reports, this synthesis outlines a range of options for responding to, and addressing, the many and increasing direct and indirect pressures on wetland ecosystems. It also presents advice to decision-makers on the trade-offs involved in the management of wetland ecosystems that will inevitably occur in the quest for sustainable development, along with the implications of these trade-offs. It also notes where further information would be useful for ongoing assessments and management.

Scope and Coverage of Wetlands

The full range of wetland types considered by the Ramsar Convention is covered in this synthesis. This includes inland water systems, coastal systems to a depth at low tide not exceeding 6 meters (but not deep oceans), human-made wetlands, and both surface and subterranean (karst and cave) systems. All inland aquatic habitats—whether fresh, brackish, or saline, and including rivers, great lakes, and inland seas—are considered. Coastal wetlands include fresh, brackish, and saline habitats (such as lagoons, estuaries, mangroves, seagrass beds, mud flats, and coral reefs). (See www.ramsar.org for further information on the definition of wetlands and the habitat typology accepted by the Convention.) As there is no clear boundary between inland and coastal systems, this particular delineation is indicative only and is not strictly applied, especially where there are strong interactions between the biodiversity, services, and pressures that affect inter-connected aquatic habitats.

The relationship between the biogeographic realms used in the MA to report on some aspects of biodiversity and the regionalization used by the Ramsar Convention, as well as the number of wetlands within each Ramsar region listed as internationally important, is presented in Box 1.3.

Box 1.2. The MA Conceptual Framework and Definitions in Relation to the Ramsar Convention

The MA conceptual framework considers at multiple scales, from local to global, the relationships and interactions between ecosystems and human well-being. The framework applies equally to all ecosystems and in this instance is adapted for wetlands as defined by the Ramsar Convention.

Changes in factors that indirectly affect wetland ecosystems, such as population, technology, and lifestyle, can lead to changes in factors that directly affect wetlands, such as the catch of fish or the application of fertilizers to increase food production. The resulting changes cause the ecosystems services derived from or supplied by the wetland to change and thereby affect human well-being. These interactions can take place at more than one spatial and time scale and can cross scales. Actions, called strategies and interventions in the framework, can be taken either to respond to negative changes or to enhance positive changes at almost all points in the framework.

The MA describes ecosystems as including biological, physical, and chemical components (equating to the terms "attributes" and "features" previously used in the Ramsar Convention); processes (equating to the term "interactions" in Ramsar); and services (equating to the terms "values, functions, and products" in Ramsar), with the latter categorized as provisioning, regulating, supporting, and cultural services.

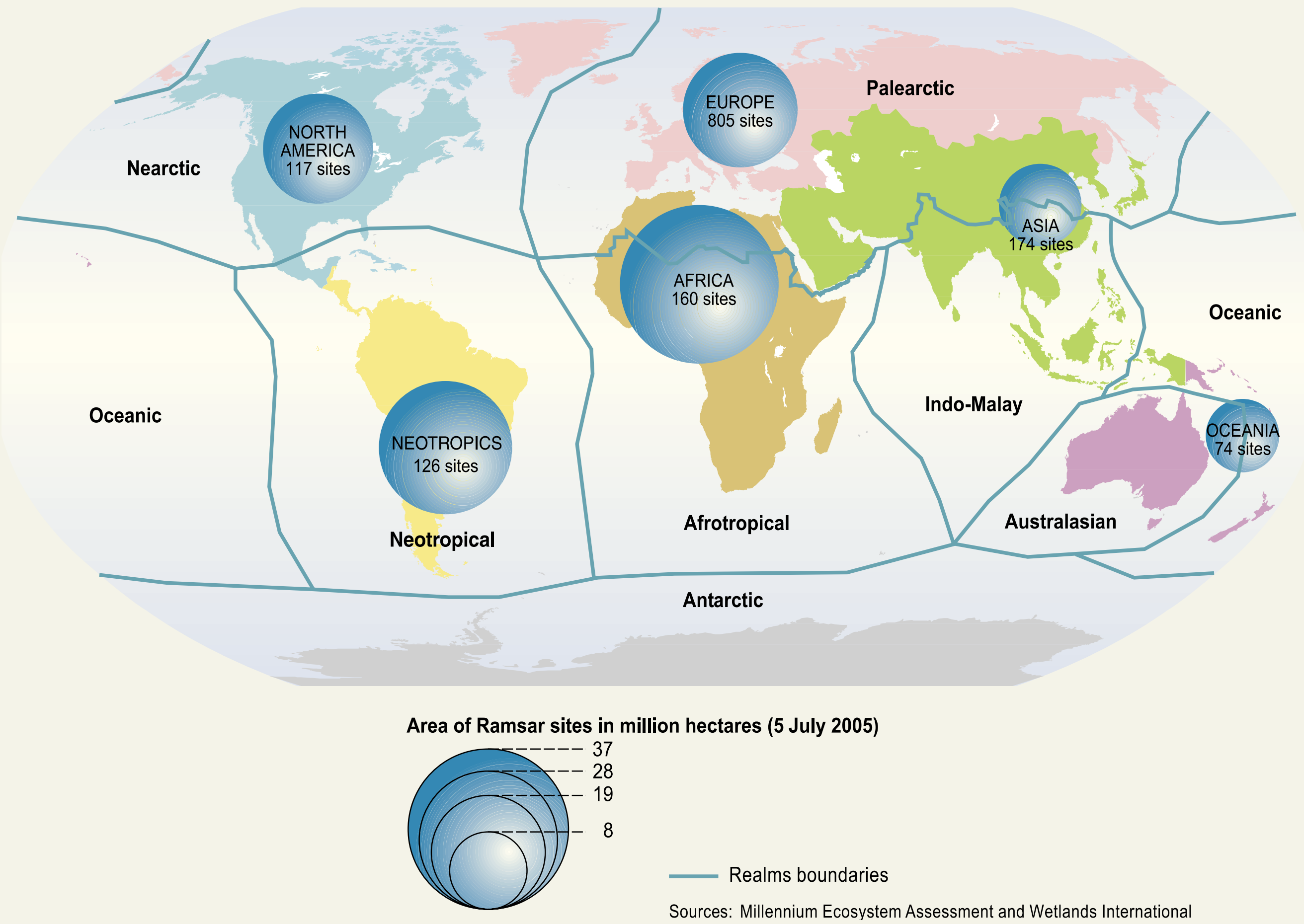
The MA conceptual framework represents an overarching structure that encapsulates how and when implementation of the Convention contributes to the wise use of wetlands and support for human well-being. Wise use of wetlands, as defined by the Convention, corresponds to the strategies and interventions shown in the framework and is an ecosystem-based approach to the maintenance of the ecological character of wetlands.

Box 1.3. Biogeographic Realms and the Ramsar Convention's Regionalization Scheme

Many biogeographical studies, including a number of those cited in the MA, refer to eight terrestrial biogeographic realms—Australasian, Antarctic, Afrotropical, Indo-Malayan, Nearctic, Neotropical, Oceania, and Palearctic—and to biomes. The geopolitical regionalization scheme adopted by the Convention for administrative purposes overlays fairly closely, but not entirely, on these biogeographic realms. As the Ramsar regionalization is based on sovereign countries, it does not include Antarctica, and Central Asian countries are included in Ramsar's Asia region instead of being spilt between the Palearctic and Indo-Malayan realms. (See Figure.) Most systems used by the MA for reporting its findings (forests, cultivated, dryland, coastal, marine, urban, polar, inland water, island, and mountain) occur in all terrestrial biogeographic realms—apart from the MA marine system, which is not mapped against the terrestrial realms.

Most Ramsar wetland types occur in all terrestrial biogeographic realms except Antarctic. All Ramsar wetland types, as reflected in the designation of Wetlands of International Importance (Ramsar sites), occur in most Ramsar regions.

Figure. Wetlands Listed as Internationally Important (Ramsar Sites) in Ramsar Regions and Commonly Accepted Global Terrestrial Biogeographic Realms



Sources: Millennium Ecosystem Assessment and Wetlands International

2. *Distribution of Wetlands and Their Species*

Extent and Distribution of Wetland Habitats

The global extent of wetlands is estimated to be in excess of 1,280 million hectares, but it is well established that this is a clear underestimate (C20.3.1). Estimates of the global extent of wetlands differ significantly among different studies and are highly dependent on the definition of wetlands used and on the methods for delineating wetlands.

The 1999 *Global Review of Wetland Resources and Priorities for Wetland Inventory* estimated wetlands extent from national inventories as approximately 1,280 million hectares, which is considerably higher than previous estimates derived from remotely sensed information. This estimate includes inland and coastal wetlands (including lakes, rivers, and marshes), near-shore marine areas (to a depth of 6 meters below low tide), and human-made wetlands such as reservoirs and rice paddies, and it was derived from multiple information sources. Nevertheless, the GRoWI figure is still considered an underestimate, especially for the Neotropics and for certain wetland types (such as intermittently flooded inland wetlands, peatlands, artificial wetlands, seagrasses, and coastal flats) where data were incomplete or not readily accessible. These gaps need to be addressed before the extent of global wetlands (inland, coastal, and human-made) can be established with a high degree of confidence.

Table 2.1 presents the two best available estimates of wetlands extent: the GRoWI assessment and the WWF/Kassel University Global Lakes and Wetlands Database.

Mapping exercises have been undertaken for wetlands, but the level of detail varies from region to region. The most recent global map (see Figure 2.1), with a 1-minute resolution, was produced by combining various digital maps and data sources, but it still suffers from the problems of definition and scale.

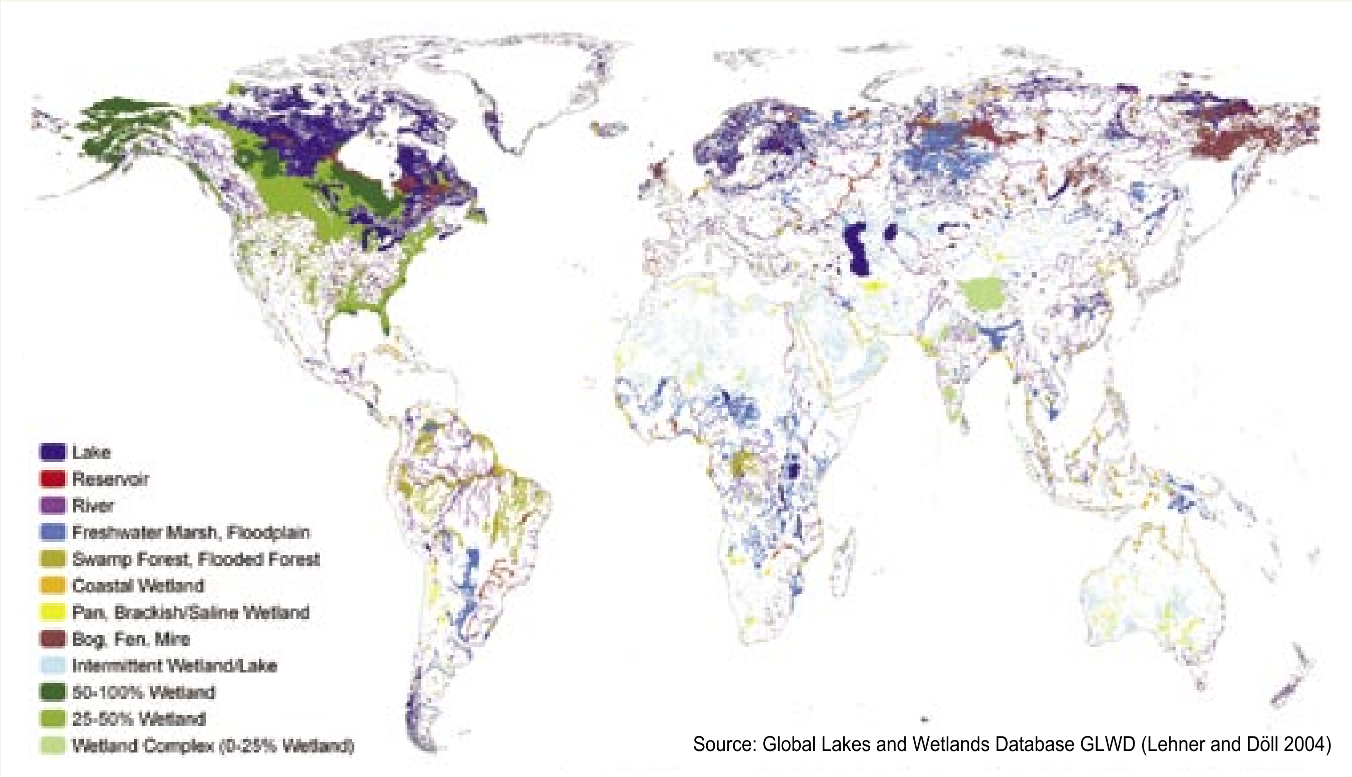
Global information on peatlands, lakes, dams, major rivers, and rice fields has been compiled but is variable or lacking for many other inland wetlands and human-made wetlands (C20.3.1). Peatlands occur in at least 173 countries worldwide, with a total area estimated as approximately 400 million hectares, the vast majority of which are in Canada (37%) and Russia (30%). There are several published inventories of rivers, listing the major river systems with their drainage area, length, and flow volume, but again there is considerable variability between estimates due to the method and definitions used. Information on river flow volume and discharge, for example, varies considerably depending on the water balance model applied and the different time periods or locations for the measurement of discharge. Reservoirs are also widespread; the number of dams in the world has increased from 5,000 in 1950 to more than 45,000 at present. They store water for 30–40% of irrigated land and are used to generate 19% of global electricity supplies. The area of rice fields has been estimated at about 130 million hectares, of which almost 90% is cultivated in Asia. Information on other human-made wetlands is variable and even lacking for many types.

Table 2.1. Estimates of Global Wetland Area by Ramsar Regions (C20.3.1)

Region	1999 Global Review of Wetland Resources (million hectares)	2004 Global Lakes and Wetlands Database (million hectares)
Africa	121–25	131
Asia	204	286
Europe	258	26
Neotropics	415	159
North America	242	287
Oceania	36	28
Total area	**~1,280**	**917**

Information on the estimated 5–15 million lakes across the globe is also highly variable and dispersed (C20.3.1). A high proportion of large lakes—defined as those with a surface area over 500 square kilometers—are found in Russia and North America, especially Canada, where glacial scouring created many depressions in which lakes have formed. Tectonic belts, such as the Rift Valley in East Africa and the Lake Baikal region in Siberia, are the sites of some of the largest and most "ancient" lakes. Lakes have been mapped reasonably well, although issues of scale also occur, with smaller lakes being more difficult to map. But there is no single repository of comprehensive lake information, which makes assessment of these water bodies difficult and time-consuming. Some of the largest lakes are saline, with the largest by far being the Caspian Sea (422,000 square kilometers). Many saline lakes occur on all continents and on many islands; given their impermanence, it is difficult to derive accurate values for the number worldwide.

Figure 2.1. Distribution of Large Lakes, Reservoirs, and Wetlands Based on Data in the Global Lakes and Wetlands Database (C20.1)



Information on the distribution of coastal wetlands such as estuaries, mangrove forests, coral reefs, and seagrass beds has been compiled but is variable or lacking for other coastal wetland types (such as rocky intertidal habitats and intertidal mudflats) (C19.2.1). The diversity of coastal habitat types and biological communities is significant, and the linkages between habitats are extremely strong, as is the extent of inter-connectivity with terrestrial systems and human settlements and infrastructure. Worldwide, there are some 1,200 major estuaries (discharges of 10 cubic meters per second), with a total area of approximately 50 million hectares. The distribution of the world's major estuaries, mangroves, coral reefs, and seagrasses is shown in Figure 2.2 on pages 23 and 24.

Mangrove forests are found in both tropical and sub-tropical areas, with global cover estimated at 16–18 million hectares and with the majority found in Asia. Reefs occur as barrier reefs, atolls, fringing reefs, or patch reefs; many islands in the Pacific and Indian Oceans and in the Caribbean Sea have extensive reefs with a combination of these types. Tropical seagrass beds or meadows occur both in association with coral reefs and removed from them, particularly in shallow, protected coastal areas such as Florida Bay in the United States, Shark Bay and the Gulf of Carpentaria in Australia, and other geomorphologically similar locations. Seagrass is also pervasive (and ecologically important) in temperate coastal areas such as the Baltic Seas.

Condition and Trends of Wetland Habitats

More than 50% of specific types of wetlands in parts of North America, Europe, Australia, and New Zealand were converted during the twentieth century (*medium to high certainty*). Extrapolation of this estimate to wider geographic areas or to other wetland types, as has been done in some studies, is *speculative* only (C20.3, C20.4). In North America, the estimates refer to inland water and coastal marshes and emergent estuarine

Figure 2.2. Distribution of Major Estuaries, Mangroves, Coral Reefs, and Seagrasses (C19.2.1)

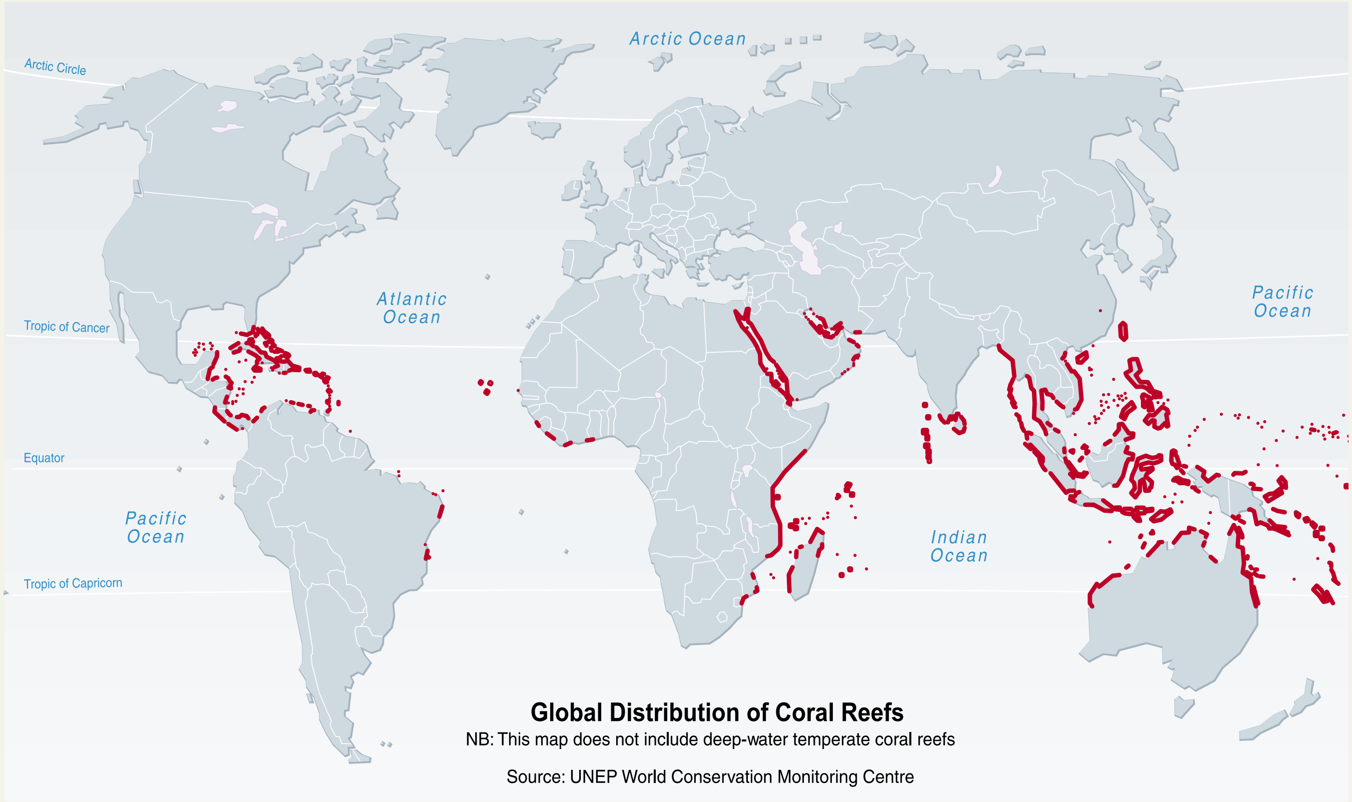
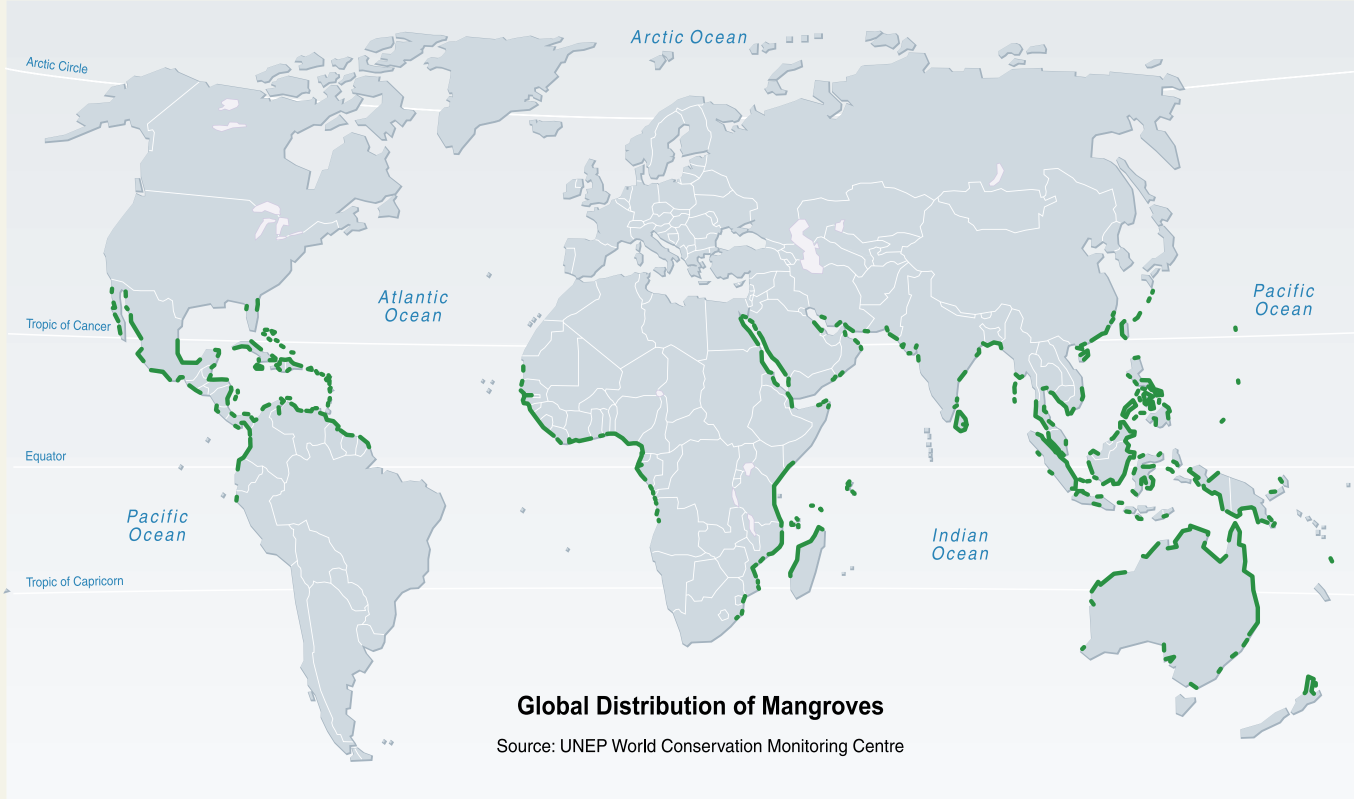
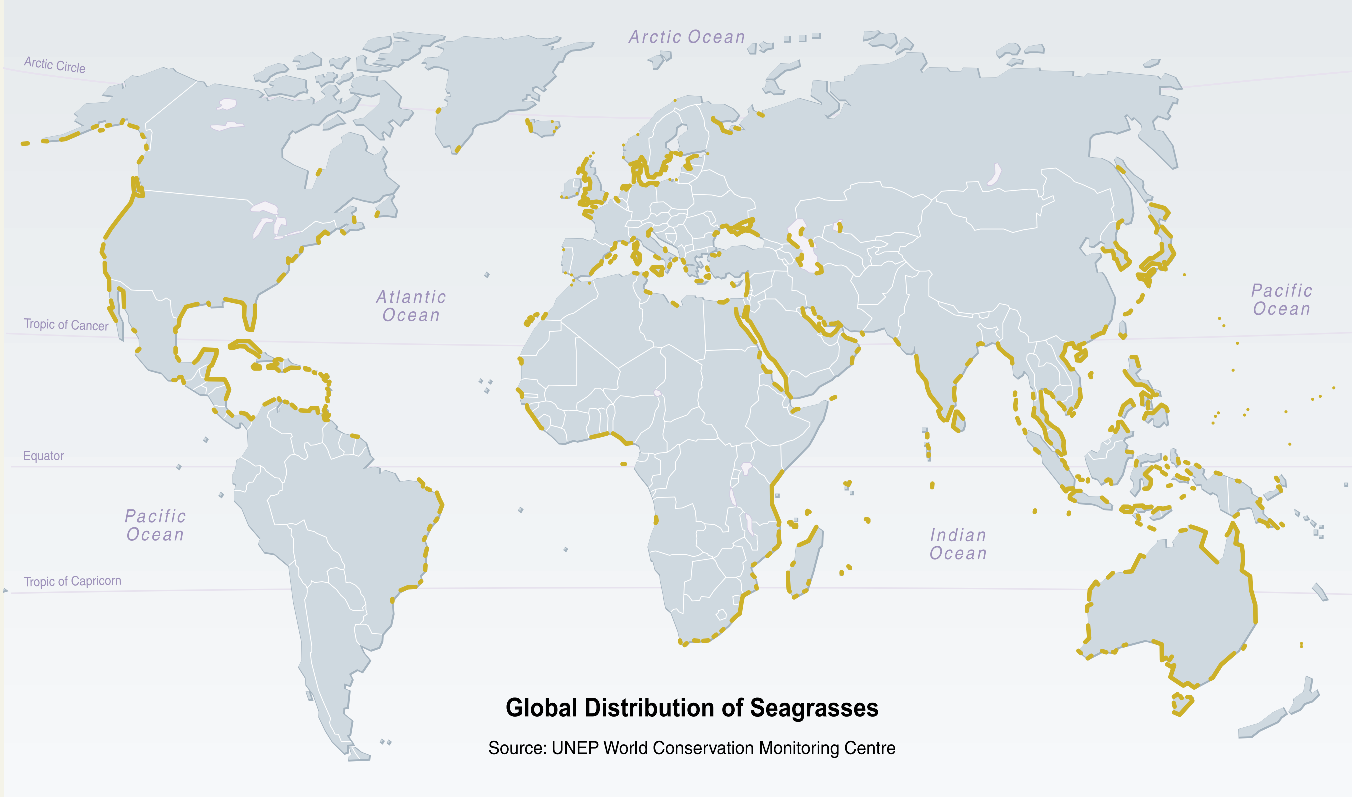


Figure 2.2. Distribution of Major Estuaries, Mangroves, Coral Reefs, and Seagrasses (C19.2.1) *(continued)*





wetlands (see Box 2.1); the estimates in Europe include the loss of peatlands; estimates in Northern Australia are of freshwater marshes; estimates in New Zealand are of inland and coastal marshes. There is insufficient information available on the extent of all wetland types being considered in this report—such as inland wetlands that are seasonally or intermittently flooded, and some coastal wetlands—to document the extent of wetland loss globally. Although the accuracy of this figure has not been established due to an absence of reliable data, it is *well established* that much of the loss of wetlands has occurred in the northern temperate zone during the first half of the twentieth century (C20.3.1).

Box 2.1. Loss of Wetlands in the Conterminous United States (C20.3.1)

The United States is one of the few countries that systematically monitors change in the extent of its wetlands. The U.S. Fish and Wildlife Service is mandated to conduct a wetlands status and trends assessment for the conterminous 48 states and report the results to Congress each decade.

Net loss of wetlands in the United States (using a narrower definition than Ramsar's and thus including only inland and coastal marshes and emergent estuarine wetlands) from 1986 to 1997 was 260,700 hectares, equivalent to an annual loss of 23,700 hectares. This rate of loss is considerably lower (80%) than during previous decades. As of 1997, an estimated 42.7 million of the 89 million hectares of wetlands present in the United States at the time of European colonization remained. Nearly all—98%—of the wetland losses from 1986 to 1997 were forested and freshwater wetlands, mostly from conversion or drainage for urban development and agricultural purposes. Only 2% were estuarine wetlands, a substantially lower rate of loss than in previous decades, although 5,850 hectares were still lost to coastal development.

The overall decline in the rate of loss is attributed primarily to wetland policies and programs that promote restoration, creation, and enhancement of wetlands, as well as to incentives that deter the draining of wetlands. Between 1986 and 1997 the United States had a net gain of about 72,870 hectares of upland wetlands, mostly due to federal protection and restoration programs and to an increase in the area of lakes and reservoirs by 47,000 hectares due to the creation of new impoundments and artificial lakes.

The loss and degradation of inland wetlands have been reported in many parts of the world, but there are few reliable estimates of the actual extent of this loss. The information available on the distribution of inland waters is on the whole better for North America than for many other areas (C20.3.1). Since the 1950s, many tropical and sub-tropical wetlands, such as swamp forests, have increasingly been lost or degraded (C20.4.1).

A global assessment of 227 major river basins showed that 37% were strongly affected by fragmentation and altered flows, 23% moderately affected, and 40% unaffected (C20.4.2). Absolute measures of the condition of wetlands are hard to develop, given the lack of baseline information. However, proxy indicators, such as the degree of fragmentation of rivers, can be used to infer the likely condition of at least some wetlands. Dams play a major role in fragmenting and modifying aquatic habitats, transforming lotic (running water) ecosystems into lentic (standing water) and semi-lentic ecosystems, altering the flow of matter and energy, and establishing barriers to migratory species movement. The global assessment of river basins found that most systems with parts of their basins in arid areas or with internal drainage systems were strongly affected; only the tundra regions of North America and Russia and the smaller coastal basins in Africa and Latin America had remaining large free-flowing rivers. While some dams in the United States (268 out of 80,000) are being decommissioned, the demand and untapped potential for these structures is still high in the developing world, particularly in Asia (C7.3.2). As of 2004, an estimated 1,500 dams were under construction, with many more planned, particularly in developing countries. (See Table 2.2.)

Table 2.2. Basins Most Threatened by Future Large Dams (C7.3.2)

Basin	Number of Dams (>60 meters) Planned or Under Construction
Yangtze Basin (China)	46
La Plata Basin (South America)	27
Tigris and Euphrates River Basin (Middle East)	26

It is *well established* that coastal ecosystems such as mangroves, coral reefs, tidal flats, and estuaries are experiencing degradation and loss (C19.2, C19.4).

Mangroves: Estimates of the loss of mangroves from countries with available multiyear data (representing 54% of total mangrove area at present) show that 35% of mangrove forests have disappeared in the last two decades. In some countries, large areas of mangrove have been lost to deforestation; in the Philippines, for instance, 210,500 hectares of mangrove—40% of the country's total mangrove cover—were lost to aquaculture from 1918 to 1988. By 1993, only 123,000 hectares of mangroves were left, equivalent to a loss of 70% in 70 years. Restoration of mangroves has been attempted, but this has not kept pace with wholesale destruction in most areas.

Coral reefs: Recent estimates indicate that approximately 20% of coral reefs have been lost, with an additional 20% having been degraded in the last several decades of the twentieth century, through impacts such as siltation and destructive fishing practices. Estuaries and coral reefs are the most threatened of all coastal ecosystems, precisely because impacts are both direct (originating from activity within the ecosystem), and indirect (originating in watersheds and inland areas). The coral reefs of the Caribbean Sea and parts of Southeast Asia have suffered the most and are still under threat from ongoing coastal development, pollution, and destructive fishing practices (C19.2.1).

Tidal flats and estuaries: Other coastal wetlands, such as tidal flats and estuaries, have also been widely degraded and lost. Along the Yellow Sea coast, around 37% of habitat in intertidal areas in China has been destroyed since 1950; South Korea has destroyed approximately 43% of habitat in intertidal areas since 1918 (C19.2.1). There has been a substantial loss of estuaries and associated wetlands globally; in California, for example, less than 10% of natural coastal wetlands remain, while in the United States more generally, more than half of original estuarine and wetland areas have been substantially altered (C19.2.1).

Other habitats: Broad regional and global estimates of losses of other habitats are not available, but major losses of seagrass habitat have been reported for the Mediterranean, Florida Bay, and parts of Australia; seagrass losses are expected to accelerate, especially in Southeast Asia and the Caribbean, as eutrophication increases, algal grazers are overfished, and coastal development increases (C19.2.1).

Wetland-dependent Species

Although limited in global extent when compared with marine and terrestrial ecosystems, many freshwater wetlands are relatively species-rich and support a disproportionately large number of species of certain faunal taxonomic groups (established but incomplete) (C20.3.2). While terrestrial and marine ecosystems have a larger percentage of known species, the relative species richness of freshwater ecosystems is higher. (See Table 2.3.)

There are about 100,000 described freshwater animal species worldwide; half of these are insects and some 20,000 are vertebrates. Some 40% of known species of fish inhabit inland waters (more than 10,000 species out of 25,000 species globally). It is anticipated that the number of aquatic animals will be far higher than current estimates given a lack of information about some taxa—for example, about 200 new species of freshwater fish are described every year.

Levels of endemism are particularly high in inland wetlands (C20.3.2). As river and lake catchments act as physical barriers for the dispersion of some taxonomic groups, such as fish, mollusks, and macro-crustacea, they can exhibit high levels of endemism. This is particularly evident in ancient lakes, such as the Great East African Lakes (including Tanganyika, Malawi, and Victoria) or Lake Baikal in Siberia, that have been isolated from other water bodies for millions of years. Lake Baikal has 78% endemism among its gastropod fauna, and Lake Victoria has more than 300 species of endemic cichlid fish. Dragonflies and damselflies (Odonata) also have high levels of endemism; for example, 111 Odonata species (64% of the fauna) in Madagascar are of conservation concern because of high diversity and endemism. Subterranean wetlands are increasingly recognized to have high species endemism—for example, the karst systems in Slovenia are known to harbor about 800 endemic animal taxa.

Coastal wetlands, such as mangroves, coral reefs, estuaries, and seagrass, contain some of the most productive communities in the world (C19.2.1). Coral reefs occur mainly in relatively nutrient-poor waters of the tropics, yet because nutrient cycling is very efficient on reefs and complex predator-prey interactions maintain diversity, productivity is high. Coral reefs also exhibit high levels of endemism. In tropical systems, the Indonesian archipelago seems to be an "epicenter" for the evolution of marine diversity; for coral genera and species, the level of diversity decreases westward, then rises in the Red Sea and Africa before decreasing again, with lowest diversity found in the Caribbean. There are similar patterns for other taxa. One of the most important processes in estuaries is the mixing of nutrients from upstream as well as from tidal sources, making estuaries one of the most fertile coastal environments. Seagrass is highly productive and an important source of food for many species of coastal organisms in both tropical and temperate regions.

Condition and Trends in Wetland-dependent Species

There is increasing evidence of a rapid and continuing widespread decline in many populations of wetland-dependent species (C20.3.2). Data on the status and population trends of species in some inland wetland-dependent groups, including mollusks, amphibians, fish, waterbirds, and some water-dependent mammals, have been compiled and show clear declines. An overall index of the trend in vertebrate species populations has

Table 2.3. Relative Species Richness of Freshwater, Marine, and Terrestrial Ecosystems (ratio between species richness and habitat extent)

Ecosystems	Habitat Extent (percent of world)	Species Richness (percent of known species)[a]	Relative Species Richness
Freshwater	0.8	2.4	3.0
Marine	70.8	14.7	0.2
Terrestrial	28.4	77.5	2.7

[a] Does not add up to 100% because 5.3% of known symbiotic species are excluded.

also been developed and shows a continuous and rapid decline in freshwater vertebrate populations since 1970—a markedly more drastic decline than for terrestrial or marine species (*medium certainty*). (See Box 2.2.) This pattern is also found at a regional scale, at least for regions with enough data to assess trends. For instance, the projected average future extinction rate for North American freshwater fauna has been estimated at about five times greater than for terrestrial fauna and three times greater than for coastal and marine mammals. Similar information does not yet exist for coastal wetland species.

Even in the case of more poorly known wetland fauna, such as invertebrates, existing assessments show that species in these groups are significantly threatened with extinction (C20.3.2). For example, the *IUCN Red List* reports that some 275 species of freshwater crustacea and 420 freshwater mollusks are globally threatened, although no comprehensive global assessment has been made of all the species in these groups. In the United States, one of the few countries to comprehensively assess freshwater mollusks and crustaceans, 50% of known crayfish species and two thirds of freshwater mollusks are at risk of extinction, and at least one in 10 freshwater mollusks are likely to have already gone extinct.

With the exception of dragonflies and damselflies (Odonata), the conservation status of other aquatic invertebrates, including insects, has not been comprehensively assessed because there are presently insufficient data (C20.3.2). A recent review of the global threat status of dragonflies and damselflies in 22 regions covering most of the world (except parts of Asia) found relatively high levels of threat. For example, in Australia 4 species are currently listed as globally threatened but 25 are considered to be in critical condition, with another 30% of species being data-deficient. In North America, 6% (25 species) are considered to be of conservation concern. In the Neotropics, 25 species are already considered globally threatened and a further 45 are considered of high conservation priority, with many others data-deficient. In most areas assessed, habitat loss and degradation of wetlands (and forests) were considered the major drivers of declines in Odonate species, often associated with overabstraction and pollution of water as well as the impacts of alien invasive species.

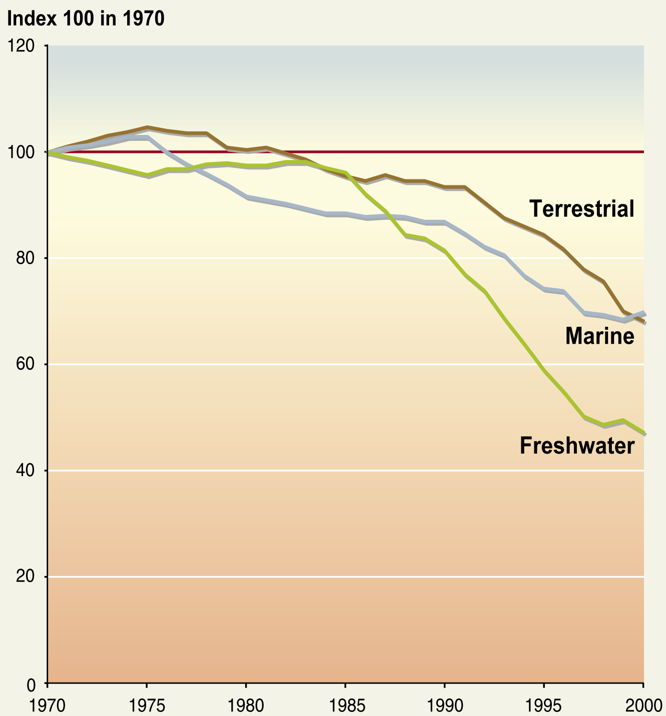
Although the status of freshwater fish species has not been assessed, it is estimated that more than 20% of the world's 10,000 described freshwater fish species have become threatened, endangered, or listed as extinct in the last few decades (C20.3.2). In the 20 countries for which assessments are most complete, an average of 17% of freshwater fish species are globally threatened. In addition, a few well-documented cases show clearly this level of threat. The most widely known is the apparent disappearance of up to 123 haplochromine cichlids in Lake Victoria, although taxonomic questions remain a problem in accurately assessing this group of fish. In Europe (including the former Soviet Union), there are 67 threatened species of freshwater fish, including sturgeons, barbs, and other cyprinids. Of the 645 ray-finned fishes listed as threatened in the *IUCN Red List*, 122 are found in the United States and 85 in Mexico, partially reflecting the high level of knowledge in these two countries.

Box 2.2. The Living Planet Index (C4.4.1, C20.3.2)

The Living Planet Index, created by the World Wide Fund for Nature and the UNEP-World Conservation Monitoring Centre, provides a measure of the trends in more than 3,000 populations of 1,145 vertebrate species around the world. The index is an aggregate of three separate indices of change in freshwater, marine, and terrestrial species. The 2004 freshwater species population index took into account trend data for 269 temperate and 54 tropical freshwater species populations, 93 of which were fish, 67 amphibians, 16 reptiles, 136 birds, and 11 mammals. The index showed that freshwater populations have declined consistently and at a faster rate than the other species groups assessed, with an average decline of 50% between 1970 and 2000. (See Figure.) Over the same period, both terrestrial and marine fauna decreased by 30%. Overall, the trend is one of continuing decline in each ecosystem over the 30-year period; the aggregate Living Plant Index fell by about 40%.

The index has a bias in the available data toward North American and European birds, and fish species other than commercial species are under-represented. It is also clear that the most species-rich parts of the world have the least information.

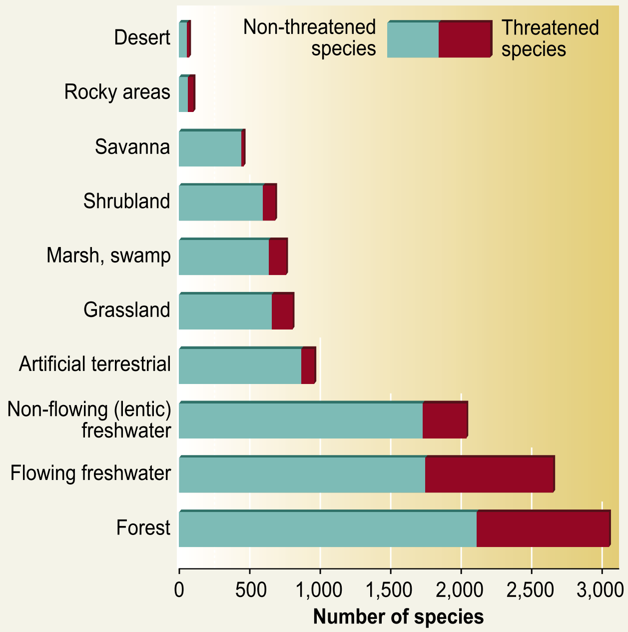
Figure. Trends in Freshwater, Marine, and Terrestrial Living Planet Indices, 1970–2000



Sources: World Wide Fund for Nature and UNEP World Conservation Monitoring Centre

Nearly one third (1,856 species) of the world's amphibian species are threatened with extinction, a large portion of which (964 species) are freshwater-dependent (C20.3.2). (By comparison, just 12% of all bird species and 23% of all mammal species are threatened.) In addition, at least 43% of all amphibian species are declining in population, indicating that the number of threatened species can be expected to rise in the future. In contrast, less than 1% of species show population increases. Species dependent on flowing water have a much higher likelihood of being threatened than those in still water. (See Figure 2.3.) Basins with the highest number of threatened freshwater species—between 13 and 98 species—include the Amazon, Yangtze, Niger, Paraná, Mekong, Red and Pearl (China), Krishna (India), and Balsas and Usumacinta (Central America). The rate of decline in the conservation status of freshwater amphibians is far greater than that of terrestrial species. As amphibians are excellent indicators of the quality of the overall environment, this underpins the notion of the current declining condition of freshwater habitats around the world.

Figure 2.3. Number of Threatened and Non-threatened Wetland-dependent Amphibian Species, by Major Habitat Type (C20.3.2)



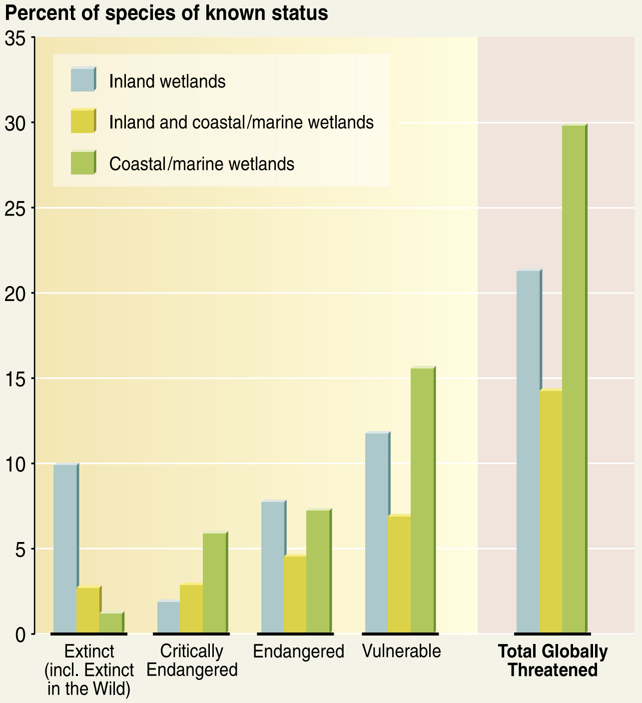
Source: Global Amphibian Assessment

Large proportions of those groups of reptiles that have been assessed, notably freshwater and marine turtles, are globally threatened (C19.2.2, C20.3.2). For example, at least 100 of around 200 species of freshwater turtles have been assessed as globally threatened. The number of critically endangered freshwater turtles more than doubled from 1996 to 2000. More than 75% of freshwater turtle species in Asia are listed in the *IUCN Red List* as globally threatened, including 18 that are critically endangered, with one being extinct. All 7 species of marine turtles, many of which use coastal wetlands for feeding and breeding, are listed in the *IUCN Red List*—globally, 3 are critically endangered, 3 are endangered, and the status of the Australian flatback remains unknown due to insufficient information. Of the 23 species of crocodilians, which inhabit a range of wetlands including marshes, swamps, rivers, lagoons, and estuaries, 4 are critically endangered, 3 endangered, and 3 vulnerable. The other species are at lower risk of extinction but are depleted or extirpated locally in some areas. There is little information on the conservation status of aquatic and semi-aquatic snakes, but several are listed as vulnerable.

It is *well established* that many wetland-dependent bird species are globally threatened, and their status continues to deteriorate faster than that of bird species in other habitats (C19.2.2, C20.3.2). Bird species that are ecologically dependent on coastal and inland wetlands, particularly migratory waterbirds, are well studied compared with other taxa, particularly in North America and Western Europe. Of the 964 bird species (excluding albatrosses and petrels) that are predominantly wetland-dependent, 203 are extinct or globally threatened (21% of total), with higher percentages of species dependent on coastal systems being globally threatened than are those dependent only on inland wetlands. (See Figure 2.4.)

Information on the net change over time to the overall threat status of the world's birds is also available and reflected in the *Red List* index. (See Figure 2.5.) The status of globally threatened birds dependent on freshwater wetlands, and even more so that of coastal seabirds, has deteriorated faster since 1988 than the status of birds dependent on other (terrestrial) ecosystems. While the *Red List* indices focus on threatened species and do not consider population trends of non-threatened species, they do provide a measure of progress in attenuating species loss. At the same time, because all known bird species have been assessed using the same criteria, potential regional or group bias is limited. Notwithstanding this, other measures of the status and trends of water birds for various regions show a similar pattern (such as the U.S. Breeding Bird Survey and trends in European waterbird populations from Wetlands International), with common species increasing while populations of more restricted and specialized groups are declining.

Figure 2.4. Globally Threatened Waterbirds, Including Seabirds, in Different Threat Categories.
Each waterbird family is allocated as depending either on inland wetlands, on inland and coastal/marine wetlands, or on coastal/marine wetlands (C20.3.2)

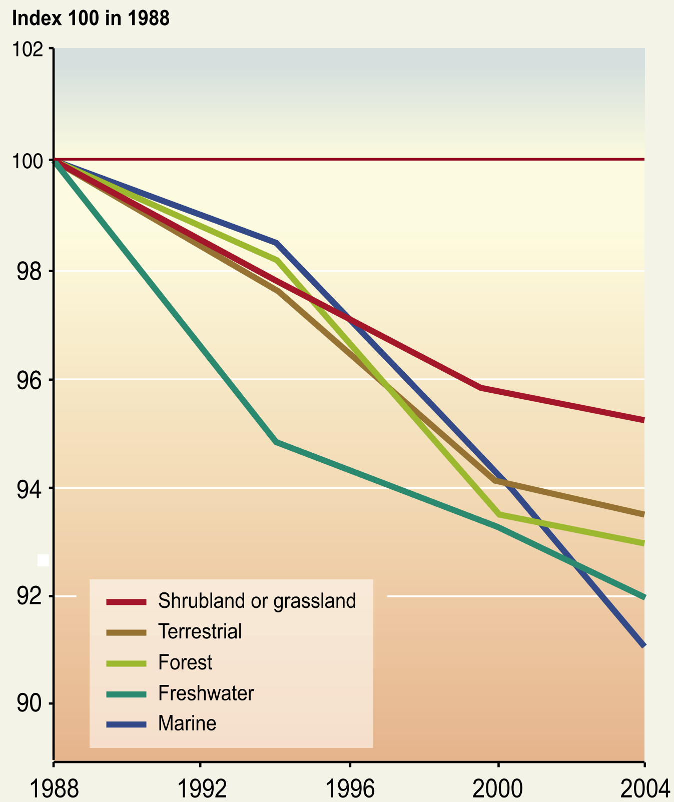


Sources: Millennium Ecosystem Assessment and BirdLife International

Based on the analysis of the trends in biogeographic populations of 33 waterbird families, 41% are in decline and more inland and coastal waterbird populations are decreasing than increasing, especially in Oceania and the Neotropics. In Europe and North America, the indices showed that waterbird populations are in a more healthy state, but even in Europe 39% of populations are decreasing. The families most affected by these population declines include darters, with 71% in decline, divers with 67%, skimmers with 60%, storks with 59%, rails and jacanas with 50% each, ibis and spoonbills with 48%, and cranes with 47%. Only gulls, flamingos, and cormorants appear to have a relatively healthy population status (C20.3.2). A similar picture emerges for Africa-Eurasia, although the status of some families in this region is worse than their global status.

A high proportion of wetland-dependent mammals that have been assessed are globally threatened, but for many species there are insufficient data for assessment purposes (C19.2, C20.3.2). Over one third (37%) of the freshwater-dependent species that were assessed by IUCN are globally threatened. These include groups such as manatees, river dolphins, and porpoises, in which all species assessed are listed by IUCN as threatened. Other freshwater mammals that have been assessed and categorized as globally threatened include freshwater seals, freshwater otters, water shrews in Malaysia and Indonesia, otter shrews in Africa, desmans, Madagascar tenrecs, marsh mongooses and otter civets, the pigmy hippopotamus, and the freshwater-dependent Pere David's deer, which has been successfully reintroduced in the wild (C20.3.2). Coastal wetland-dependent mammals also show high levels of threat; almost a quarter of all seals, sea lions, and walruses are listed by IUCN as threatened, and worldwide estimated mortalities across all cetacean species add up to several hundred thousands every year (C19.2.2).

Figure 2.5. *IUCN Red List* Indices for Birds in Different Ecosystems (C20.3.2)



Source: BirdLife International/Red List Consortium

3. *Wetland Services*

Diversity and Value of Wetland Services

Wetland ecosystems provide a diversity of services vital for human well-being and poverty alleviation (C19, C20). (See Table 3.1.) It is *well established* that provisioning services from wetlands, such as food (notably fish) and fiber are essential for human well-being. Supporting and regulating services (such as nutrient cycling) are critical to sustaining vital ecosystem functions that deliver many benefits to people. The delivery of fresh water is a particularly important service both directly and indirectly. In addition, wetlands have significant aesthetic, educational, cultural, and spiritual values and provide invaluable opportunities for recreation and tourism.

The principal supply of renewable fresh water for human use comes from an array of inland wetlands, including lakes, rivers, swamps, and shallow groundwater aquifers (C7.2.1). The renewable resource base expressed as long-term mean runoff has been estimated to fall between 33,500 and 47,000 cubic kilometers per year. By one estimate, one third of global renewable water supply is accessible to humans, when taking into account both its physical proximity to population and its variation over time, such as when flood waves pass uncaptured on their way to the ocean. Inland waters and mountains provide water to two thirds of global population and drylands to one third. Inland wetlands serve 12 times as many people downstream through river corridors as they do through locally derived runoff.

Groundwater, often recharged through wetlands, plays an important role in water supply, providing drinking water to an estimated 1.5–3 billion people (C7.2.1). It also serves as the source water for 40% of industrial use and 20% of irrigation. Despite its importance, sustainable use of groundwater has often not been sufficiently supported through appropriate pricing and management action.

Another important water supply is represented by the widespread construction of artificial impoundments that stabilize river flow. Today, approximately 45,000 large dams (more than 15 meters in height or more than 5 meters high and holding 3 million cubic meters) and possibly 800,000 smaller dams have been built for municipal, industrial, hydropower, agricultural, and recreational water supply and for flood control. Recent estimates place the volume of water trapped behind (documented) dams at 6,000–7,000 cubic kilometers.

Fish and fishery products are particularly important ecosystem services derived from inland waters (C20.2.5). Inland fisheries are of special importance in developing countries as they are sometimes the primary source of animal protein for rural communities. For example, people in Cambodia obtain about 60–80% of their total animal protein from the fishery in Tonle Sap and associated floodplains; in Malawi, 70–75% of the total animal protein for both urban and rural low-income families comes from inland fisheries. A large proportion of the recorded inland fisheries catch comes from developing countries, and the actual catch is thought to be several times the official 2001 figure of 8.7 million tons, as much of the inland catch is under-reported. An estimated 2 million tons of fish and other aquatic animals are consumed annually in the lower Mekong Basin alone, with 1.5 million tons originating from natural wetlands and 240,000 tons from reservoirs; the total value of the catch is about $1.2 billion. In Africa, fishing and harvesting of aquatic plants from the large floodplains and swamps associated with major lakes are significant sources of subsistence and income for local communities.

Coastal wetlands such as estuaries, marshes, mangroves, and coral reefs deliver many services for people (C19.3.2). They are especially important for providing food (capture fisheries in coastal waters alone account for $34 billion in yields annually

Table 3.1. Relative Magnitude (per Unit Area) of Ecosystem Services Derived from Different Types of Wetland Ecosystems (Derived from C19 Table 19.2, C20 Table 20.1)

Scale is low •, medium ●, to high: ⬤; not known = **?**; blank cells indicate that the service is not considered applicable to the wetland type. The information in the table represents expert opinion for a global average pattern for wetlands; there will be local and regional differences in relative magnitudes.

Services	Comments and Examples	Permanent and Temporary Rivers and Streams	Permanent Lakes, Reservoirs	Seasonal Lakes, Marshes, and Swamps, Including Floodplains	Forested Wetlands, Marshes, and Swamps, Including Floodplains	Alpine and Tundra Wetlands	Springs and Oases	Geothermal Wetlands	Underground Wetlands, Including Caves and Groundwater Systems
Inland Wetlands									
Provisioning									
Food	production of fish, wild game, fruits, grains, and so on	⬤	⬤	⬤	⬤	•	•		
Fresh water	storage and retention of water; provision of water for irrigation and for drinking	⬤	⬤	●	•	•	•		⬤
Fiber and fuel	production of timber, fuelwood, peat, fodder, aggregates	●	●	•	⬤	●	•	•	
Biochemical products	extraction of materials from biota	•	•	?	?	?	?	?	?
Genetic materials	medicine; genes for resistance to plant pathogens, ornamental species, and so on	•	•	?	•	?	?	?	?
Regulating									
Climate regulation	regulation of greenhouse gases, temperature, precipitation, and other climatic processes; chemical composition of the atmosphere	•	⬤	•	⬤	•	•	•	•
Hydrological regimes	groundwater recharge and discharge; storage of water for agriculture or industry	⬤	⬤	●	●	•	•		•
Pollution control and detoxification	retention, recovery, and removal of excess nutrients and pollutants	⬤	●	•	●	•	•		●
Erosion protection	retention of soils and prevention of structural change (such as coastal erosion, bank slumping, and so on)	●	•	•	●	?	•		•
Natural hazards	flood control; storm protection	●	⬤	⬤	●	●	•		•
Cultural									
Spiritual and inspirational	personal feelings and well-being; religious significance	⬤	⬤	●	●	•	●	•	•
Recreational	opportunities for tourism and recreational activities	⬤	⬤	●	•	•	•	•	•
Aesthetic	appreciation of natural features	●	●	•	●	•	•	•	•

Table 3.1. Relative Magnitude (per Unit Area) of Ecosystem Services Derived from Different Types of Wetland Ecosystems (Derived from C19 Table 19.2, C20 Table 20.1) *(continued)*

Scale is low •, medium ●, to high: ⬤; not known = **?**; blank cells indicate that the service is not considered applicable to the wetland type. The information in the table represents expert opinion for a global average pattern for wetlands; there will be local and regional differences in relative magnitudes.

Services	Comments and Examples	Permanent and Temporary Rivers and Streams	Permanent Lakes, Reservoirs	Seasonal Lakes, Marshes, and Swamps, Including Floodplains	Forested Wetlands, Marshes, and Swamps, Including Floodplains	Alpine and Tundra Wetlands	Springs and Oases	Geothermal Wetlands	Underground Wetlands, Including Caves and Groundwater Systems
Cultural *(continued)*									
Educational	opportunities for formal and informal education and training	⬤	⬤	●	●	•	•	•	•
Supporting									
Biodiversity	habitats for resident or transient species	⬤	⬤	●	●	•	•	•	•
Soil formation	sediment retention and accumulation of organic matter	⬤	•	●	⬤	•	?	?	
Nutrient cycling	storage, recycling, processing, and acquisition of nutrients	⬤	⬤	⬤	⬤	•	•	?	•
Pollination	support for pollinators	•	•	•	●	•	•		

Services	Comments and Examples	Estuaries and Marshes	Mangroves	Lagoons, Including Salt Ponds	Intertidal Flats, Beaches, and Dunes	Kelp	Rock and Shell Reefs	Seagrass Beds	Coral Reefs
Coastal Wetlands									
Provisioning									
Food	production of fish, algae, and invertebrates	⬤	⬤	•	●	•	●	•	●
Fresh water	storage and retention of water; provision of water for irrigation and for drinking	•		•					
Fiber, timber, fuel	production of timber, fuelwood, peat, fodder, aggregates	⬤	⬤	●					
Biochemical products	extraction of materials from biota	•	•			•			•
Genetic materials	medicine; genes for resistance to plant pathogens, ornamental species, and so on	•	•	•		●			•

Table 3.1. Relative Magnitude (per Unit Area) of Ecosystem Services Derived from Different Types of Wetland Ecosystems (Derived from C19 Table 19.2, C20 Table 20.1) *(continued)*

Scale is low ●, medium ●, to high: ●; not known = **?**; blank cells indicate that the service is not considered applicable to the wetland type. The information in the table represents expert opinion for a global average pattern for wetlands; there will be local and regional differences in relative magnitudes.

Services	Comments and Examples	Estuaries and Marshes	Mangroves	Lagoons, Including Salt Ponds	Intertidal Flats, Beaches, and Dunes	Kelp	Rock and Shell Reefs	Seagrass Beds	Coral Reefs
Regulating									
Climate regulation	regulation of greenhouse gases, temperature, precipitation, and other climatic processes; chemical composition of the atmosphere	medium	medium	medium	low		low	low	medium
Biological regulation (C11.3)	resistance of species invasions; regulating interactions between different trophic levels; preserving functional diversity and interactions	medium	high	medium	low		low		low
Hydrological regimes	groundwater recharge/discharge; storage of water for agriculture or industry	low		low					
Pollution control and detoxification	retention, recovery, and removal of excess nutrients and pollutants	high	high	medium		?	low	low	low
Erosion protection	retention of soils	medium	high	low				low	low
Natural hazards	flood control; storm protection	high	high	low	low	low	medium	medium	high
Cultural									
Spiritual and inspirational	personal feelings and well-being	high	low	medium	high	low	low	low	high
Recreational	opportunities for tourism and recreational activities	high	low	low	high	low			high
Aesthetic	appreciation of natural features	medium	low	medium	medium				high
Educational	opportunities for formal and informal education and training	low	low	low	low		low		low
Supporting									
Biodiversity	habitats for resident or transient species	medium	medium	low	high	low	high	low	high
Soil formation	sediment retention and accumulation of organic matter	medium	medium	low	low				
Nutrient cycling	storage, recycling, processing, and acquisition of nutrients	medium	medium	medium	low	low	low		medium

(C19.2.1)). Many estuaries, intertidal flats, beaches, dunes, and coral reefs also have spiritual, aesthetic, and recreational values. Most coastal wetlands play a role in delivering supporting services as well, such as nutrient cycling and soil formation. Coastal areas, including coastal wetlands, coastal river floodplains, and coastal vegetation, all play an important role in reducing the impacts of floodwaters produced by coastal storm events (C16.1.1).

Wetlands provide an important service by treating and detoxifying a variety of waste products (C15.7.5). Water flowing through a wetland area may be considerably cleaner upon its exit from the wetland. Some wetlands have been found to reduce the concentration of nitrate by more than 80%. Some artificially constructed wetlands have been developed specifically to treat nitrogen-rich sewage effluents. Metals and many organic compounds may be adsorbed to the sediments (that is, accumulated on their surface) in the wetlands. The relatively slow passage of water through wetlands provides time for pathogens to lose their viability or be consumed by other organisms in the ecosystem. However, wetlands can become "hotspots" of contamination—wastes can build up to concentrations high enough to have detrimental effects on wetland functions. Unfortunately, the threshold between where loadings are tolerated and where they will do damage to wetlands is not easily determined.

Wetlands are important tourism destinations because of their aesthetic value and the high diversity of the animal and plant life they contain (C19.2, C19.3.2, C20.2.6). In some locations, tourism plays a major part in supporting rural economies, although there are often great disparities between access to and involvement in such activities. Recreational fishing can generate considerable income: some 35–45 million people take part in recreational fishing (inland and saltwater) in the United States, spending a total of $24–37 billion each year on their hobby. Reefs support high diversity that in turn supports a thriving and valuable recreational diving industry. For example, much of the economic value of coral reefs—with net benefits estimated at nearly $30 billion each year—is generated from nature-based tourism and diving. The demand from tourists for biologically rich sites to visit increases the value of intrinsically linked habitats, such as mangroves and seagrass beds. Temperate bays, semi-enclosed seas, and estuaries can generate tourism revenues of similar orders of magnitude. The negative effects of recreation and tourism are particularly noticeable when they introduce inequities and do not support and develop local economies, and especially where the resources that support the recreation and tourism are degraded.

Wetlands play an important role in the regulation of global climate by sequestering and releasing significant amounts of carbon (C20.2.4). Inland water systems play two critical but contrasting roles in mitigating the effects of climate change: the regulation of greenhouse gases (especially carbon dioxide) and the physical buffering of climate change impacts. Inland water systems have been identified as significant storehouses (sinks) of carbon as well as sources of carbon dioxide (for instance, boreal peatlands), as net sources of carbon sequestration in sediments, and as transporters of carbon to the sea. Although covering only an estimated 3–4% of the world's land area, peatlands are estimated to hold 540 gigatons of carbon, representing about 1.5% of the total estimated global carbon storage and about 25–30% of that contained in terrestrial vegetation and soils. Inland waters also contribute to the regulation of local climate.

Wetlands provide many nonmarketed and marketed benefits to people, and the total economic value of unconverted wetlands is often greater than that of converted wetlands (*medium certainty*) (C19.3.2, C20.2). There are many examples of the economic value of intact wetlands exceeding that of converted or otherwise altered wetlands. (See Box 3.1.) Estimates for the global economic importance of wetlands are highly variable, with an upper value of $15 trillion. Figures such as these are strongly disputed on methodological grounds by many economists, who point to limitations in the methods and urge careful consideration of the assumptions made. Regardless of the ongoing debate

Box 3.1. Two Examples of the Costs and Benefits of Retaining or Converting Natural Coastal and Inland Wetlands (C5 Box 5.2)

Draining freshwater marshes for agriculture (Canada): Draining freshwater marshes in one of Canada's most productive agricultural areas yielded net private benefits, but in large part this was only because of provision of substantial drainage subsidies. When the social benefits of retaining wetlands, arising from sustainable hunting, angling, and trapping, are calculated, however, they greatly exceeded agricultural gains. For all three marsh types considered, the net present value was higher when the wetlands remained intact (average for three wetland types of approximately $5,800 compared with the total economic value of a converted wetland of $2,400 per hectare).

Conversion of a mangrove system to aquaculture (Thailand): Although conversion for aquaculture made sense in terms of short-term private benefits, it did not once external costs were factored in. The global benefits of carbon sequestration were considered to be similar in intact and degraded systems. However, the substantial social benefits associated with the original mangrove cover (from timber, charcoal, non-timber forest products, offshore fisheries, and storm protection) fell to almost zero following conversion. Summing all measured services, the total economic value of intact mangroves was a minimum of $1,000 and possibly as high as $36,000 per hectare, while that of shrimp farming was about $200 per hectare.

about the means of calculating the economic value of wetlands, it is now well established that they are valuable and deliver many services for people. This does not mean that conversion of wetlands is never economically justified, but it illustrates the fact that many of the economic and social benefits of wetlands have not been taken into account by decision-makers.

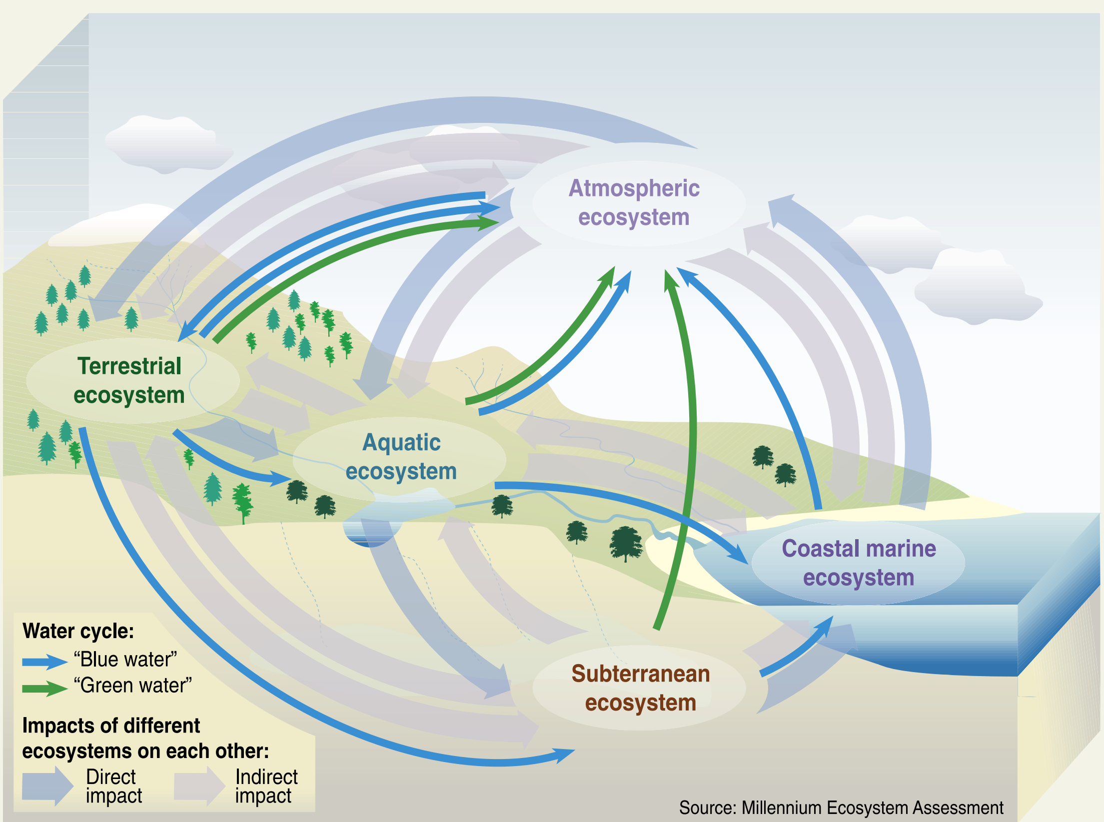
The declining condition of wetlands has placed their ecosystem services and the people who depend on them at increasing risk (C7.2, C7.4, C8.3, SG7). Humans now withdraw about 3,600 cubic kilometers of water a year from inland wetlands—a substantial fraction of the available global continental runoff (C7.2). Global freshwater use has been increasing at about 20% per decade from 1960 to 2000 and is estimated to continue to increase by 10% by 2010. In river basins in arid or populous regions, the rate of water use can be much higher. In addition, supplies of fresh water in many parts of the world continue to be polluted. Pollution of inland wetlands by inorganic nitrogen has doubled globally since 1960 and has increased more than tenfold in many industrialized parts of the world. Many pollutants are long-lived and can be transformed into compounds whose behaviors, synergistic interactions, and impacts are for the most part unknown. As a consequence of pollution, the capacity of many wetlands to provide clean and reliable sources of water has been reduced.

Water scarcity and declining access to fresh water is a globally significant and accelerating problem for 1–2 billion people worldwide, leading to reductions in food production, human health, and economic development (C7.2). With population growth and the overexploitation and contamination of water resources, the gap between available water and water demand is increasing in many parts of the world. Scarcity of water will affect all businesses either directly or indirectly, just as increases in the price of petroleum affect the state of the global economy (*Business and Industry Synthesis*). Governments will be called on to allocate supplies and adjudicate water rights.

The Synergistic Role of Wetlands and the Global Water (Hydrological) Cycle

Both inland and coastal wetlands have a significant influence on the water (hydrological) cycle and hence the supply of water for people and the many uses they make of it, including for irrigation, energy, and transport. The water cycle is the movement of water between all parts of Earth in its different forms (vapor, liquid, and solid) and throughout the broader biophysical environment (atmospheric, marine, terrestrial, aquatic, and subterranean). (See Figure 3.1.) Water resources, via water itself, are linked to all aspects of this broader environment. Two components of the water

Figure 3.1. Interrelationships Among Environmental Components of Global Water Cycle, Including Cycling of "Green Water" and "Blue Water" (Derived from C7 Box 7.1)



cycle are generally recognized: "blue water" is all water that is controlled by physical processes, including evaporation, and "green water" is water that is influenced by biological processes such as evapotranspiration by vegetation.

The global water cycle plays a fundamental role in supporting both inland and coastal wetlands, while at the same time wetlands have a significant influence on the water cycle itself (C7.2, C19.2.3, C20.2.1). Wetlands can either increase or decrease particular components of the water cycle. The interrelationship between wetlands and the water cycle extends well into the coastal zone, with coastal wetlands being influenced by the inflow of fresh water from catchments as well as by the tides and other coastal/oceanic factors that in turn influence the freshwater aspects of the water cycle. Although there is insufficient information on wetland hydrology to fully meet the needs of decision-makers, there is a progressive decline in investments to generate new hydrological data or enhance the quality of existing information at global, national, and local levels, particularly in developing countries (C7.1.2).

It is *well established* that inland wetlands provide a wide array of hydrological services, but the nature and value of these is not consistent, and many are not well understood (C20.2.1). There are several long-standing generalizations about the hydrological services performed by wetlands, notably that they reduce floods (C16.2.1), promote groundwater recharge, and regulate river flows, specifically the augmentation of low flows (for instance, wetlands act as sponges that soak up water during wet periods and release it during dry ones). While there are numerous examples of wetlands, notably floodplains, where this does occur, there is increasing evidence that such generalizations are not applicable for all hydrological contexts or wetland types. Indeed, there are many instances where the opposite occurs: where wetlands reduce low flows, increase floods, or act as a barrier to groundwater recharge. This variation is not unexpected given the wide range of wetlands—from entirely groundwater-fed springs to large inland river floodplains. When divided into hydrologically similar types, however, services do tend toward greater consistency for some wetland types. (See Box 3.2.)

Maintenance of the key hydrological services performed by wetlands enables them to continue to deliver a wide range of critical and important regulatory and provisioning ecological services to humans (C20.2). Historically, it is *well established* that the maintenance, protection, and even restoration of wetlands have often been encouraged because of the manifold hydrological services they perform. However, while some of these hydrological services, such as water storage, flood attenuation, and the augmentation of dry-season flows, are likely to be seen as favorable for human well-being, others that are essential to maintain wetland ecological character (such as flooding and evaporation from wetland vegetation) may complicate water management efforts aimed at balancing differing needs between cities, navigation, agriculture, and wetlands.

Maintaining the hydrological regime of a wetland and its natural variability is necessary to maintain the ecological characteristics of the wetland, including its biodiversity (*high certainty*) (derived from C19.2, C20.2). (See Table 3.2.) Hydrological regime and topography are generally the most important determinants of the establishment and maintenance of specific types of wetland and wetland processes, creating the unique physicochemical conditions that make wetlands different from both deepwater aquatic systems and well-drained terrestrial systems. Hydrological conditions affect numerous abiotic factors, including nutrient availability, soil anerobiosis, and salinity in both coastal and inland wetlands, which in turn determine the biota that establish in a wetland. These biotic components can alter the hydrology and other physicochemical features of the wetland.

Wetlands such as floodplains, lakes, and reservoirs help to attenuate floods. Flood attenuation potential can be estimated by the "residence time" of water in rivers, lakes, reservoirs, and soils. Residence time is defined as the time taken for water falling

Box 3.2. Hydrological Services of Wetlands

Although the influence of a wetland on the hydrological cycle is site-specific, some general patterns found in assessments in North America and a smaller number of European assessments (and a very small number of assessments in Asia and South America) are described here (C7, C20).

Gross water balance: Wetlands evaporate more water than other land types, such as cultivated land, grassland, or forests. Around 65% of studies reviewed concluded that non-riverine wetlands reduce average annual flow in rivers. Some 25% of studies were neutral, and in only 10% did such wetlands increase flows. There appear to be no obvious distinctions among wetland sub-types or geographical regions in this regard.

Flow regulation: Inland wetlands are important water storage sites during wet periods and often provide a reserve of water during dry periods. However, there is strong evidence that some wetlands with high evapotranspiration rates reduce the flow of water in downstream rivers during dry periods. This is backed by overwhelming evidence that shows evaporation from wetlands to be higher than from non-wetland portions of the catchment during dry periods; there is no discernible difference for different wetland sub-types. In only 20% of cases examined did wetlands increase river flows during the dry season.

Flood-related services: Floodplain wetlands almost always reduce floods (and their peaks) or delay them. Many wetlands in the headwaters of river systems (such as bogs and river margins) probably perform a similar service. However, some headwater wetlands are known to increase flood peaks and generate flood flows. They often increase the immediate response of rivers to rainfall, due to a tendency to be saturated, generating higher volumes of flood flow even if the flood peak is not increased.

Pollution control and detoxification: The valuable role played by wetland plants and substrates in trapping sediments, nutrients, and pollutants is *well established*. Where erosion has increased as a consequence of wide-scale vegetation clearing, many shallow water bodies have trapped high levels of sediment that would otherwise be transported downstream and deposited in coastal areas or on nearby reefs. Vegetation along the edge of Lake Victoria, East Africa, was found to retain 60–92% of phosphorus. More generally, it is estimated that wetlands intercept more than 80% of nitrogen flowing from terrestrial systems (although figures vary due to temperature and size of the area) (C7.2.5, C12.2.3). In West Bengal, India, water hyacinth is used to remove heavy metals, and other aquatic plants remove grease and oil, enabling members of a fishers' cooperative to harvest one ton of fish per day from ponds that receive 23 million liters of polluted water daily from both industrial and domestic sources. However, excessive loads of domestic sewage or industrial effluent can degrade inland wetlands, with a loss of both biota and services (C20.1.1). The costs of reversing damages to waste-degraded ecosystems are typically large; in some cases, rehabilitation is effectively impossible (CWG).

Groundwater services: Services delivered by groundwater are generally less well understood than those derived from surface waters. Many wetlands exist because they overlie impermeable soils or rocks and there is therefore little or no interaction with groundwater. However, numerous wetlands are groundwater-dependent and fed largely or wholly by groundwater, such as wetlands that form at springs, oases, and many lakes. In some instances, wetlands may promote less groundwater recharge than other land types. In other cases, such as floodplains overlying sandy soils (in West Africa and India, for example), recharge of the aquifer occurs during flooding. The direction of water movement between the wetland and the ground may change in the same wetland, such as in some peatlands in Madagascar and along many river reaches, depending on season and local hydrological conditions.

River flow and hydrological regime variability: These services vary greatly between different types of wetland and their localities. For instance, different headwater wetlands and peat bogs showed increases, decreases, or neutral effects on variability. Glaciers and snowmelt also contribute to flows and their variability and timing. While floodplains (such as the Okavango delta in Africa and the Barito floodplain in Indonesia) reduce flow variability, principally by reducing flood peaks, other wetlands (such as many headwater wetlands) serve to increase flow variability through both increasing flood peaks and reducing dry-season flows.

as precipitation to pass through a system: the longer the residence time, the larger the buffering capacity to attenuate peak flood events. Larger rivers (such as the Congo and the Amazon) have a greater attenuation capacity than smaller rivers. Nearly 2 billion people live in areas with a residence time of one year or less and are thus in areas of high flood risk with low attenuation potential. Most of these people live in northern South America, highly populated regions of northern India and Southeast Asia, Central Europe, and the southwest coast of Africa. Large and extreme flood events have high costs both in terms of human life and expenditure on mitigation and recovery measures (C16.2.2).

However, floods also play an important role in maintaining the productivity of wetlands (and agriculture in floodplains), since they transport dissolved or suspended sediments and nutrients to the floodplains. The presence of a natural flood regime thus contributes to the livelihoods of millions of people, particularly those who depend on floodplains for flood-recession agriculture and pasturage and for fish production (C20.2.1).

Table 3.2. Examples of Hydrological-Ecological Relationships at Different River Flows That Support Ecological Character of Wetlands and Their Services (Derived from C19.2, C20.2)

Flow Component	Ecological Role
Low (base) flows *Normal level:*	provide adequate habitat space for aquatic organisms maintain suitable water temperatures, dissolved oxygen, and other chemical conditions, including salinity maintain water table levels in floodplain and plant soil moisture provide drinking water for terrestrial animals keep fish and amphibian eggs suspended enable passage of fish to feeding and spawning areas support hyporheic organisms (living in saturated sediments)
Low (base) flows *Drought level:*	enable recruitment of certain floodplain plants purge invasive, introduced species from aquatic and riparian communities concentrate prey into limited areas to the benefit of predators
Higher flows (small flood pulses)	shape physical character of river channel, including availability and heterogeneity of different biotopes (such as riffles, pools) and microhabitats restore normal water quality after prolonged low flows, flushing away waste products, pollutants, and proliferations of nuisance algae maintain suitable salinity conditions in estuaries prevent encroachment of riparian vegetation into the channel aerate eggs in spawning gravels, prevent siltation of cobble interstices determine size of river bed substrata (sand, gravel, cobble, boulder)
Large floods	provide fish migration and spawning cues provide new feeding opportunities for fish and waterbirds recharge floodplain water table maintain diversity in floodplain forest types through prolonged inundation (plant species have differing tolerances for flooding) and their natural regeneration processes control distribution and abundance of plants on floodplain trigger new phases of life cycles (such as insects) enable fish to spawn on floodplain, provide nursery area for juvenile fish deposit nutrients on floodplain maintain balance of species in aquatic and riparian communities create sites for recruitment of colonizing plants shape physical character and habitats of river channels and floodplain deposit substrata (gravel, cobble) in spawning areas flush organic materials (food) and woody debris (habitat structures) into channel purge invasive, introduced species from aquatic and riparian communities disburse seeds and fruits of riparian plants drive lateral movement of river channel, forming new habitats (secondary channels, oxbow lakes) provide plant seedlings with prolonged access to soil moisture drive floodplain productivity

4. *Drivers of Loss and Change to Wetland Ecosystems*

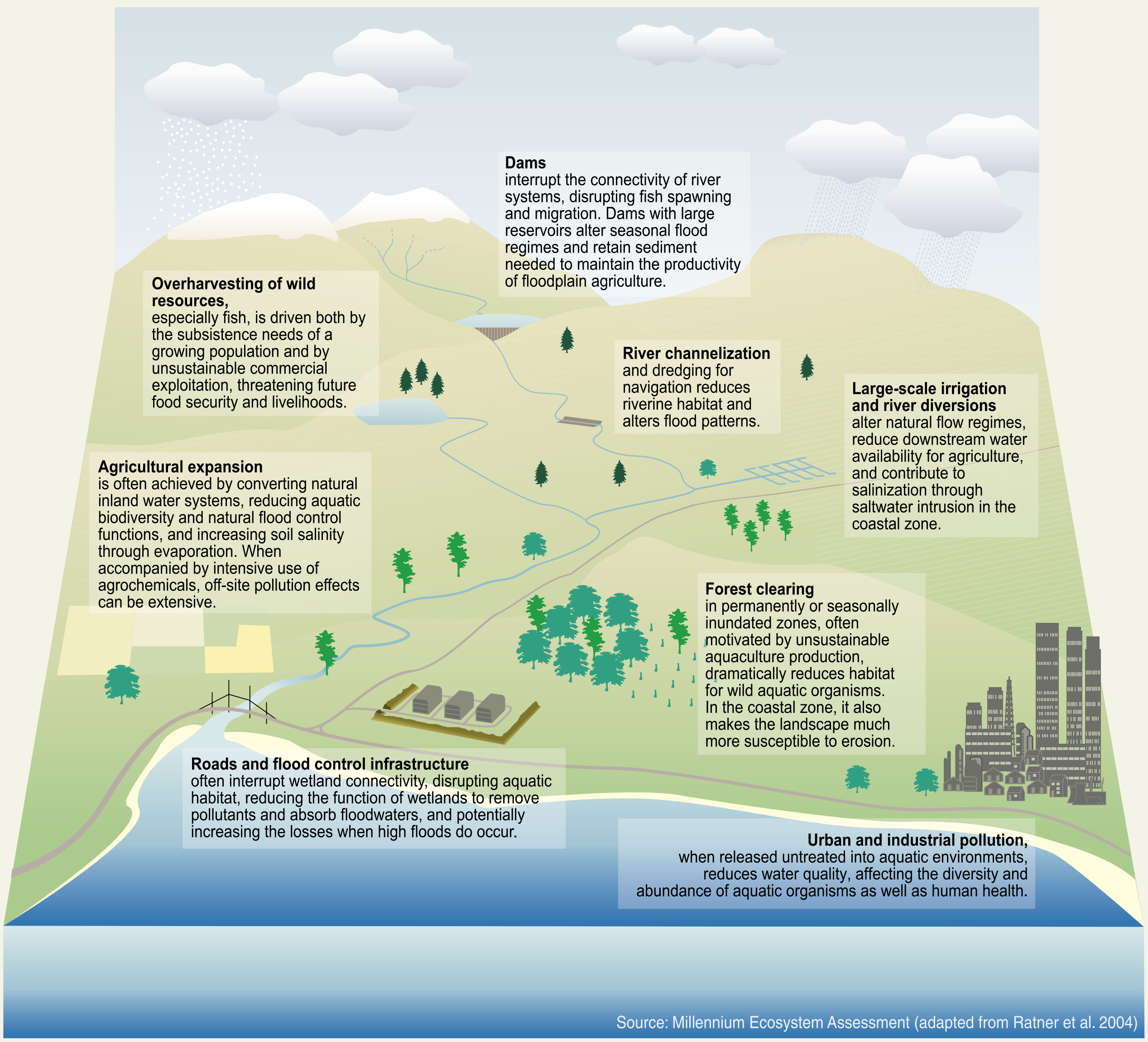
Wetlands

The degradation and loss of inland wetlands and species has been driven by infrastructure development (such as dams, dikes, and levees), land conversion, water withdrawals, pollution, overharvesting, and the introduction of invasive alien species. Global climate change and nutrient loading are projected to become increasingly important drivers in the next 50 years (C7, C19, C20, R9, R13). The analysis presented in this chapter focuses primarily on direct drivers as illustrated in Figure 4.1.

Increased human use of fresh water has reduced the amount available to maintain the ecological character of many inland water systems (C7.3, C20.4.2, C22.5.2, R7.4). Throughout the world, the construction of dams and other infrastructure and the withdrawal of water for use in agriculture, industry, and households has changed flow regimes, changed the transport of sediments and nutrients, modified habitat, and disrupted migration routes of aquatic biota such as salmon. The amount of water impounded behind dams quadrupled since

Figure 4.1. Pictorial Representation of Some Direct Drivers of Change in Inland and Coastal Wetlands

Invasive species, climate change, and land conversion to urban or suburban areas affect all components of the catchment and coastal zone and are therefore not represented pictorially (C19.4.1, C20.4).



Source: Millennium Ecosystem Assessment (adapted from Ratner et al. 2004)

1960, and three to six times as much water is held in reservoirs as in natural rivers.

As a result of consumptive use and interbasin transfers, several of the world's largest rivers (including the Nile, Yellow, and Colorado) have been transformed into seasonally (and in some cases entirely) non-discharging river channels in their lower reaches. One third of all rivers for which contemporary and predisturbed discharges could be compared showed substantial declines in discharges to the ocean. Long-term trend analysis (> 25 years) of 145 major world rivers indicated that discharge had declined in more than one fifth (C7.2.4). As water flows to many wetlands have declined, so have sediment flows. Delivery of ecologically important nutrients is also impeded by freshwater diversion in watersheds, affecting not only coastal ecology but also marine fisheries yields. Further, these changes have also altered the flow velocity in rivers, transforming some to large lakes, such as Kariba Lake (southern Africa); have created a chain of connected deep reservoirs, such as those along the Volga River (Russia); have resulted in channelization, such as that along the Mississippi and Missouri Rivers (United States); or have significantly reduced flows to floodplains and downstream habitats, including deltas such as the Indus (Pakistan) (C20.4.2).

The more than 45,000 existing large dams and additional planned facilities generate both positive and negative outcomes for humans (C20.4.2). Positive effects on human well-being include flow stabilization for irrigation for food production, domestic water supply, flood control, and generation of hydroelectricity. Negative effects include, among others, loss of economic livelihoods, fragmentation and destruction of habitats, loss of species, health issues associated with stagnant water, and loss of sediments and nutrients destined for the coastal zone. Inter-basin transfers, particularly large transfers between major river systems, will be particularly harmful to downstream ecosystems in the source catchments. In India and China, for example, transfer projects costing hundreds of billions of dollars are proposed (R7.4).

Conversion (clearing or transformation) or drainage for agricultural development has been the principal cause of inland wetland loss worldwide (*high certainty*) (C20.4.1). By 1985, an estimated 56–65% of available inland and coastal marshes had been drained for intensive agriculture in Europe and North America, 27% in Asia, 6% in South America, and 2% in Africa. Intensification of agriculture has also increased pressure on inland water ecosystems due to increased water withdrawals for irrigation and nutrient and pesticide leakage from cultivated lands. Intensification also generally reduces biodiversity within agricultural landscapes and requires higher energy inputs in the form of mechanization and the production of chemical fertilizers (C19.5.2, C20.4.1). In the majority of cases, the people most affected by reduced water supplies, increased pollution, and loss of biodiversity are the poor, who depend on freshwater resources not only for drinking water but also for food and income.

The Aral Sea represents one of the most extreme cases in which water for irrigated agriculture has caused severe and irreversible environmental degradation of an inland water system. (See Box 4.1 and Figure 4.2.) Similarly, Lake Chad shrank over 35 years from about 2.5 million hectares in surface area to only one twentieth that size at the end of the twentieth century as a

Box 4.1. The Aral Sea: A Degraded Inland Sea (C20.4.1)

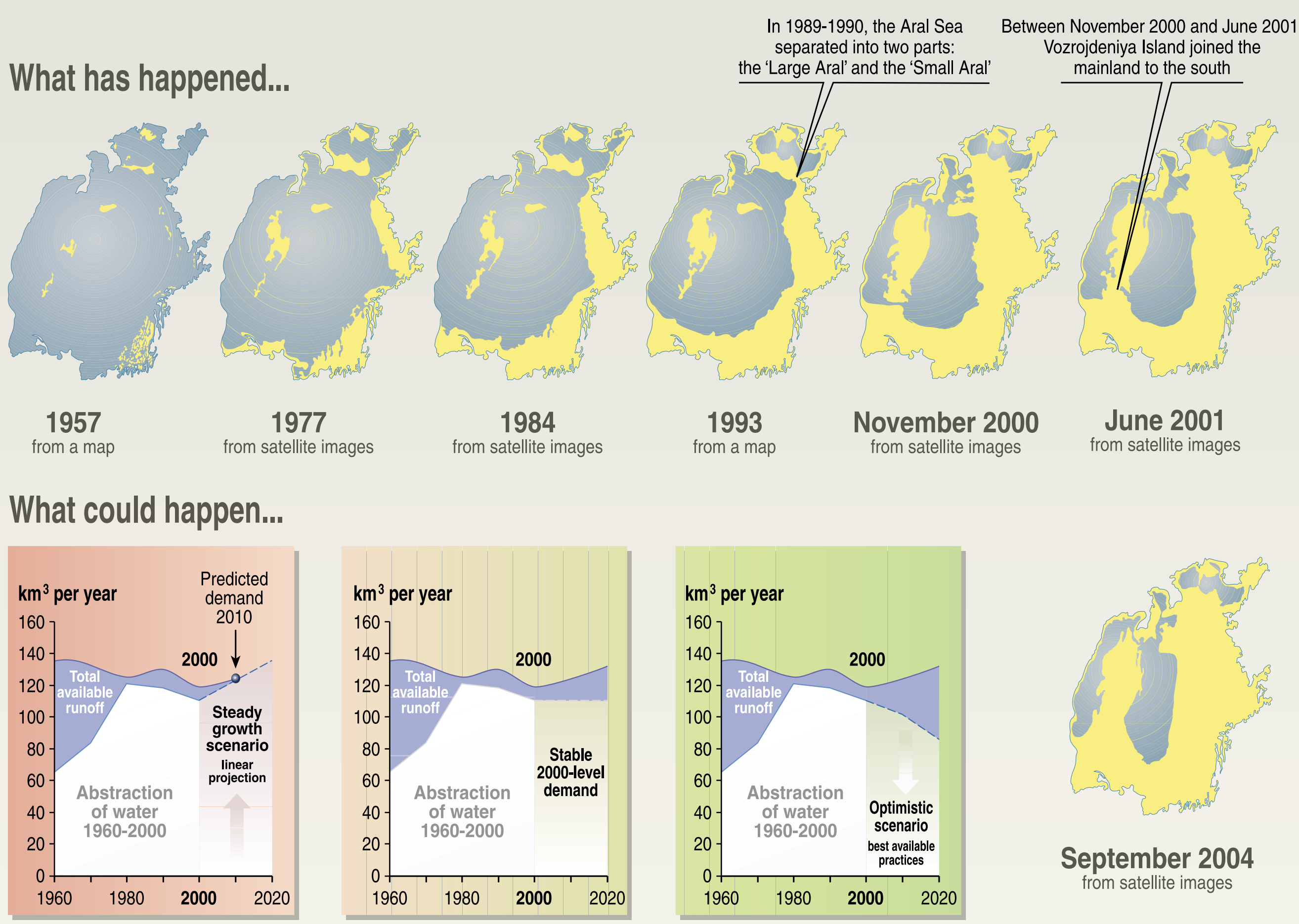
During the past 50 years, the Aral Sea has been reduced to one fifth of its original size and significantly degraded by pollution as a consequence of water withdrawals and water diversion to meet the needs of large-scale cotton cultivation. The hydrological change has included the construction of more than 94 water reservoirs and 24,000 kilometers of channels, with 40% of the annual water inflow of 80–100 cubic kilometers taken for irrigation. The sea is now only about 20% of its former volume and it comprises three separate entities: the Small Sea, with an area of 3,000 square kilometers, a volume of 20 cubic kilometers, and a salinity of 18–20 grams per liter; the eastern part of the Large Sea, with an area of 9,150 square kilometers, a volume of 29.5 cubic kilometers, and a salinity of 120 grams per liter; and the western part of the Large Sea, with an area of 4,950 square kilometers, a volume of 79.6 cubic kilometers, and a salinity of 80 grams per liter. The shoreline has retreated 100–150 kilometers and has exposed some 45,000 square kilometers of former seabed and created a salty desert, generating in excess of 100 million tons of salt-laden dust, which has grave consequences for human health.

Along with these changes, the socioeconomically important fishing industry has gone, as have many plant and animal species. Only a few of the former 34 fish species survive, with some of the lake's endemic fish becoming extinct. Waterbirds have similarly been drastically affected, with a loss of breeding and stopover habitats for migratory species in the deltas of the Amu Darya and Syr Darya. New wetland habitats have been produced through the construction of irrigation areas, but it is unlikely that these compensate adequately for the losses of the different natural habitats. The local climate has also been affected. For example, the humidity has decreased from around 40% to 30%, resulting in a loss of pasture productivity (C5.5).

Around the Aral Sea, far-reaching environmental and ecological problems (such as dust storms, erosion, and poor water quality for drinking and other purposes) have harmed human health. Rates of anemia, tuberculosis, kidney and liver diseases, respiratory infections, allergies, and cancer have increased and now far exceed those in the rest of the former Soviet Union and present-day Russia. The rate of birth abnormalities—another serious consequence of pollution—is also increasing. One in every 20 babies is born with abnormalities, a figure approximately five times higher than in European countries.

The consequences of the management decisions for the sea have been drastic, although some were foreseen, and deliberate trade-offs were made in favor of economic outcomes. In 1995, it was estimated that an investment of $16 billion could result in net water savings of 12 cubic kilometers per year, which could then help to restore the hydrology of the lake. But the prospects for funding were not very optimistic.

Figure 4.2. Decline in Size of the Aral Sea since 1957 (C20.4.1)



Sources: Nikolaï Denisov, GRID-Arendal, Norway; Scientific Information Center of International Coordination Water Commission (SIC ICWC); International Fund for Saving the Aral Sea (IFAS); The World Bank; National Aeronautics and Space Administration (NASA); United States Geological Survey (USGS), *Earthshots : Satellite images of environmental change*, United States Department of the Interior, 2000.

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consequence of natural and human-induced effects, with the subsequent loss of many species and ecosystem services (C20.4.1). The Mesopotamian marshlands in Iraq originally covered 1.5–2 million hectares but were devastated in recent decades by massive drainage and dam construction along the Tigris and Euphrates Rivers. In addition, in the early 1990s massive drainage schemes were used to divert large volumes of water from these marshlands (C20.4.2).

Water from lakes that experience algal blooms is more expensive to purify for drinking or other industrial uses (S7.3.2). Eutrophication can reduce or eliminate fish populations. Possibly the most striking loss in services is the loss of many of the cultural services provided by lakes. Foul odors of rotting algae, slime-covered lakes, and toxic chemicals produced by some blue-green algae during blooms keep people from swimming, boating, and otherwise enjoying the aesthetic value of lakes.

The greatest threat to coastal wetlands is development-related conversion of coastal ecosystems, leading to large-scale losses of habitats and services (C19). Other direct drivers affecting coastal wetlands include diversion of freshwater flows, nitrogen loading, overharvesting, siltation, changes in water temperature, and species invasions. The primary indirect drivers of change have been the growth of human populations in coastal areas coupled with growing economic activity. Nearly half of the world's major cities are located within 50 kilometers of the coast, and coastal population densities are 2.6 times larger than the density of inland areas. This population pressure leads to conversion of coastal wetlands as a result of urban and suburban expansion. In addition, mangroves have been widely converted to aquaculture. As noted earlier, in countries for which sufficient data are available nearly 35% of mangroves have been converted in the last two decades. Given the extensive changes in land use and cover that have occurred in many coastal areas, it is unlikely that many of the observed changes in habitat and species loss will be readily reversed.

Other important drivers of change in coastal wetlands include:

■ Freshwater diversion from estuaries has meant significant losses in the delivery of water and sediment to nursery areas and fishing grounds in the coastal zone (*high certainty*) and to floodplains, affecting the livelihood of millions of people who depend on these coastal areas and floodplains for flood-recession agriculture and pasturage and for fish production and capture fisheries (C19.2.1). Worldwide, although human activities have increased sediment flows in rivers by about 20%, reservoirs and water diversions prevent about 30% of sediments from reaching the oceans, resulting in a net reduction of sediment delivery to estuaries of roughly 10%.

■ The flux of reactive (biologically available) nitrogen to the coasts and oceans increased by 80% from 1860 to 1990, with resulting eutrophication that has harmed coastal fisheries and contributes to coral reef regime shifts that are effectively irreversible (R9).

■ Seagrass ecosystems are damaged by a wide range of human impacts, including dredging and anchoring in seagrass meadows, coastal development, eutrophication, hyper-salinization resulting from reduction in freshwater inflows, siltation, habitat conversion for the purposes of algae farming, and climate change. Major losses of seagrass habitat have been reported in the Mediterranean, Florida Bay, and Australia, and current losses are expected to accelerate, especially in Southeast Asia and the Caribbean (C19.2.1.5).

■ Coral reefs have been degraded through direct human actions (overfishing, coral mining) and indirectly through water pollution, sedimentation, and climate change (C19.2). Many coral reefs have undergone major, although often partially reversible, bleaching episodes when local sea surface temperatures have increased during one month by 0.5–1° Celsius above the average of the hottest month.

■ Disruption and fragmentation of coastal wetlands important as migration routes have endangered many species and resulted in the loss of others. For example, the decline of certain long-distance East Atlantic flyway waterbird populations (while other populations on the same flyway are stable or increasing) has been attributed to their high dependence on deteriorating critically important spring staging areas, notably the international Wadden Sea, that are being affected by commercial shell fisheries (C19.2.2).

■ Estuarine systems are among the most invaded ecosystems in the world, with introduced species causing major ecological changes. For example, San Francisco Bay in California has over 210 invasive species, with one new species established every 14 weeks between 1961 and 1995, brought in by ballast water of large ships or occurring as a result of fishing activities. The ecological consequences of the invasions include habitat loss and alteration, altered water flow and food webs, the creation of novel and unnatural habitats subsequently colonized by other invasive alien species, abnormally effective filtration of the water column, hybridization with native species, highly destructive predators, and introductions of pathogens and disease (C19.2.1).

Human pressures on rapidly diminishing areas of coastal resources are increasingly compromising many of the ecosystem services crucial to the well-being of coastal economies and peoples (C19.1). Coastal fishing has depleted stocks of finfish, crustaceans, and mollusks in all regions, reducing food supply and incomes and disrupting coastal and marine food webs. Large-scale coastal fisheries deprive coastal communities of subsistence and are causing increasing conflicts, especially in Asia and Africa. Aquaculture production in coastal areas continues to grow in response to increasing industrial-country market demand, resulting in habitat loss, overexploitation of fisheries for fishmeal, and pollution. The alteration and conversion of coastal wetlands has increased the vulnerability of coastal and shoreline regions to storm damage and erosion (C19). Mangroves, coral reefs, and dune systems serve as buffers, diminishing the impact of storms, hurricanes, floods, and waves and thereby contributing to the well-being of coastal communities in both the developing and the industrial world.

The loss of mangroves is caused by aquaculture development, deforestation for firewood and other land uses, and freshwater diversion (C19.2). In Asia, more than half of the loss of mangroves has been due to increased aquaculture (38% for shrimp and 14% fish), about a quarter has been due to deforestation, and another 11% due to upstream freshwater diversion. In Latin America, mangrove destruction has occurred as a consequence of expansion of agriculture and cattle-raising, the cutting of firewood and building materials, and the establishment of shrimp aquaculture.

Over the past four decades, excessive nutrient loading has emerged as one of the most important direct drivers of ecosystem change in inland and coastal wetlands. Human activities have now roughly doubled the rate of creation of reactive nitrogen on the land surfaces of Earth (R9.2). The flux of reactive nitrogen to the oceans increased by nearly 80% from 1860 to 1990, from roughly 27 teragrams (10^{12} grams) of nitrogen per year to 48 teragrams in 1990 (R9). (This change is not uniform over Earth, however, and while some regions such as Labrador and Hudson's Bay in Canada have seen little if any change, the fluxes from more developed regions such as the northeastern United States, the watersheds of the North Sea in Europe, and the Yellow River basin in China have increased ten- to fifteenfold.) Excessive nitrogen loading can cause algal blooms, decreased drinking water, eutrophication of freshwater ecosystems (a process whereby excessive plant growth depletes oxygen in the water), and hypoxia in coastal wetlands (substantial depletion of oxygen, resulting in die-offs of support fish and other aquatic animals).

Phosphorus applications have increased threefold since 1960, with a steady increase until 1990, followed by leveling off at a level approximately equal to applications in the 1980s. These changes are mirrored by phosphorus accumulation in soils, which maintain high levels of phosphorus runoff that can cause eutrophication of fresh waters and coastal waters. Potential consequences include eutrophication of freshwater ecosystems and hypoxia in coastal wetlands.

While the introduction of nutrients into ecosystems can have both beneficial effects (such as increased crop productivity) and adverse effects (such as eutrophication of inland and coastal waters), the beneficial effects will eventually reach a plateau as more nutrients are added (that is, additional inputs will not lead to further increases in crop yield), while the harmful effects will continue to grow.

Global climate change is expected to exacerbate the loss and degradation of many wetlands and the loss or decline of their species and to harm the human populations dependent on their services; however, projections about the extent of such loss and degradation or decline are not yet well established (C19.4.1, C20.4.6, R13). Climate change is projected to lead to increased precipitation over more than half of Earth's surface, and this will make more water available to society and ecosystems. However, increases in precipitation will not be universal, and climate change will also cause substantial decrease in precipitation in other areas. Despite the benefits of increased precipitation for some freshwater wetlands, the climate changes projected by the Intergovernmental Panel on Climate Change are likely to have pronounced harmful impacts on many wetland ecosystems. Specifically:

- Many coastal wetlands will change as a consequence of projected sea level rise, increased storm and tidal surges, changes in storm intensity and frequency, and subsequent changes in river flow regimes and sediment transport. There will be adverse consequences for wetland species, especially those that cannot relocate to suitable habitats, as well as migratory species that rely on a variety of wetland types throughout their life cycle.
- Of all the world's ecosystems, coral reefs may be the most vulnerable to the effects of climate change. Coral reefs and atolls will be significantly affected by projected future sea level rise, warming oceans, and changes in storm frequency and intensity (*high certainty*). Although projected increases in carbon dioxide and temperature over the next 50 years exceed the conditions under which coral reefs have flourished over the past half-million years, the extent of the impact on coral reefs is uncertain, since some species show far greater tolerance to climate change and coral bleaching than others.
- Global climate change impacts will often exacerbate the impacts of other drivers of degradation of wetlands. For example, decreased precipitation as a result of climate change will exacerbate problems associated with already growing demands for water. Higher sea surface temperatures will exacerbate threats to coral reefs associated with increased sedimentation. In limited cases, however, global climate change could lessen pressure on some wetlands, particularly in areas where precipitation increases.
- Warming can also exacerbate the problem of eutrophication, leading to algal blooms, fish kills, and dead zones.
- Specific adverse consequences of global climate change include the already observed changes in the distribution of coastal wintering shorebirds in Western Europe due to rising mid-winter temperatures. It is also anticipated that climate change will lead to population declines in high-Arctic breeding waterbird species as a result of habitat loss and that the distribution of many fish species will shift toward the poles, with cold-water fish being further restricted in their range and cool- and warm-water fish expanding in range (*medium certainty*).

■ The incidence of vector-borne diseases such as malaria and dengue and of waterborne diseases such as cholera is projected to increase in many regions (*medium to high certainty*).

There is *established but incomplete* evidence that changes being made in ecosystems are increasing the likelihood of nonlinear and potentially abrupt changes in ecosystems, with important consequences for human well-being (S.SDM). This is likely to be the case as much for wetlands as for other ecosystems. These nonlinear changes are sometimes abrupt; they can also be large in magnitude and difficult, expensive, or impossible to reverse. Capabilities for predicting some nonlinear changes are improving, but for most ecosystems and for most potential nonlinear changes, science cannot predict the thresholds at which the change will be encountered (C6.2, S13.4). As an example, once a threshold of nutrient loading is achieved, changes in freshwater and coastal ecosystems can be abrupt and extensive, creating harmful algal blooms (including blooms of toxic species) and sometimes leading to the formation of oxygen-depleted zones, killing all animal life (S13.4).

The increased likelihood of these nonlinear changes stems from the loss of biodiversity and growing pressures from multiple direct drivers of ecosystem change. The loss of species and genetic diversity decreases the resilience of ecosystems, which is their ability to maintain particular ecosystem services as conditions change. In addition, growing pressures from drivers such as overharvesting, climate change, invasive species, and nutrient loading push ecosystems toward thresholds that they might otherwise not encounter. Once an ecosystem has undergone a nonlinear change, recovery to the original state may take decades or centuries and may sometimes be impossible.

Wetland-dependent Species

While habitat loss is the primary cause of extinction of freshwater species, the introduction of non-native invasive species is the second most important cause of decline (C20.4.3). Worldwide, two thirds of the freshwater species introduced into the tropics and more than 50% of those introduced to temperate regions have established self-sustaining populations. The spread of invasive alien species is a global phenomenon that is increasing with the spread of aquaculture, shipping, and global commerce; examples include the pan-tropical weeds salvinia and water hyacinth that originated in South America but that are now widely distributed across the tropics. The cane toad, bull frog, European domestic pig, carp, and zebra mussel are examples of animals that have become established outside of their native range and have disrupted the inland water systems they invaded.

Modifications to water regimes have drastically affected the migration patterns of birds and fish and the composition of riparian zones, opened up access to invasive alien species, and contributed to an overall loss of freshwater biodiversity and inland fishery resources (C20.4.2). In many instances, the construction of reservoirs has resulted in the disappearance of fish species adapted to river systems and the proliferation of species adapted to lakes, many of which were non-native. Indirect impacts of flow alteration, such as the reduction of floods and loss of lateral connections on floodplains, are also important. Examples include the decline of the sturgeon and the caviar industry in rivers such as the Volga (Russia) and the sharp decline of Mormyridae (an elephant-nosed fish family of Osteoglossiformes) in Lakes Kainji and Volta (both in West Africa), after the inundation of their preferred habitats as a result of dams. In tropical Asia, change in flooding patterns due to river modification has affected riverine and wetland-dependent mammal populations, such as the marshland deer and the Asian rhino in Thailand, India, and China, and diadromous fish stocks, such as the sturgeon in China; similar cases have been reported for North and South America.

Habitat loss and degradation are by far the greatest threat to amphibians at present, affecting over 70% of species, but newly recognized fungal diseases are seriously affecting an increasing number of species (*medium certainty*) (C20.3.2). Almost four times as many wetland-dependent amphibian species are affected by habitat loss and degradation as by the next most common threat, pollution. Although disease appears to be a relatively less significant threat for amphibians, newly recognized fungal diseases are affecting an increasing number of species; for those affected, disease can cause sudden and dramatic population declines, resulting in very rapid extinction. In comparison, although habitat loss and degradation affect a much greater number of species, the rate at which a species declines is usually much slower. Perhaps most disturbing is that many species are declining for unknown reasons, complicating efforts to design and implement effective conservation strategies.

Land use change and habitat loss, along with the deterioration and degradation of both breeding and nonbreeding wetland habitats, are widely recognized as being the major causes of the widespread pattern of declining waterbird populations and species (*high certainty*) (C19.2.2, C20.4). In several regions, agricultural intensification, sometimes coupled with increasing severity and duration of droughts, seems to be the major driver. For migrant waterbirds such as shorebirds (waders), and especially those that are long-distance Arctic-breeding migrants, deterioration of critically important coastal spring staging areas (such as the international Wadden Sea, the Delaware Bay in the United States, and the Yellow River Delta in China) are strongly implicated in population declines. Maintaining the ecological character of such staging areas is increasingly recognized as vital for survival of Arctic-breeding species, yet many such coastal areas remain under threat.

Human-related impacts—particularly habitat destruction, direct harvest of adults and eggs, international trade, bycatch, and pollution—are seriously threatening the survival of marine turtles (C19.2.2). Green turtle populations are particularly at risk in the Indo-Pacific, primarily due to high levels of directed take of adults, juveniles, and eggs. Leatherback turtle populations are especially at risk in the Eastern Pacific; conservative estimates are that long-line and gill-net fisheries were responsible for the mortality of at least 1,500 female leatherbacks per year in the Pacific during the 1990s. In many parts of the world, however, direct harvest—as occurs for the hawksbill—and incidental capture of marine turtles in inshore fisheries represent a greater source of mortality than bycatch in longline fisheries. In addition to mortalities experienced at sea, habitat loss and destruction of nesting beaches and important foraging grounds have contributed to marine turtle population declines. Pollution has also been linked to increased incidence of fibropapilloma disease, which kills hundreds of turtles annually.

The effects of climate change on wetland taxa are generally considered to be additive to the impacts of direct drivers such as habitat degradation (*medium certainty*) (C19.2.2). Changes in nonbreeding distribution of coastal wintering shorebirds in Western Europe have been attributed to rising mid-winter temperatures. Seabird breeding failures in the North Sea in 2004 have been linked to a northward shift in plankton distribution driven by rising sea temperatures. The climate has warmed more quickly in portions of the Arctic (particularly in the western North American Arctic and central Siberia) and Antarctic (especially the Antarctic peninsular) than in any other region on Earth.

As a consequence of regional warming, ecosystem services and human well-being in polar regions have already been substantially affected (*high certainty*) (C25). Warming-induced thaw of permafrost is widespread in Arctic wetlands, causing threshold changes in ecosystem services, including subsistence resources and climate feedbacks (energy and trace gas fluxes), and support for industrial and residential infrastructure. Changes in polar biodiversity are affecting the resources on which Arctic people depend for their livelihoods. Important changes include increased shrub dominance in Arctic wetlands, which contributes to summer warming trends and alters forage available to caribou; changes in insect abundance that alter food availability to wetland birds; increased abundance of snow geese that are degrading Arctic wetlands; and overgrazing by domestic reindeer in parts of Fennoscandia and Russia. For waterbirds, it is projected that reduction in areas of Arctic tundra breeding habitat will contribute to population declines in high-Arctic breeding species (C19.2.2).

Economic Drivers of Loss and Change

Economic-based information deficiencies, market distortions, and perverse subsidies contribute to the loss of many wetlands. Broader and interrelated economic drivers of change are crucial considerations when assessing responses to direct drivers of change at both site-based and regional scales. (See Box 4.2.)

Box 4.2. Information Deficiencies, Distortions, and Perverse Subsidies (C20.4)

There are a number of broad and interrelated economic reasons why wetlands and other ecosystems continue to be lost and degraded even though benefits gained from maintaining them often are greater than the benefits associated with their conversion.

- In some cases, the benefits of conversion exceed that of the maintenance of the wetland, such as in prime agricultural areas or on the borders of growing urban areas. As more and more wetlands are lost, however, the relative value of the conservation of the remaining wetlands increases and these situations should become increasingly rare.
- The individuals who benefit most from the conservation of wetlands are often local residents, and these individuals have often been disenfranchised from decision-making processes. Decisions concerning wetlands are often made through processes that are unsympathetic to local needs or that lack transparency and accountability.
- There is a lack of awareness of the connection between ecosystem services provided by natural systems and the impacts on humans. As a system degrades, so do the ecosystem services on which humans depend. While not widely evaluated or recognized or used in decision-making, it has been shown that even when only a few ecosystem services are considered, their loss upon conversion often outweighs any gains in marketed benefits. Although this is an understandable reflection of substantial technical difficulties in undertaking some evaluations, future work needs to focus on comparing delivery of multiple services across a range of competing land uses if it is to better inform policy decisions. Decision-making, however, is not independent of existing governance structure.
- Many services delivered by wetlands are not marketed (such as flood mitigation, climate regulation, groundwater recharge, and prevention of erosion) and accrue to society at large at local and global scales. More degradation of these "public goods" takes place than is in society's interests because no one person has an incentive to pay to maintain the service, and when an action results in the degradation of a service that harms other individuals, no market mechanism exists (nor, in many cases, could it exist) to ensure that the individuals harmed are compensated for the damages they suffer. Hence, conserving relatively intact habitats will often require compensatory mechanisms to mitigate the impact of private, local benefits foregone, especially in developing countries. The development of market instruments that capture at a private level the social and global values of relatively undisturbed ecosystems—for example, through carbon or biodiversity credits or through premium pricing for sustainably harvested wild-caught fish or timber—is a crucial step toward sustainability.
- Finally, the private benefits of conversion are often exaggerated by perverse subsidies. The drainage of wetlands for agriculture in Canada, as for many other wetlands across the United States and Europe, has been driven by private benefits arising from government tax incentives and subsidies. While over the short term these programs may be rational with respect to public or private policy objectives, over the longer term many result in both economic inefficiency and the erosion of natural services. Globally, the subset of subsidies that are both economically and ecologically perverse totals between $950 billion and $1,950 billion each year (depending on whether the hidden subsidies of external costs are also factored in). Identifying and then working to remove these distortions would simultaneously reduce rates of habitat loss, free up public funds for investing in sustainable resource use, and save money.

5. *Human Well-being*

The loss and degradation of wetland ecosystem services harms the health and well-being of individuals and local communities and diminishes development prospects for all nations (C19.6, C20.6). The services provided by wetlands are vital for human well-being and poverty alleviation. The sustainable use and, where necessary, restoration of wetland ecosystem services can often help people meet basic needs for water, food, shelter, and good health. This is particularly true in dryland regions. (See Box 5.1.) As the human population has grown and urbanization has increased, more and more people rely on wetland services such as clean water or fisheries being delivered to them from some distance away though trade networks or the development of infrastructure for water transport. In both rural and urban areas, the poor are likely to suffer most when the availability and quality of water and food are reduced, whether due to failures in infrastructure and trade networks or to the demise of wetlands.

Degradation and loss have reduced the capacity of wetlands to provide sufficient amounts and quality of water (C7.3, C7.4, C19.2, C20.4). It is well established that maintenance of an adequate flow of good-quality water is needed to maintain the health of inland water systems, as well as estuaries and deltas. The reverse is also true: healthy inland water systems generate and maintain adequate flows of good-quality water (C20.6). Water engineering to facilitate use by humans has fragmented aquatic habitats, interfered with migration patterns of economically important fisheries, polluted receiving waters, and interfered with the capacity of inland water ecosystems to provide reliable, high-quality sources of water (C7.3). The degradation of inland water systems reduces the potential of these systems to mitigate the effects of pollutants through detoxification and waste processing and results in an overall reduction in human well-being (C20.6).

The provision of ecosystem services by coastal systems can be highly dependent on the condition of coastal freshwater wetlands (C19.2.1). Water quality in river systems plays a crucial role in the sustainability of coastal aquatic habitats, food webs, and commercial fisheries that serve as a major protein source for humans. The decline of traditional fisheries (due to commercial exploitation of coastal fisheries and damage to inland water ecosystems due to water extraction and diversion) can have severe negative nutritional consequences for poor artisanal fishers (C8.5, C19.2.3). Water quality degradation is usually most severe in areas where water is scarce, such as arid, semiarid, and dry subhumid regions, due to the reduced capacity for waste dilution (C20.4).

Inland Wetlands

The loss and degradation of inland waters and floodplains has reduced their natural ability to buffer or ameliorate the impacts of floods; this threatens the security of individuals and entire communities (C6.5.2, C16.4.2, C20.4.2, C20.6). Forested riparian wetlands adjacent to the Mississippi River in the United

Box 5.1. Wetlands in Drylands: Impact of Changes in Wetland Services on Human Well-being (Derived from C22.5.2)

Wetlands such as marshes and rivers that are found in drylands are particularly important for well-being due to the scarcity of water in these regions. The supply of water from these wetlands is essential for food production. Other key services delivered by wetlands in drylands include:

- nutrient cycling and primary production of water bodies;
- soil formation away from wetlands;
- provision of aquatic animals and plants as food;
- drinking water for people and for livestock using terrestrial forage;
- wild food plants and cultivated crops produced by lands surrounding water bodies and often affected by seasonal water receding and flooding;
- provision of fuelwood from the highly productive wetland edges;
- biochemicals from both aquatic and terrestrial species;
- climate regulation through evaporative cooling;
- water purification, especially by marshes;
- support of biodiversity, including species that spend most of the time away from the dryland wetlands but for which these wetlands are critical for their survival, such as migratory birds; and
- cultural services—recreational, spiritual, and religious.

The large-scale appropriation of river, lake, and marsh water for dryland irrigation by diversion canals and dams along with marsh reclamation for dryland agricultural development, directly expressed in wetland shrinkage, leads to the degradation or loss of most of the services provided by wetlands in drylands. It also diminishes services provided by other ecosystems, since dams and reduced river flow diminish sediment load and decrease nutrient output to downstream water bodies.

States had the capacity to store about 60 days of river discharge. With the removal of the wetlands through canalization, construction of levees, and draining, the remaining wetlands have a storage capacity of less than 12 days discharge—an 80% reduction in flood storage capacity. The extensive loss of these wetlands was an important factor contributing to the severity and damage of the 1993 flood in the Mississippi Basin (C16.1.1). The majority of large floods have occurred in Asia during the last few decades, but few countries have been free of damaging floods (C16.2.2). In Bangladesh, the inundation of more than half of the country is not uncommon—about two thirds of the country was inundated in the 1998 flood. The floods in Central Europe in August 2002 caused damage totaling nearly 15 billion euros. Floods (and droughts) typically affect the poorest people most severely, as they often live in vulnerable areas and have few financial resources for avoidance, mitigation, or adaptation (C20.6).

Coastal Wetlands

Resource overexploitation and coastal degradation have undermined subsistence use of coastal ecosystems, harming local communities as well as national economies (C19.6). For instance, the net economic benefit from coral reefs—including fisheries, coastal protection, tourism, and biodiversity values, which are currently worth some $30 billion annually—will be diminished from ever-accelerating coastal degradation. Many coastal communities, especially in poorer developing countries, are trapped in a vicious cycle of poverty, resource depletion, and further impoverishment. This phenomenon is not unique to communities dependent on coral reefs, but it is noteworthy that once coral reefs are destroyed, restoration is extremely difficult, and costs brought about by loss of services such as coastal protection continue to be incurred for long periods.

Even when people are made aware of the importance of coastal ecosystems, they still may not be able to stop the kinds of activities that destroy or degrade these areas unless alternative resources or livelihoods are made available to them (C19.6). For instance, boat builders of the coastal and island communities of East Africa have little choice but to remove mangrove from key nursery habitats, which actually support the very fisheries on which their boat-building industry is based. Few alternative materials for boats exist except when conservation projects have expressly built in alternatives and training on how to use them. In areas in which resource extraction is moving beyond ecologically sustainable limits or in which the removal of the resource causes major physical changes to the habitat, the search for alternatives is particularly crucial.

Wetlands and Human Health

The continued degradation of wetlands, and more specifically the continued decline in water quantity and quality, will result in further impoverishment of human health (*high certainty*), especially for vulnerable people in developing countries, where technological fixes and alternatives are not as readily available (C7, C20.6, R16). The burden of disease from inadequate water, sanitation, and hygiene totals 1.7 million deaths and results in the loss of at least 54 million healthy life years annually. Some 1.1 billion people lack access to clean drinking water, and more than 2.6 billion lack access to sanitation (C7.ES). Globally, the economic cost of the pollution of coastal waters is estimated to be $16 billion annually, mainly due to human health impacts (C19.3.1).

Although largely eliminated in wealthier nations, water-related diseases are among the most common causes of illness and death, affecting mainly the poor in developing countries (C20.6). Human health is closely linked to safe drinking water and sanitation; degraded and polluted inland waters are very likely to lead to human illness and death (C7.4.5, C20.6). Water-related diseases that are exacerbated by the degradation of inland waters include those caused by the ingestion of water contaminated by human or animal feces or urine containing pathogenic bacteria or viruses, including cholera, typhoid, amoebic and bacillary dysentery, and other diarrheal diseases; diseases passed on by intermediate hosts such as aquatic snails or insects that breed in aquatic ecosystems, including dracunculiasis, schistosomiasis, and other helminthes, as well as dengue, filariasis, malaria, onchocerciasis, trypanosomiasis, and yellow fever; and diseases that occur when there is insufficient clean water for washing and basic hygiene or when there is contact with contaminated water, including scabies, trachoma, typhus and flea, and lice and tick-borne diseases.

Large dam construction has been associated with outbreaks of several different diseases (C14.2.1, C14 Box 14.1), and small dams are likely to have an equal or greater impact on human health because there is usually a high degree of water contact with people and animals. Intense transmission of diseases such as schistosomiasis, onchocerciasis, malaria, lymphatic filariasis, and dracunculosis is associated with small dams in many African countries, including Cameroon, Kenya, Ghana, Mali, Rwanda, and Zambia (C14.2.1). Tropical rice irrigation systems have also been linked to vector-borne diseases such as malaria and Japanese encephalitis.

Some waterborne pollutants (chemical and microbiological) have a major effect on human health; some chemical pollutants accumulate in the food chain to the point where they harm people (C20.6). Many countries now experience problems with elevated levels of nitrates in groundwater from the large-scale use of organic and inorganic fertilizers. Excess nitrate in drinking water has been linked to methemoglobin anemia in infants, the so-called blue baby syndrome. Arsenicosis, the effect of arsenic

poisoning when drinking arsenic-rich water over a long period, is also known and is a particularly severe problem in Bangladesh and Western Bengal, where some 35–77 million inhabitants are exposed to excessively high levels in water drawn from wells. On the whole, though, it is still difficult to quantify the cumulative effects of long-term exposure to a variety of chemicals.

Pollution puts coastal inhabitants at great risk—directly by affecting human health and indirectly by degrading the resource base on which many people depend. Poor sanitation affects not only slum dwellers but others as well (C19.6). South Asian waters are highly polluted, partly as a result of the 825 million people who lack basic sanitation services. Pathogens are spread more quickly and reach greater numbers of people in coastal ecosystems that have become degraded (C14.2.1). Chronic exposure to heavy metals and other bioaccumulating pollutants may not cause death in large numbers of people, but the cumulative effect can lead to reproductive failure and significantly decreased well-being. Food security is also greatly compromised in degraded coastal ecosystems. In addition, evidence exists from wildlife studies that humans are at risk from a number of chemicals that mimic or block the natural functioning of hormones, interfering with natural body processes, including normal sexual development (C20.5.6).

While preservation of ecosystems can sometimes prevent the emergence or spread of disease, trade-offs do sometimes exist between the maintenance of undisturbed ecosystems and risks of human disease (C14.1.3). Malaria control efforts, for example, which relied heavily on the insecticide DDT and the draining of marshes, caused enormous damage to wetland and other ecosystems but did often reduce the prevalence of the disease. Such trade-offs also have an important temporal aspect. For example, draining wetlands can reduce mosquito breeding sites for immediate benefit, but the wetland services of filtering water, detoxifying wastes, or providing species habitat will be lost.

6. *Scenarios for the Future of Wetlands*

The MA explores the consequences for ecosystem services and human well-being of four plausible futures to the year 2050. These scenarios, developed by the MA Scenarios Working Group, are used to explore a range of contexts under which sustainable development could be pursued, as well as a wide range of approaches in support of sustainable development or, in the context of the Ramsar Convention, the wise use of wetlands (S8).

Scenarios are plausible and relevant stories about how the future might unfold. They are not forecasts, projections, predictions, or recommendations. Rather, they are designed to explore the implications of different plausible changes in driving forces based on current knowledge of underlying socioecological processes (S2).

The four scenarios developed by the MA are *Global Orchestration, Order from Strength, Adapting Mosaic,* and *TechnoGarden* (S8.1). (See Box 6.1.) Statements of certainty associated with findings related to the MA scenarios are conditional statements; they refer to levels of certainty or uncertainty in the particular projection should that scenario and its associated changes in drivers unfold. They do not indicate the likelihood that any particular scenario and its associated projection will come to pass.

Box 6.1. The MA Scenarios (based on S.SDM Box S1 and Figure S1)

The MA developed four scenarios to explore plausible futures for ecosystems and human wellbeing:

Global Orchestration: This scenario depicts a globally connected society that focuses on global trade and economic liberalization and takes a reactive approach to ecosystem problems but that also takes strong steps to reduce poverty and inequality and to invest in public goods such as infrastructure and education. Economic growth in this scenario is the highest of the four scenarios, while it is assumed to have the lowest population in 2050.

Order from Strength: This scenario represents a regionalized and fragmented world concerned with security and protection, emphasizing primarily regional markets, paying little attention to public goods, and taking a reactive approach to ecosystem problems. Economic growth rates are the lowest of the scenarios (particularly low in developing countries) and decrease with time, while population growth is the highest.

Adapting Mosaic: In this scenario, regional watershed-scale ecosystems are the focus of political and economic activity. Local institutions are strengthened and local ecosystem management strategies are common; societies develop a strongly proactive approach to the management of ecosystems. Economic growth rates are somewhat low initially but increase with time, and population in 2050 is nearly as high as in *Order from Strength*.

TechnoGarden: This scenario depicts a globally connected world relying strongly on environmentally sound technology, using highly managed, often engineered, ecosystems to deliver ecosystem services, and taking a proactive approach to the management of ecosystems in an effort to avoid problems. Economic growth is relatively high and accelerates, while population in 2050 is in the mid-range of the scenarios.

Plausible Futures for Wetlands

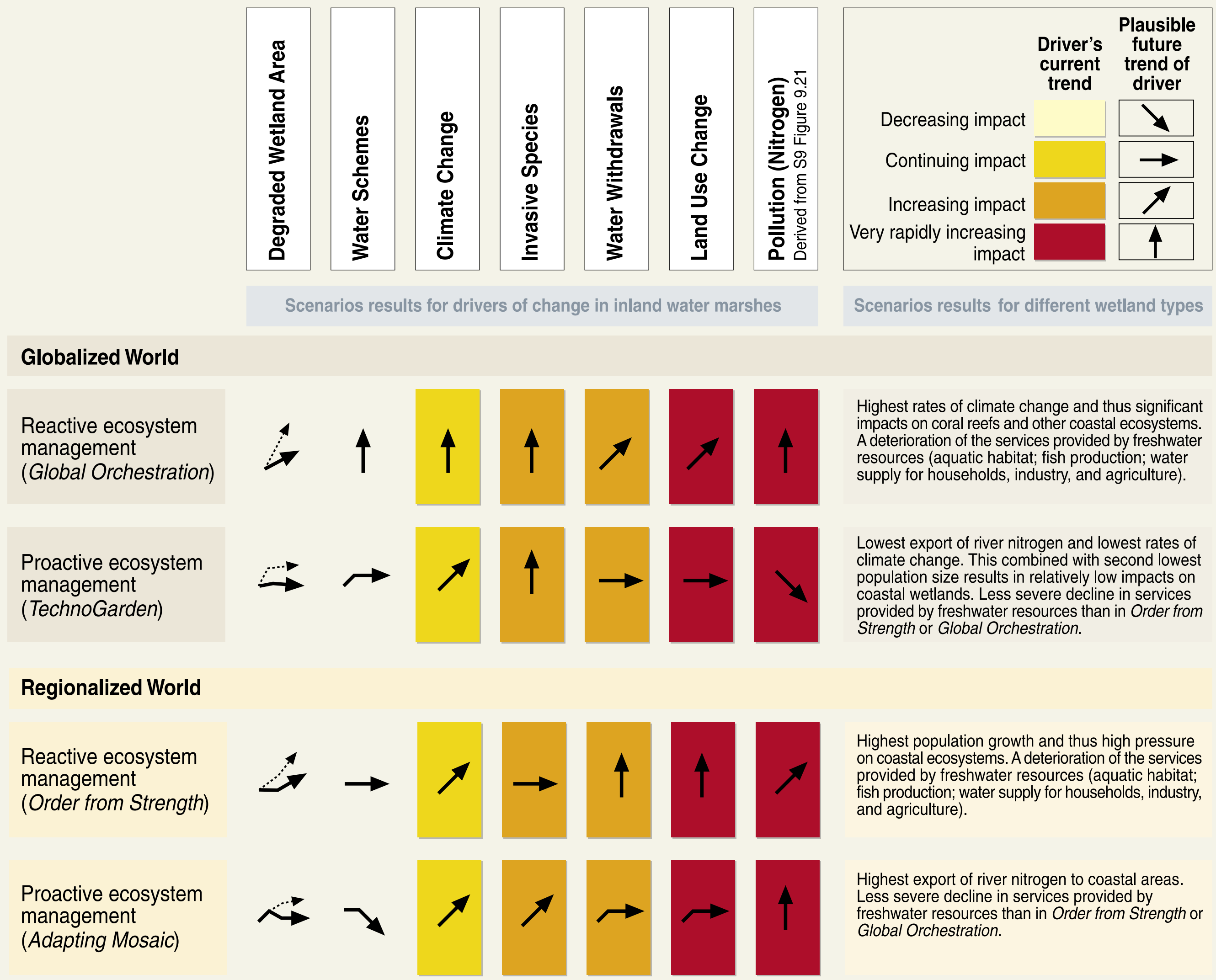
The area of inland water marshes is expected to decrease under the *Global Orchestration* and *Order from Strength* scenarios and to remain relatively unchanged under the *TechnoGarden* and *Adapting Mosaic* scenarios (S14). (See Figure 6.1.) In *Global Orchestration*, wetland area decreases because of the expansion of agricultural land. *Order from Strength* has the largest expansion of agricultural land of the scenarios, which poses the largest risk to the extent and ecological character of wetlands. *Adapting Mosaic* also has a large expansion of agricultural land and population, although not as large as *Order from Strength*, but because of proactive approaches to local water management, wetland loss is mitigated. *TechnoGarden* has the smallest increase in pressure on the environment, with little change in the extent of wetlands. Although population increases substantially in both *Order from Strength* and *Adapting Mosaic*, short-term wetland loss could occur slowly in these two scenarios, for different reasons. If wetlands are more sensitive (the dotted lines in Figure 6.1), population and invasive species have substantially larger impacts. In particular, in *Order from Strength* the conversion of wetlands to other uses, particularly for inefficient production of food, would further accelerate the loss and degradation of inland wetlands.

Toward 2050, however, differences in land use and agricultural technology lead to increasing differences in the trends of loss in inland water marshes. In both *Order from Strength* and *Global Orchestration*, there is a long-term increase of conversion to agricultural land use. For *TechnoGarden* and *Adapting Mosaic*, however, the development of technologies and skills for agroecosystem management could induce restoration of wetlands. Furthermore, toward 2050 climate change begins to have significant impacts on wetlands. Though various scenarios of climate change (S9) do not show a significant change in effective precipitation (the difference between precipitation and evapotranspiration), it is expected that sea level rise leads to loss of coastal wetlands, such as estuaries or tidal flats, and deltas. (See S8 Table 8.10 for a more detailed consideration of the implications for coastal wetlands.) Climate change is most pronounced in *Global Orchestration*, *Order from Strength*, and *Adapting Mosaic*, but is not so strong in *TechnoGarden*, thus permitting the slowing or even reversal of wetland loss in the first 20 years of the century.

The demand for provisioning services, such as food, fiber, and water, strongly increases in all four scenarios, due to expected growth in population and economies and to changing consumption patterns (*medium to high certainty*) (S9.4). This is likely to be the case as much for wetlands as for other ecosystems.

Figure 6.1. Plausible Main Direct Drivers of Change in Wetlands under Different MA Scenarios.
(S8.7.1.2, S8 Fig 8.5, S9)

For "Degraded Wetland Area," solid lines indicate the best case, and dashed lines the worst case, envisaged for each scenario. The cell color indicates the current trend in each driver (trends not available separately for water schemes). For the other cells, the arrows indicate the trend in the driver. Horizontal arrows indicate stabilization of the impact; diagonal and vertical arrows indicate progressively stronger increasing trends in impact. Thus a vertical arrow indicates that the effect of the driver on the degradation of wetlands is currently growing stronger.



Source: Millennium Ecosystem Assessment

Increasing demand for provisioning services leads to further stress on the ecosystems that provide these services (*high certainty*). Demand is dampened somewhat by increasing efficiency in the use of resources.

Vast changes are expected in world freshwater resources and hence in the ecosystem services provided by freshwater systems (S9.4.5). Climate change will lead to increased precipitation over more than half of Earth's surface and this will make more water available to society and ecosystems (*medium certainty*). However, more precipitation is also likely to increase the frequency of flooding in many areas (*high certainty*). Under *Global Orchestration* and *Order from Strength*, massive increases in water withdrawals are expected to lead to an increase in untreated wastewater discharges in developing countries, causing a deterioration of freshwater quality. Climate change leads to both increasing and declining river runoff, depending on the region.

The combination of huge increases in water withdrawals, decreasing water quality, and decreasing runoff in some areas leads to an intensification of water stress over wide areas (S14.2.2). A deterioration of the services provided by freshwater resources—aquatic habitat, fish production, and water supply for households, industry, and agriculture—is expected under the two scenarios that adopt reactive approaches to environmental problems (*Global Orchestration* and *Order from Strength*) (*medium certainty*). A less severe decline is expected under the other two scenarios, which proactively attempt to avoid environmental problems.

Under the MA scenarios, water availability is projected to decrease in 30% of the world's rivers. This is largely the result of climate change and, to a lesser extent, increasing water withdrawals by humans. For the 110 modeled river basins that are drying, the basin-specific percentage of fish species likely to face extinction ranges from about 1% to 60% for 2050 and from 1% to 65% by 2100 (*low certainty*). Rivers that are forecast to lose fish species are concentrated in poor tropical and sub-tropical countries, where the needs for human adaptation are most likely to exceed governmental and societal capacity to cope. The loss of fish diversity is likely to be an underestimate, since many of the rivers and lakes affected also are projected to experience increased temperatures, eutrophication, acidification, and increased invasions by non-native species. In 70% of the world's rivers, water availability will increase. This will raise the potential for production of fishes adapted to higher flow habitats, which would likely be non-indigenous species (*low certainty*) (S10.3.2). No quantitative models exist that allow estimation of any additional consequences of increased discharge on biodiversity.

After 2050, climate change and its impacts (such as sea level rise) have an increasing effect on the provision of ecosystem services (*medium certainty*) (S9.3.4). Under the four MA scenarios, global temperature is projected to increase significantly: 1.5–2.0° Celsius above pre-industrial levels in 2050, and 2.0–3.5° Celsius in 2100, depending on the scenario and using median estimates for climate change sensitivity. Global average precipitation is projected to increase (*medium certainty*), but some areas will become more arid while others will become moister. Climate change will directly alter ecosystem services, for example, by causing changes in the productivity and growing zones of cultivated and noncultivated vegetation. Climate change also alters the frequency of extreme events, with associated risks to ecosystem services. Finally, it will indirectly affect ecosystem services in many ways, such as by causing sea level to rise, which threatens mangroves and other vegetation that now protect shorelines.

Land use change is expected to continue to be a major driver of changes in the provision of ecosystem services up to 2050 (*medium to high certainty*). The *Order from Strength* scenario has the greatest land use changes, with large increases on both crop and grazing areas. The two proactive scenarios—*TechnoGarden* and *Adapting Mosaic*—are the most land-conserving scenarios because of increasingly efficient agricultural production, lower meat consumption, and lower population increases. Existing wetlands and the services they provide (such as water purification) are faced with increasing risk in some areas due to reduced runoff or intensified land use in all scenarios.

Habitat loss in terrestrial ecosystems is projected to lead to a decline in the local diversity of native species and the ecosystem services they provide in all four scenarios *(very certain)* (S10). This is likely to be the case for wetland systems as much as any other systems. Habitat loss will eventually lead to global extinctions as species approach equilibrium with the remnant habitat. Although there is *high certainty* that this will happen eventually, the time to equilibrium is *very uncertain*, especially given continued habitat loss through time. Time lags between habitat reduction and extinction provide an opportunity to deploy aggressive restoration practices that may rescue those species that otherwise may be heading toward extinction.

Excessive nutrient loading is expected to become a growing threat to rivers, lakes, marshes, coastal zones, and coral reefs. Humans now produce more reactive (biologically available) nitrogen than is produced by all natural pathways combined, and some projections suggest that this may increase by roughly a further two thirds by 2050. Three out of four MA scenarios project that the global flux of nitrogen to coastal ecosystems will increase by a further 10–20% by 2030 (*medium certainty*), with almost all of the increase occurring in developing countries.

Trade-offs among Wetland Ecosystem Services

In all four MA scenarios, actions taken to increase the supply of provisioning ecosystem services such as food and water result in reductions in the supply of supporting, regulating, and cultural services (S12). Such trade-offs have far-reaching consequences for maintaining ecosystem functioning in the long term. Scenarios in which long-term consequences of trade-offs are not considered exhibit the largest risk of declines in supporting and regulating services (such as climate change and biodiversity loss). Those in which a proactive approach to ecosystem management is taken via flexible ecosystem governance mechanisms and learning or technological innovations are more likely to sustain ecosystem services in the future.

Major policy decisions in the next 50–100 years will have to address many trade-offs between agricultural production and water quality, land use and biodiversity, water use and aquatic biodiversity, and current water use for irrigation and future agricultural production—indeed, between all current and future uses of nonrenewable wetland resources (S12). These trade-offs appear consistently throughout all four scenarios. In 2050, the trade-offs among wetland services are projected to be more intense than at present. Strong inverse relationships exist between food and water and between food and biodiversity (both terrestrial, through land conversion, and aquatic, through flow reduction and pollution). Use of fertilizers to improve agricultural production leads to eutrophication of fresh water and estuaries and to declines in services (such as food, recreation, fresh water, and biodiversity) provided by lakes and estuaries. There are substantial possibilities for mitigating these trade-offs through developments in agricultural technology, integrated agroecological systems, agricultural research and training, and market reforms. There are possibilities for mitigating trade-offs through land management that is more biodiversity-friendly and through integrated water management.

Some of the most important changes in wetland services that may occur in the future will result from large ecological changes that are difficult or impossible to predict and that may be difficult, impossible, or expensive to reverse. Slow losses of resilience in an ecosystem can set the stage for large or abrupt changes that may occur after a threshold is reached or after an ecosystem is subjected to a random event such as a climate fluctuation (*established but incomplete*) (S3, S5). For example, the incremental buildup of phosphorus in soils gradually increases the vulnerability of lakes and reservoirs to runoff events that trigger oxygen depletion, toxic algae blooms, and fish kills. Cumulative effects of overfishing and nutrient runoff make coral reefs susceptible to severe deterioration triggered by storms, invasive species, or disease. The prospect of large unexpected shifts can be addressed by policies that hedge (for instance, by diversifying the services used in a particular region), choosing reversible actions, monitoring to detect impending changes in ecosystems, and adjusting flexibly as new knowledge of ecosystem change becomes available.

Implications of the Scenarios for Action (S14.ES)

Each scenario yields a different package of gains, losses, and vulnerabilities to components of human well-being in different regions and populations (S.SDM). Actions that focus on improving the lives of the poor by reducing barriers to international flows of goods, services, and capital tend to lead to the most improvement in health and social relations for the currently most disadvantaged people. But human vulnerability to ecological surprises is high. Globally integrated approaches that focus on technology and property rights for ecosystem services generally improve human well-being in terms of health, security, social relations, and material needs. If the same technologies are used globally, however, local culture can be lost or undervalued. High levels of trade lead to more rapid spread of emergent diseases, somewhat reducing the gains in health in all areas. Locally focused, learning-based approaches lead to the largest improvements in social relations.

Proactive or anticipatory management of ecosystems is generally advantageous in the MA scenarios, but it is particularly beneficial under conditions of changing or novel conditions (S.SDM). Ecological surprises are inevitable because of the complexity of the interactions and because of limitations in current understanding of the dynamic properties of ecosystems. Currently well understood phenomena that were surprises of the past century include the ability of pests to evolve resistance to biocides, the contribution to desertification of certain types of land use, biomagnification of toxins, and the increase in vulnerability of ecosystems to eutrophication and unwanted species due to removal of predators. While we do not know which surprises lie ahead in the next 50 years, we can be certain that there will be some. In general, proactive action to manage systems sustainably and to build resilience into systems will be advantageous, particularly when conditions are changing rapidly, when surprise events are likely, or when uncertainty is high. This approach is beneficial largely because the restoration of ecosystems or ecosystem services following their degradation or collapse is generally more costly and time-consuming than preventing degradation, if that is possible at all.

Prospects for the Ramsar Convention across the Scenarios

Under all four MA scenarios, the relevance of the Ramsar Convention is clear as pressures on wetlands and water resources increase. However, two basic contrasts explored in the MA scenarios—global versus regional worlds and proactive versus anticipatory environmental management—have somewhat different implications for the future role of the Convention.

The nature and magnitude of future stress on wetlands and the prospects for helping protect them under the Ramsar Convention are diverse across the scenarios: some stresses are stronger in the globalization scenarios; others are stronger in the regional fragmentation scenarios. Approaches focused on learning about ecosystems could lead to high success in wetland protection, especially if the international cooperation frameworks can shift their focus to regional managers and can act as an information gathering and networking base for local management projects (S14.ES). Most existing international protection mechanisms are designed for success in globally connected worlds and might need to be reformed in response to weakened global institutions in locally oriented development paths. Greater pressure for agricultural land and massive increases in water withdrawals pose larger threats of wetland drainage and conversion in the regionally fragmented scenarios (*Adapting Mosaic* and *Order from Strength*) than do the significant but smaller land and water stresses in the high-growth globalized worlds.

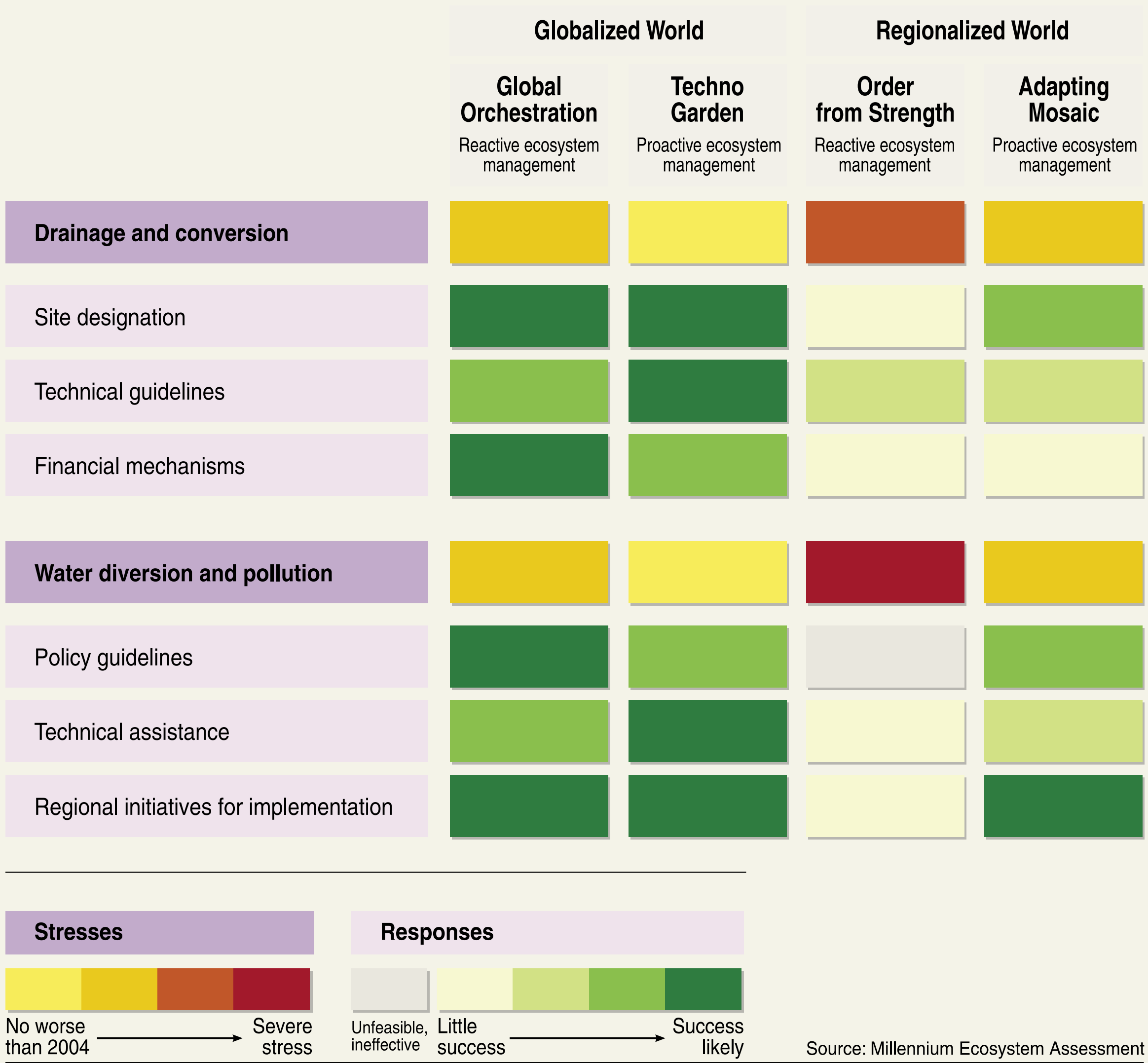
The motivation for and the perceived benefits of including wetlands in the List of Wetlands of International Importance are greater in a future in which countries have a rich web of economic, cultural, and environmental linkages, such as the *Adapting Mosaic* scenario (S14.3.3). Strongly connected, policy-oriented scenarios such as *Global Orchestration* may provide benefits of improved coordination for traditional international agreements among nations. However, the reactive approach to management of the *Global Orchestration* scenario lowers the ability of conventions to truly protect wetlands because of lower interest in ecosystem function and management. In a dynamic, innovation-oriented future (such as exists in *TechnoGarden*), the Ramsar Convention might usefully emphasize technical assistance projects, whereas a free-market- and trade-oriented world such as *Global Orchestration* is more likely to encourage the use of financial mechanisms and economic instruments.

While the increase in pressure on inland water marshes is relatively modest in *Adapting Mosaic*, the role of the Ramsar Convention in helping to protect or counterbalance the risks is much different than in the globalization scenarios. (See Figure 6.2.) In regionalized scenarios, Ramsar might be most effective as an information gathering, synthesizing, and networking organization for forging wetland protection agreements among regions. The clear worst case for the effectiveness of the Convention is the *Order from Strength* world, in which the multiple severe threats to wetlands—high population growth, slow technological development, and negligence of the environment—are combined with weakened global institutions.

Funding to support regional initiatives for implementation through the Ramsar Convention is more likely in the futures in which countries are interconnected (S14.3.3). Communication, education, and public awareness are more likely to be able to contribute to wetland conservation in the environmentally oriented scenarios (*TechnoGarden* and *Adapting Mosaic)*, although *Global Orchestration* also offers good chances. In the globalization scenarios, the high level of affluence and the increasing leisure time of people are likely to give an unprecedented rise to ecotourism, and this in itself could provide a very strong economic motivation to pursue the wise use of wetlands. Ecotourism also supports the value of listing wetlands of international importance as an implementation mechanism, because a listed wetland could be an obvious source for guidebooks and tourism operators in selecting destinations.

The more decentralized scenarios, while putting less weight on global actions, may result in existing treaties carrying a greater burden than at present (S14). In *Order from Strength* and *Adapting Mosaic*, the constraints, opportunities, and trends that continue to be relevant at global level may find their main expression through a few international cooperation frameworks such as Ramsar even though the emphasis of sociopolitical systems is more regional. Those responsible for implementing the

Figure 6.2. Summary of Key Stresses and Prospects for Success of Responses under the Four MA Scenarios for Contracting Parties to the Ramsar Convention (S14.3.3)



convention may need to find innovative methods, including exchanging experience, defining baselines for monitoring overall change, and advising on best practicable legal standards.

The mix of actors responsible for implementing agreements such as the Ramsar Convention differs among the scenarios (S14). In *TechnoGarden*, there is a greater role for the private sector. In *Adapting Mosaic*, a greater role develops for NGOs, civil society, and the local private sector. By 2050, there may also be a large role for international or global groups that work to coordinate the knowledge of local and regional management groups. In both these scenarios, implementation becomes to a greater degree a matter of public-private partnership. However, one consequence is that the challenge of assessing performance and effectiveness of the treaty, accounting for and correcting deficiencies, becomes more complex.

7. *Responses for the Wise Use of Wetlands*

By responses we mean the range of human actions, including policies, strategies, and interventions, to address specific issues, needs, opportunities, or problems (RWG). In the context of ecosystem management, responses may involve governance, institutional, legal, technical, economic, or behavioral changes and may operate at local or micro, regional, national, or international level (or a combination of these) and at various time scales.

Strategic Objectives for Responses

A priority when making decisions that directly or indirectly influence wetlands is to ensure that the decisions are informed by consideration of the full range of benefits and values provided by different wetland ecosystem services. Historically, decisions concerning wetland management have favored either wetland conversion or management for a single ecosystem service such as water supply or food production. As wetlands become scarcer and as we understand the benefits provided by the entire array of ecosystem services, the best options will increasingly involve managing wetlands for a broad array of services. This in turn requires the maintenance of the wetland ecological character—the ecosystem components and processes that underpin the delivery of ecosystem services—which is the goal of the "wise use of wetlands and their resources" advocated by the Ramsar Convention (C20.5). The close match between the Ramsar wise use objective and the MA conceptual framework, in the context of response options, is illustrated by the role played by the "Wise Use Handbook" guidelines in Ramsar's "toolkit" for addressing different components of the framework. (See Box 7.1.)

A key approach for safeguarding the ecological character is to maintain the quantity and quality of the water on which wetlands depend. A variety of methods and tools are available for assessing "environmental flow" requirements and for implementing allocations of water to meet these requirements. In this way, maintenance of the wetland is systematically addressed alongside the allocation of water to meet other objectives, such as irrigation and drinking water supply, with full consideration of the trade-offs involved.

Determining Objectives for Wetland Condition

Stakeholder participation at all stages of planning and development processes, combined with the use of scenarios, can assist decision-making concerning wetlands, particularly when considering the environmental water requirements of wetlands (C20.6, R7.2.3). Historically, many changes in wetland services have been the inadvertent result of decisions taken for other purposes (R7.2). For example, damming a river and diverting water for irrigation prior to the development of our current understanding of the effects of reduced flows on ecosystems downstream was in effect a decision to not supply water to support other services. The trade-offs involved in these decisions were not transparent, given the limited understanding about the impacts of different drivers on wetlands and the limited knowledge of the full range of wetland values.

Explicit decisions about objectives for wetlands management and the desired future condition of a wetland can aid planning and management (R.7.2.1). A number of planning frameworks and tools can be used for this purpose, such as the Downstream Response to Imposed Flow Transformation framework. (See Box 7.2.) This framework differs from others, such as the Instream Flow Incremental Methodology (United States primarily) and Catchment Abstraction Management Strategies (United Kingdom), in its explicit consideration of the socioeconomic implications of different scenarios. Baseline information on the location and condition of wetlands and water resources, through standardized forms of inventory and assessment, is a key part of the platform for setting objectives and implementing responses. While having comprehensive information is desirable, its absence should not be an impediment to taking action. The most effective approach is to seek a balance between available data and expert judgment.

Governance and Institutional Responses

Good governance and institutions, and the political and legal mandates they provide, underpin the successful implementation of all response options (R7.2). Scale issues need to be dealt with in governance and institutional responses in order to deal in the most effective way with the drivers affecting wetlands and water. Strong governance arrangements and institutions favoring ecosystem conservation and sustainable use are required at multiple levels and across different sectors. The success or failure of responses depends greatly on the institutional setting in which the responses are undertaken, and responses are more likely to fail if adequate resources for aspects such as monitoring, evaluation, and enforcement are not provided.

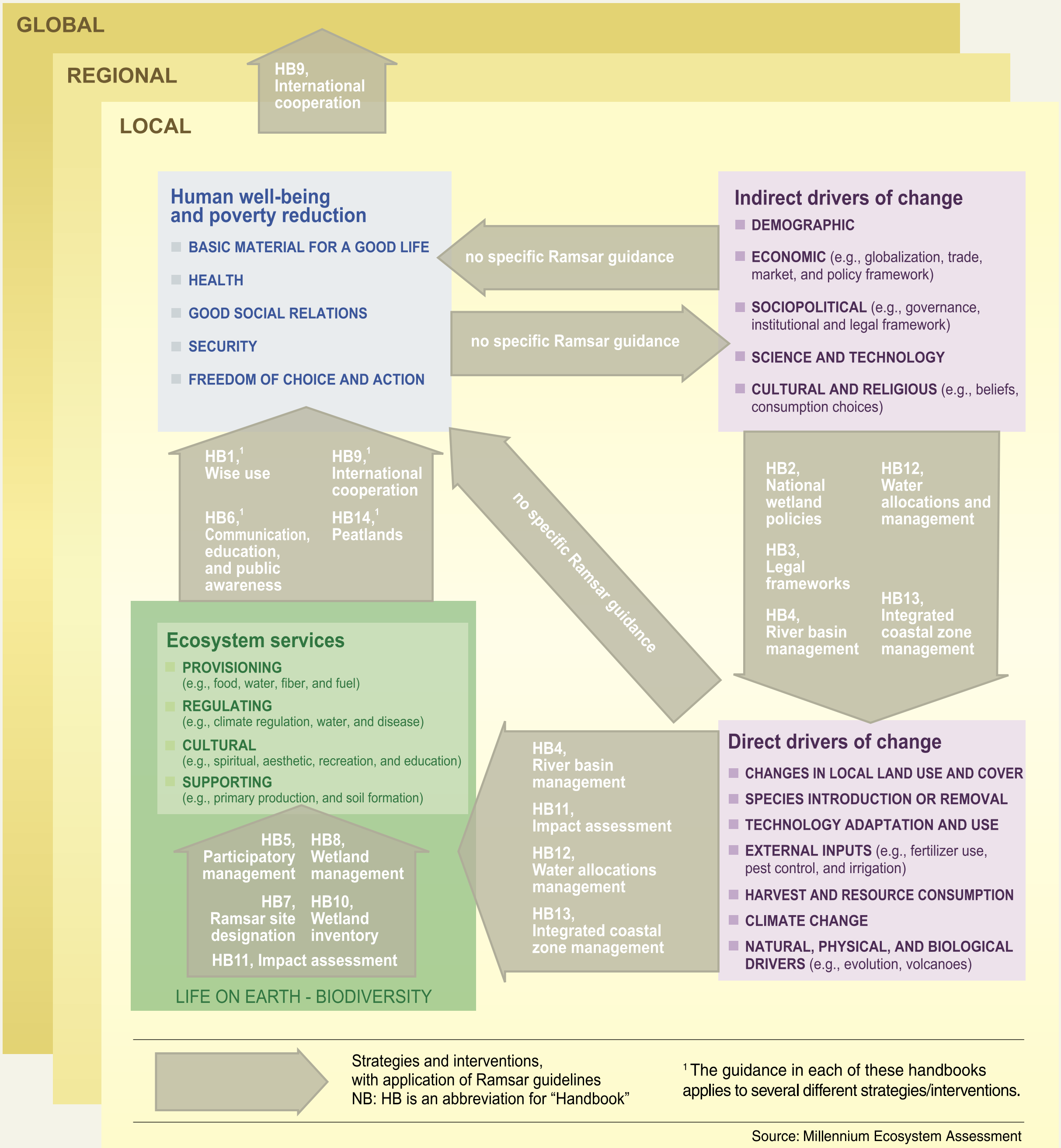
National and international policy and legislation are a primary component of governance and institutions (R7). This has also been emphasized under the Ramsar Convention and supported by specific guidance in the "Wise Use Handbooks" series. The recently adopted Water Framework Directive of the European Union is a pioneering example of a legal framework at the regional level for basin-scale management and other measures.

Recognition of the importance of public participation and equity in decision-making is growing, and national policies are increasingly being used to support stakeholder participation (R7.2.3). The degradation of freshwater and other ecosystem services has generally had a disproportionate impact on sectors of society that are excluded from participation in the decision-making process. Increasing participation at relevant levels supports the concept of subsidiarity—assigning roles and

Box 7.1. The MA's Conceptual Framework and the Ramsar Wise Use Concept (C20.6)

The MA conceptual framework for ecosystems and human well-being provides a valuable framework for delivery of the Ramsar Convention's concept of the "wise use of all wetlands." In the MA construct, "wise use" equates to the maintenance and delivery of ecosystem services to human well-being and poverty reduction through maintenance of the ecological character of wetlands.

The Figure illustrates where interventions using each of the Ramsar Wise Use Handbooks can be applied in the MA conceptual framework. Many of the current Ramsar guidelines concern interventions that apply directly to ecosystems and their processes. Others—such as those concerning river basin management, water allocations and management for maintaining wetland ecosystem functions, and impact assessment—form interventions addressing aspects of the direct drivers of change to ecosystems. Only two sets of Ramsar guidelines—on national wetland policies and on reviewing legislative and institutional frameworks—deal wholly with indirect drivers of change. Some guidelines—such as those on international cooperation, on global action for peatlands, on communications, education, and public awareness, and on the Convention's original "wise use" guidelines—include strategies and interventions that apply to several parts of the MA conceptual framework. The Figure also demonstrates that there are only a small number of levels in the framework for which Ramsar Wise Use Handbooks do not provide at least some guidance.



Source: Millennium Ecosystem Assessment

Box 7.2. The DRIFT Framework (R7.2)

The Downstream Response to Imposed Flow Transformation framework is an interactive and holistic approach for advising on environmental flows for rivers targeted for water-management activities. It uses experienced scientists from a range of biophysical disciplines, and where there are subsistence users of the river, it engages a number of socioeconomic disciplines. It produces a set of flow-related scenarios that describe a modified flow regime, the resulting condition of the river or species, the effect on water resource availability for off-stream users, and the social and economic costs and benefits. The process involves one or more multidisciplinary workshops attended by a range of affected stakeholders to develop agreed biophysical and socioeconomic scenarios.

The development of scenarios requires an assessment of biophysical, social, and economic data and may draw on results from other predictive models that assess the responses of specific biota to flow (such as the Physical Habitat Simulation Model). DRIFT should run in parallel with two other exercises: a macroeconomic assessment of the wider implications of each scenario and a Public Participation Process whereby people other than subsistence users can contribute to finding the best solution.

responsibilities at the management level closest to where they will have effect. Participation allows for a better understanding of the impacts of responses, the distribution of costs and benefits associated with trade-offs, and the identification of a broader range of response options. To be effective, however, this depends on access to policy-making and decision-making processes and on transparency, information, and awareness. These in turn facilitate accountability, due redress and access to justice, and overall better confidence that the system is serving the public interest as a whole.

The effective management of inland wetlands and water resources will require improved arrangements for river (or lake or aquifer) basin–scale management and integrated coastal zone management. The effective management of wetlands and water resources requires not only intersectoral coordination but also coordination across different jurisdictions. Actions taken upstream or upcurrent can have profound impacts on wetland resources downstream or down current. This in turn requires the use of integrated river basin or coastal zone management (C20.6, R15.5.3, R15.5.4). These integrated regional approaches to water resources management are recognized also as key strategy to contribute to the objectives of poverty alleviation. To date, however, few efforts at implementing IRBM have actually succeeded in achieving social, economic, and environmental objectives simultaneously (R15.5.4). (See Box 7.3.) One of the key lessons emerging from ICZM experiences is that more integration per se does not guarantee better outcomes. Adopting an incremental approach—focusing on a few issues initially and then gradually addressing additional ones as capacity increases—is often more feasible and effective. In addition, these approaches can only succeed if appropriate institutional and governance arrangements are in place and, in particular, if the authority and resources of the management mechanism are consistent with their responsibilities.

Over the past 20 years there has been a significant expansion in international agreements, programs, and institutions pertaining to water and drivers of wetland change, such as invasive alien species. These include the multilateral Convention on Biological Diversity, the Ramsar Convention on Wetlands, and the International Convention on the Control and Management of Ships' Ballast Water and Sediments (R7.2). While these have contributed to broader awareness of the drivers of wetland change, especially water-related issues, there is also a general acknowledgement that a wide gap exists between formal policies and actual practices. The effectiveness of multilateral and bilateral environmental agreements varies according to the nature of the environmental problem and several other factors. Factors that support the effective implementation of and compliance with treaties include the political will to implement responses required to meet the objectives of the agreement; a reporting mechanism, preferably at a national level and standardized between Contracting Parties; sufficient human resources to monitor compliance; monitoring by civil society; the availability of financial resources; the establishment of sanctions; and implementation at the national level (R5.2.8).

The Ramsar Convention provides a modest level of assistance for wetland conservation initiatives in developing countries or countries with economies in transition. Most treaties have a reporting system and publish data on parties' follow-up of decisions; these data are often incomplete, however. The Ramsar Convention is an example of an agreement that requires a tangible commitment from parties: the designation of sites as internationally important wetlands based on agreed criteria.

Greater coordination of actions between agreements would result in more-effective implementation (R5.2.8). This has been highlighted in many contexts: in addition, the MA scenarios demonstrate the fundamental interdependence between activities concerning energy, climate change, biodiversity, wetlands, desertification, food, agriculture, health, trade, and economy and consequently the need for relevant international agreements to work together. The Ramsar Convention has been successful in achieving this, with formal cooperation arrangements in operation with, among others, the World Heritage Convention, the Convention on Migratory Species, and the Convention on Biological Diversity. Further opportunities exist for collaboration between bilateral and non-binding treaties in place between some countries, as well as for taking a broader view and establishing links with treaties that at first sight may not be seen as dealing with biodiversity issues. Examples include the World Trade Organiza-

Box 7.3. Effectiveness of River Basin Organizations

A variety of factors influence the success of river basin management organizations. In principle, these arrangements should promote effective management of wetland systems since they align with hydrologically defined geographical units (R7.2). River basin organizations vary from those with the authority to plan, promote, and enforce their plans to those with principally an advisory role. Such institutions have existed in various forms across the world for at least 50 years; long-established though not always effective examples include the Chesapeake Bay Program in the United States, the Laguna Lake Development Authority in the Philippines, and the International Commission for the Rhine.

Where river basin organizations have succeeded, the success has often been based on their ability to deliver common aims of jurisdictions (such as coordinated water management to supply irrigation) and to support common cultural values. A further factor contributing to success is a specific mandate with defined achievable measures for implementing basin-wide goals, such as the "cap" placed on water diversions implemented and monitored through the Murray-Darling Basin Commission in Australia.

The effectiveness of basin-level organizations will depend on the kinds of development paths made possible by water allocation decisions, the acceptability of the resulting distribution of costs and benefits among stakeholders (whether these help to achieve objectives of poverty alleviation), and the maintenance or restoration of at least those ecosystem processes that support the provision of desired services (R7.2.4). RBOs are constrained or enabled primarily by the extent to which all the relevant stakeholders participate, are able to agree on objectives and management plans, and cooperate in their implementation.

For international transboundary wetlands, including river systems, lakes, and aquifers, sovereignty is an important issue, making it more challenging to establish a basin-scale organization supported by appropriate governance arrangements (R7.2.4). For example, riparian states in the Nile River basin have historically experienced political discord and mistrust, making the task of cooperatively managing the basin difficult despite institutional and nongovernmental provision for positive initiatives. In a transboundary situation, the capacity to implement agreements and plans will depend on the level of commitment of individual countries to integrated river basin management and ecosystem management and on whether the nations have mutual or complementary interests and relative bargaining power.

The difficulty in establishing and maintaining successful river basin organizations between nation states suggests that incentives need to be stronger, including stressing issues of mutual self-interest. Alternatives such as intergovernmental agreements that mandate development of management arrangements at the basin scale may need to be explored. Tensions often exist between basin-wide interests and those at local scales. Sub-basin-level organizations (such as watershed councils, land care groups, and village-level catchment committees) play important roles in addressing problems that are difficult to detect or address at larger scales. In contrast, basin-scale actors tend to be representatives of interested parties, which may include government agencies, NGOs, and associations of resource users. So far, there is little evidence of successful scaling up from village to basin levels.

One challenge that is particularly pronounced in transboundary water management is the strengthening of provisions for various aspects of public involvement, which includes access to information, public participation, and access to justice or legal recourse. An important tool for public involvement is the development of a process for transboundary environmental impact assessment (R7.2.4).

tion's Agreement on Sanitary and Phytosanitary Measures and the International Convention on the Control and Management of Ships' Ballast Water and Sediments, which addresses the spread of invasive alien species.

The ecosystem approach, as articulated by the Convention on Biological Diversity and the Ramsar Convention, has been developed as an overall strategy for integrated environmental management promoting conservation and sustainable use in an equitable way (R15.3.3). The approach has importance beyond traditional commodity and amenity considerations. It focuses on managing environmental resources and human needs across landscapes and is a response to the tendency of managing ecosystems for a single good or services, trying to balance tradeoffs to both human well-being and ecosystem services. The ecosystem approach has been applied to health issues, recognizing the inextricable link between humans and their biophysical, social, and economic environments as well as the link to groundwater management.

Systems of protected areas are another important category of response in international, regional, sub-regional, and national frameworks (R5.2.1). Site selection, adequate representation, and management are among the key issues determining the effectiveness of protected area networks. Especially for aquatic systems, which are not easily "fenced" from surrounding areas, a regional or landscape approach is necessary. Protected area networks at all levels, including the designation of Wetlands of International Importance under the Ramsar Convention, play an important role, given the fact that individual sites are often functionally interconnected by reason of shared hydrology, migratory species, and so on.

Area-based targets are often inappropriate for riverine systems, which are inherently linear in nature (R5.2.1). Size-based targets for riverine systems may be expressed in length, or upstream catchments can be subdivided into small drainage

basins that constitute selection units and therefore are polygonal. Targets for freshwater systems in some cases are inappropriate as a result of attempts to force freshwater systems into terrestrially based planning models. In general, far less attention has been given to planning for freshwater biodiversity than for terrestrial and marine biodiversity. Mimicking as far as possible the natural hydrological regime may be among the most important strategies for freshwater biodiversity conservation. This strategy may fit awkwardly within a conservation framework built exclusively around protected areas unless these areas can be created to protect hydrological processes.

Wetland restoration is a broad response category that has become controversial in part because of the uncertainty about what is necessary to create and restore wetlands—that is, what combination of processes leads to the establishment of a desired combination of wetland structure and function (R7.4.2). Wetland restoration approaches are numerous and include engineering solutions such as backfilling canals and the removal of contaminated groundwater, biological interventions including controlling the impact of feral fish and reestablishing wetland plants, and hydrological management to increase the effective inundation across floodplains and reintroduction of drying cycles. The conclusion of numerous studies is that created wetlands rarely perform the same functions or house the same biodiversity as the original site. For this reason, it is unlikely that created wetlands are going to structurally and functionally completely replace destroyed wetlands. The key to success is the setting of well-stated goals that form part of a broader comprehensive and rigorous process for planning, developing, implementing, and evaluating the restoration projects and for adopting an adaptive management approach.

Monitoring, as part of an adaptive management approach, is key to determining the success of response options (R18.3). Although indicators of biophysical response are available and well described, those for measuring the effectiveness of governance and institutions are in general not very thoroughly developed. Monitoring needs to cover a range of spatial and temporal scales. As an example, where "environmental water" is stored in a dam and released periodically, there will be a need for short-term investigative monitoring to determine the ecosystem response to that particular event. Monitoring may also need to take place at an ecosystem scale and over a period of a decade or more to measure changes in the condition of the entire system. It is widely accepted that much monitoring, even when prescribed to measure the effectiveness of responses, has typically been poorly designed and implemented. Responses are more likely to fail if adequate resources for monitoring, evaluation, and enforcement are not provided. The most robust monitoring systems have high levels of transparency and provision for access to information by different stakeholder groups.

Economic Responses

Economic valuation can provide a powerful tool for placing wetlands on the agendas of conservation and development decision-makers. Economic valuation aims to quantify the benefits (both marketed and nonmarketed) that people obtain from wetland ecosystem services. This makes them directly comparable with other sectors of the economy when investments are appraised, activities are planned, policies are formulated, or land and water resource use decisions are made. More important, it enables decision-makers and the public to evaluate the full economic costs and benefits of any proposed change in a wetland. A better understanding of the economic value of wetlands enables them to be considered as economically productive systems, alongside other possible uses of land, resources, and funds.

The concept of total economic value has now become one of the most widely used frameworks for identifying, minimizing, and quantifying the contribution of ecosystem services to human well-being (C2.3.3, CF6). Looking at the total economic value of a wetland essentially involves considering its full range of characteristics as an integrated system—its resource stocks or assets, the flows of environmental services, and the attributes of the ecosystem as a whole. It covers direct and indirect values and option and non-use values. (See Box 7.4.)

A wide range of methods that move beyond the use of direct market prices are available and are increasingly used for valuing wetlands (C2.3.3). These include approaches that elicit preferences directly (such as through contingent valuation methods) as well as those that use indirect methods to infer preferences from actions to purchase related services (for example, through production functions, dose-response relationships, travel costs, replacement costs, or mitigative or avertive expenditures). These methods, and their application to wetland ecosystems, are summarized in Box 7.5.

Relatively simple, low-cost, and easy-to-implement techniques are now available to value many wetland ecosystem services (C2.3.3, C20.6). Valuation techniques are increasingly being used to generate practical management and policy information. These adaptations of economic concepts, methods, and models have enabled wetland values to be much more easily and accurately expressed. The amount of information on the economic value of temperate and tropical wetlands is growing. Despite the advances that have been made in calculating and expressing the value of wetland services, a major challenge remains: ensuring that the results are fed into decision-making processes and used to influence conservation and development agendas.

Box 7.4. The Total Economic Value of Wetlands

Total economic value involves assessing four categories of ecosystem services value:

- ***Direct use values*** are derived from ecosystem services that are used directly by humans. They include the value of consumptive uses such as harvesting of food products, timber for fuel or construction, medicinal products, and hunting of animals for consumption as well as the value of non-consumptive uses such as the enjoyment of recreational and cultural amenities like wildlife and bird watching, water sports, and spiritual and social services that do not require harvesting of products. Direct use values correspond broadly to the MA's definition of provisioning and cultural services. They are typically enjoyed by people located in the ecosystem itself.
- ***Indirect use values*** are derived from ecosystem services that provide benefits outside the ecosystem itself. Examples include the natural water filtration function of wetlands, which often benefits people far downstream; the storm protection function of coastal mangrove forests, which benefits coastal properties and infrastructure; and carbon sequestration, which benefits the entire global community by reducing climate change. This category of benefits corresponds broadly to the MA's notion of regulating and supporting services.
- ***Option values*** are derived from preserving the option to use in the future services that may not be used at present, either by oneself (option value) or by others or heirs (bequest value). Provisioning, regulating, and cultural services may all form part of option value to the extent that they are not used now but may be used in the future.
- ***Non-use values*** refer to the value people may place on knowing that a resource exists even if they never use that resource directly. This kind of value is usually known as existence value (or, sometimes, passive use value). This is one area of partial overlap with non-utilitarian sources of value.

Economic interventions, including payments for services and markets, have long existed for resources such as water that, in many contexts, have long been traded goods. At the same time, water and the wetlands supported by water have typically been undervalued and consequently underpriced, leading to the inefficient and ineffective management of water for people and ecosystems (R7.3). Market-based approaches are now being extended to cover the environmental attributes and qualities of these goods (such as environmental flows and water quality), as well as new goods (such as groundwater). Market-based mechanisms have demonstrated a capacity to change the distribution of water and the quantity of pollutants in river systems and also show promise of limiting or compensating more direct land use changes that result in, for example, wetland draining or filling.

Box 7.5. Commonly Used Valuation Tools, with Examples of their Application (C2, C7, C20, R7)

Replacement costs: Even where wetland services have no market themselves, they often have alternatives or substitutes that can be bought and sold. These replacement costs can be used as a proxy for wetland resource and ecosystem values, although they usually represent only partial estimates or are underestimates.

In order to value the nonmarketed use of papyrus products by local households in Bushenyi District, Uganda, the price of substitute products was used. Annual household consumption of papyrus products was expressed in terms of equivalent market substitutes, including clay tiles instead of thatch, rubber floor coverings instead of mats, plastic bowls instead of baskets, and purchased firewood instead of papyrus fuel. Replacement costs were also used to value the benefit of South Korea's coastal wetlands in treating wastewaters and pollutants. Here, the costs of building and operating a waste treatment facility were used as a proxy for the replacement cost of wetland services.

Effects on production: Other economic processes often rely on wetland resources as inputs or on the essential life support provided by wetland services. Where they have a market, it is possible to look at the contribution of wetland goods and services to the output or income of these wider production and consumption opportunities in order to assess their value.

The benefit of the Hadejia-Nguru wetlands for groundwater recharge was valued using a production function approach. Wetland value was assessed by modeling the demand for water for household consumption and dry-season irrigated agricultural production and by relating welfare changes to changes in groundwater levels. Similarly, the economic value of mangroves in Pagbilao, Philippines, was assessed by looking at their contribution to fisheries production. Sustainable harvests were calculated, and the impacts of mangrove nutrient production on productivity were isolated in order to determine the role of mangrove management in fisheries production.

Damage costs avoided: The reduction or loss of wetland goods and services frequently incurs costs in terms of damage to or reduction of other economic activities. The damage costs that are avoided can be taken to represent the economic losses foregone by conserving wetlands.

Wetlands around the Tana River and Delta in Kenya provide important flood attenuation services for nearby infrastructure and surrounding human settlements. These services were partially valued by modeling the impact of wetland loss on the frequency and severity of flooding and by assessing the costs of damage potentially avoided to roads, buildings, and other infrastructure.

Mitigative or avertive expenditures: It is almost always necessary to take action to mitigate or avert the negative effects of the loss of wetland goods and services so as to avoid economic damage. These costs can be used as indicators of the value of conserving wetlands in terms of expenditures avoided.

Coastal marshes and mangroves play an important role in shoreline stabilization, erosion control, and flood and storm protection on Mahé Island in the Seychelles. The value associated with these functions was calculated by applying a preventive expenditure approach. In the absence of wetlands services it would be necessary to construct groynes and flood barriers to offset or mitigate coastal erosion and damage to infrastructure, the cost of which was used as a proxy for the value of coastal marsh and mangrove services.

Hedonic pricing: Hedonic methods look at the differentials in property prices and wages between locations and isolate the proportion of this difference that can be ascribed to the existence or quality of wetland goods and services.

The amenity and landscape benefits of Bhoj wetland in the city of Bhopal, India, were valued using hedonic pricing methods. This compared house prices in different parts of the city and isolated the premium on property prices for houses in close proximity to the Upper and Lower Lakes.

Travel costs: Wetlands typically hold a high value as a recreational resource or destination. Although in many cases no charge is made to view or enjoy natural ecosystems and species, people still spend time and money to reach wetlands. This expenditure—on transport, food, equipment, accommodations, time, and so on—can be calculated, and a demand function can be constructed relating visitation rates to expenditures made. These travel costs reflect the value that people place on the leisure, recreational, or tourism aspects of wetlands.

The travel cost method was applied to gauge the recreational value of wildlife viewing in Lake Nakuru National Park, Kenya. This was done by giving a questionnaire to visitors regarding their origin, distance traveled, income, and expenses. Demand curves were constructed using regression analysis to describe the relationship between travel costs and number of visits, and the individual and aggregate willingness to pay for wetland recreational services was estimated.

Contingent valuation: Even where wetland ecological services have no market price and no close replacements or substitutes, they frequently have a high value to people. Contingent valuation techniques infer the value that people place on wetland services by asking them their willingness to pay for them (or willingness to accept compensation for their loss) under the hypothetical scenario that they would be available for purchase.

Contingent valuation methods were used to assess the value of maintaining the Chao Phraya River in Thailand as a clean and well-functioning environment. A survey was carried out to gauge Bangkok residents' willingness to pay for such an environment through eliciting bids for various measures to improve instream river water quality and to minimize pollution loads entering the river.

Recent efforts have aimed at exploring the potential of water markets as a tool for reallocation of water to meet ecosystem needs as well as the traditional goal of improving resource efficiency for the provision of water to irrigation, hydropower, and drinking water supplies (R7.3.1). Markets that have treated water solely as a private good and a tradable commodity can have adverse social and environmental consequences. In contrast, too much emphasis on water as a public and local resource can limit market activity, such as water trading. Where markets are used to reallocate water to higher-value uses, it is necessary to be explicit about ecosystem water requirements (quantity and quality). Appropriate management arrangements are necessary to guide application of such water to meet desired objectives for ecosystem condition and functioning. To meet ecosystem needs, either a purchasing program or the ability to reduce water allocations is required, ideally in combination with the establishment of a "cap" or upper limit. (See Box 7.6.) As well as illustrating a market approach, this provides an example of the role of regulation. The provision of funds for water recovery from existing users, such as the irrigation industry, coupled with efficiency measures is seen as a less confrontational mechanism than a pure regulatory approach.

Because the benefits to improved stream flow and freshwater ecosystems are inherently public goods, the role of good governance and complete property rights for water remain fundamental enabling conditions for well-functioning markets. While there is a role for the use of markets to develop efficient water allocations, there is also a role for governments to regulate in providing stable and appropriate institutions for these markets to operate (R7.3.2). The primary distinction between systems that regulate and allocate water is the degree to which users have a private right to the use and ownership of water.

Payments for services derived from a river basin can support the management of wetlands or protect catchments that provide wetlands with adequate quantities and qualities of water, and hence they act as an incentive to deal with drivers of wetland change such as altered hydrology, pollution, and land use change. Payment arrangements for these services essentially consist of the negotiation of arrangements among buyers and sellers of these services. They take various forms, depending on the nature of the service, the scale of relevant ecosystem processes that support it, and the socioeconomic and institutional context. These range from informal, community-based initiatives to more-formal contracts between individual parties and complex arrangements among multiple parties facilitated by intermediary organizations. They may also include a mix of market-based, regulatory, and policy incentives that are more likely to become necessary at larger scales, when threats are beyond the response capacity of individual communities. The effectiveness of payment arrangements will largely depend on stakeholder willingness to pay for them (R7.3).

Box 7.6. The Murray-Darling Basin Cap (R7.2)

In June 1993, an Australian Ministerial Council directed that a study be undertaken into the issue of altered flows and their consequences for the rivers of the Murray-Darling Basin. This led to an audit of water use, which confirmed increasing levels of diversions and associated declines in river health. In response, the Council introduced an interim cap (an upper limit) on water diversions in the Basin in 1995. This was established as a permanent cap on 1 July 1997. In agreeing to the implementation of the cap, the Council essentially made a decision about the balance between the social and economic benefits derived from development of the Basin's water resource and the water needs of the riverine ecosystem. Implementation of the cap is the responsibility of the member states to the Murray-Darling Basin initiative. Water Audit Monitoring Reports are prepared annually to ensure state water use is consistent with the cap, and an Independent Audit Group reviews progress on its implementation.

Selecting Responses

Selection of responses needs to make explicit the trade-offs, risks, uncertainty, and assumptions inherent in any suite of options and hence requires transparency and accountability in decision-making processes (R18, CF.SDM). Decision-makers are faced with uncertainty in choosing among responses—uncertainties in both the method of assessment and the outcomes of a response. The consistent treatment of uncertainty and risk is crucial to assist with the clarity and utility of both. As part of any assessment process, it is crucial to estimate the uncertainty of findings even if a detailed quantitative appraisal is unavailable. Uncertainty may arise due to the complex systems within which response measures for ecosystem services are embedded. Three main information domains are important for successfully choosing and implementing response options related to wetlands (see Box 7.7): biophysical information about the ecosystem status and processes; socioeconomic information about the social context in which and for which the decision will be made; and, as an important subset of the latter, information about the values, norms, and interests of the key stakeholders shaping and affected by the decision (R18).

Many interventions being considered to achieve Millennium Development Goals such as poverty reduction and hunger alleviation could lead to the loss and degradation of wetlands and

Box 7.7. Promising Responses for Specific Sectors That Potentially Affect Wetlands (RWG)

Agriculture

- Removal of production subsidies that have adverse economic, social, and environmental effects.
- Investments in agricultural science and technology and natural resource management to support a new agricultural revolution to meet worldwide food needs.
- Use of response polices that recognize the role of women in the production and use of food and that are designed to empower women by providing knowledge and ensuring access to and control of resources necessary for food security.
- Application of a mix of regulatory and incentive- and market-based mechanisms to reduce overuse of nutrients.

Fisheries and Aquaculture

- Reduction of marine fishing capacity.
- Strict regulation of marine fisheries, especially with regards to fishing quotas.
- Establishment of appropriate regulatory systems to reduce the detrimental environmental impacts of aquaculture.

Water

- Payments for ecosystem services provided by watersheds.
- Improved allocation of rights to freshwater resources to align incentives with conservation needs.
- Increased transparency of information regarding water management and improved representation of marginalized stakeholders.
- Development of water markets and water pricing.
- Increased emphasis on the use of the natural environment and nonstructural measures for flood control.

water resources that would both harm progress toward other goals and ultimately undermine progress toward all goals (C8.6). (See Figure 7.1) The goals of improved human welfare, improved conservation and ecosystem integrity, improved availability of safe water for human use, protection of the global atmosphere, and sustainable food production are not inherently incompatible. However, the simultaneous pursuit of these distinct objectives on a sectoral basis with reference to one goal and disregard for the others will likely exacerbate the deterioration of wetlands.

For example, it is not uncommon for strategies aiming to increase food production and reduce poverty to propose the conversion of marshes to agriculture, conversion of mangroves to aquaculture, and significant increases in the use of fertilizers to increase crop production. This approach, however, by increasing the input of water pollutants, removing the natural water filtering service provided by wetlands, and removing a key ecosystem services provided by mangroves that the poor rely upon, such as timber and charcoal supply and fish habitat, could make the development goal of improved water and sanitation more difficult to achieve and may in fact increase poverty for some groups of people. In contrast, a development strategy that factors in the full range of benefits provided by wetlands might better achieve the set of development goals with little or no harm to the wetlands. Good governance and collaboration between institutions underpins the successful implementation of all response options for maintaining or restoring the ecological character of wetlands globally. Maintenance of the ecological character of wetlands will ensure that existing services continue to be delivered.

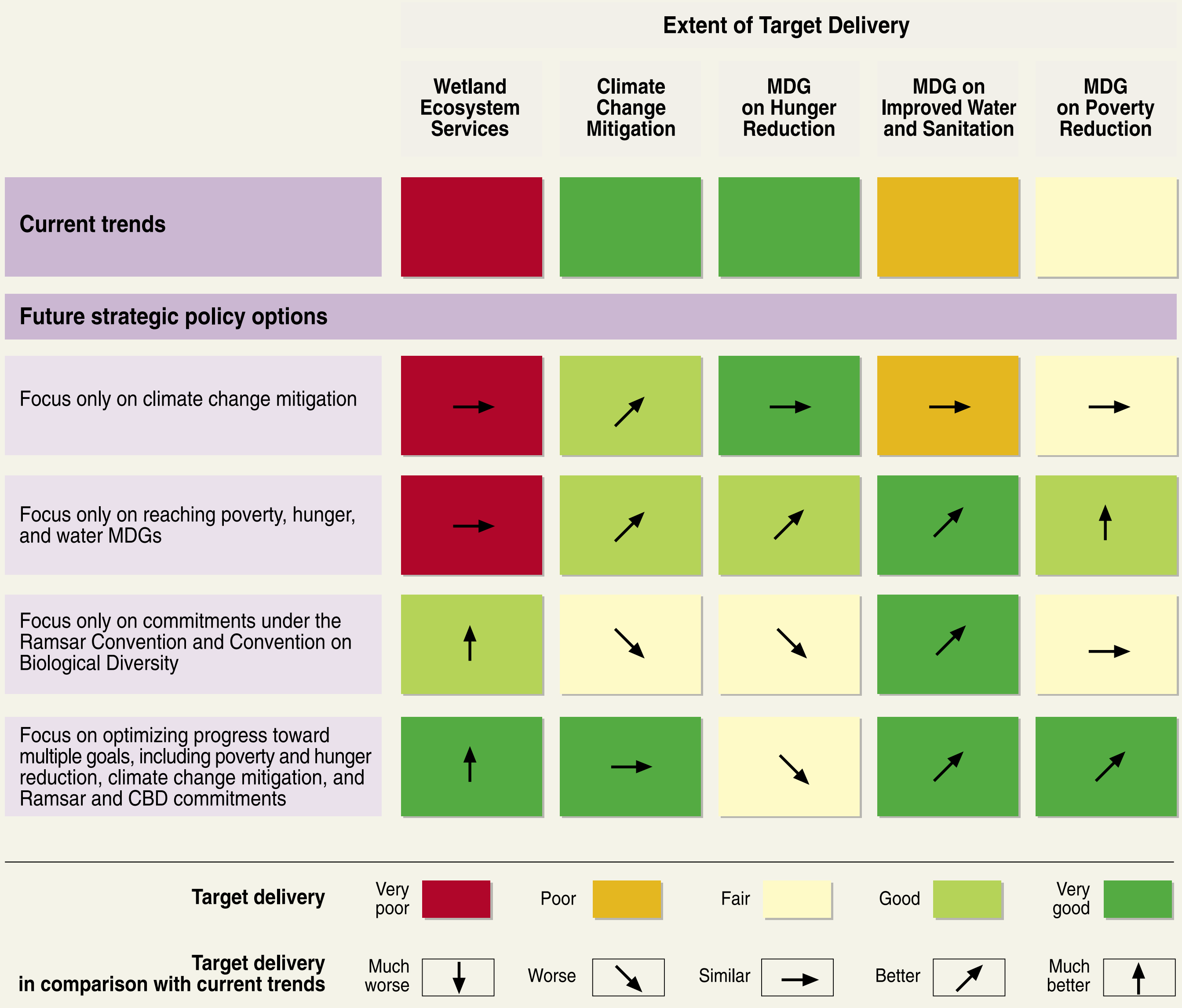
A major conceptual shift among policy-makers and decision-makers is required to ensure that cross-sectoral approaches that incorporate the principles of consultation and transparency, address trade-offs, and ensure the long-term future of the services provided and supported by wetlands are adopted and implemented effectively. As these approaches place greater emphasis on the sustainable use of wetlands and their resources, they will better support sustainable development and improved human well-being. Failure to adopt cross-sectoral approaches will mean that any short-term gains in human well-being resulting from current development policies will not be sustained. The wetlands and services on which people depend will continue to exist only if management approaches are changed and the current trends in wetland loss and degradation are stopped and reversed.

Many of the responses designed with a primary focus on wetlands and water resources will not be sustainable or sufficient unless other indirect and direct drivers of change are addressed and enabling conditions are established. For example, the sustainability of protected areas for wetlands will be severely threatened by human-caused climate change. Similarly, the management of ecosystem services cannot be sustainable globally if the growth in consumption of services continues unabated. Responses also need to address the enabling conditions that determine the effectiveness and degree of implementation of the wetland-focused actions.

In particular, changes in institutional and environmental governance frameworks are often required to create these enabling conditions. Today's institutions were not designed to take into account the threats associated with the loss and the degradation of ecosystem services. Nor were they well designed to deal with the management of common pool resources, a characteristic of many ecosystem services. Issues of ownership and access to resources, rights to participation in decision-making, and regulation of particular types of resource use or discharge of wastes can strongly influence the sustainability of ecosystem management and are fundamental determinants of who wins and who loses from changes in ecosystems. Corruption, a major obstacle to effective management of ecosystems, also stems from weak systems of regulation and accountability.

Figure 7.1. Indicative Trade-offs Involved in Approaches to Achieve the MDGs (Derived from C7, C20, R13, R19)

The Figure shows the implications for the future delivery of wetland ecosystem services of different strategic policy options for the achievement of intergovernmental environmental commitments: carbon mitigation (Kyoto Protocol), the poverty and hunger Millennium Development Goals, and environmental conventions concerned with water and ecosystems (Ramsar and CBD). Each row provides a hypothetical case where actions are taken to achieve a particular goal (such as carbon mitigation, poverty or hunger reduction, or wetland service delivery) using strategies that maximize the short-term progress toward that goal without any consideration given to alternative goals. The colored boxes show the likely extent of achievement of the different global targets under each strategy. The arrows indicate the extent of improvement (or otherwise) of target delivery under each strategy option in comparison with current trends. Although the actual trade-offs may differ in specific locations, in general overall progress is likely to be less when the goals are addressed in isolation than when they are addressed jointly.



Source: Millennium Ecosystem Assessment

Responses that address direct and indirect drivers and that seek to establish enabling conditions that would be particularly important for biodiversity and ecosystem services include the following:

■ *Elimination of subsidies that promote excessive use of ecosystem services (and, where possible, transfer of these subsidies to payments for nonmarketed ecosystem services).* Subsidies paid to the agricultural sectors of OECD countries between 2001 and 2003 averaged over $324 billion annually, or one third the global value of agricultural products in 2000. A significant proportion of this total involved production subsidies that led to overproduction, reduced the profitability of agriculture in developing countries, and promoted overuse of fertilizers and pesticides. Many countries outside the OECD also have inappropriate input and production subsidies. These subsidies could instead be directed to payments to farmers to produce nonmarketed ecosystem services through the maintenance of forest cover or wetlands or payments to protect biodiversity and thereby help to establish economic incentives to provide these public goods. Similar problems are created by fishery subsidies, which amounted to approximately $6.2 billion in OECD countries in 2002, or about 20% of the gross value of production. Water use is also often subsidized, for example by public water supply systems that do not charge consumers for the cost of the water supply infrastructure and maintenance or, as is often the case with groundwater pumping, indirectly through energy subsidies.

Although removal of perverse subsidies will produce net benefits, it will not be without costs. Some of the people benefiting from production subsidies (through either the low prices of products that result from the subsidies or as direct recipients of subsidies) are poor and would be harmed by their removal. Compensatory mechanisms may be needed for these groups. Moreover, removal of agricultural subsidies within the OECD would need to be accompanied by actions designed to minimize adverse impacts on ecosystem services in developing countries. But the basic challenge remains that the current economic system relies fundamentally on economic growth that disregards its impact on natural resources.

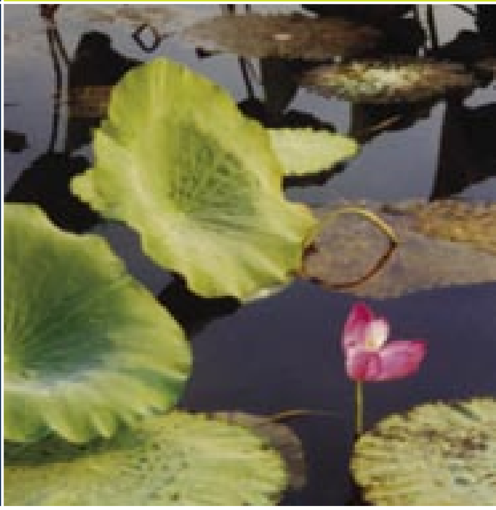
■ *Sustainable intensification of agriculture.* The expansion of agriculture will continue to be a major driver of wetland loss. In regions where agricultural expansion continues to be a large threat to wetlands, the development, assessment, and diffusion of technologies that could increase the production of food per unit area sustainably, without harmful trade-offs related to excessive consumption of water or use of nutrients or pesticides, would significantly lessen pressure on wetlands. In many cases, appropriate technologies already exist that could be applied more widely, but countries lack the financial resources and intuitional capabilities to gain and use these technologies.

■ *Slowing and adapting to climate change.* By the end of the century, climate change and its impacts may be the dominant direct driver of change of ecosystem services globally. Harm to ecosystems will grow with both increasing rates of change in climate and increasing absolute amounts of change. Some ecosystem services in some regions may initially benefit from increases in temperature or precipitation expected under climate scenarios, but the balance of evidence indicates that there will be a significant net harmful impact on ecosystem services worldwide if global mean surface temperature increase more than 2° Celsius above preindustrial levels or faster than 0.2° Celsius per decade (*medium certainty*). Given the inertia in the climate system, actions to facilitate the adaptation of biodiversity and ecosystems to climate change will be necessary to mitigate negative impacts. These may include the development of ecological corridors or networks.

■ *Slowing the global growth in nutrient loading even while increasing fertilizer application in regions where crop yields are constrained by the lack of fertilizers, such as parts of sub-Saharan Africa.* Technologies already exist for the reduction of nutrient pollution at reasonable costs, but new policies are needed for these tools to be applied on a sufficient scale to slow and ultimately reverse the increase in nutrient loading.

■ *Correction of market failures and internalization of environmental externalities that lead to the degradation of ecosystem services.* Because many ecosystem services are not traded in markets, markets fail to provide appropriate signals that might otherwise contribute to the efficient allocation and sustainable use of the services. In addition, many of the harmful trade-offs and costs associated with the management of one ecosystem service are borne by others and so are not weighed in sectoral decisions regarding the management of that service. In countries with supportive institutions in place, market-based tools could be more effectively applied to correct some market failures and internalize externalities, particularly with respect to provisioning ecosystem services. Various economic instruments or market-based approaches that show promise, in addition to the creation of new markets for ecosystem services and payments for ecosystem services noted earlier, include taxes or user fees for activities with "external costs," establishment of cap-and-trade systems for reduction of pollutants, and mechanisms to allow consumer preferences to be expressed through markets (through certification schemes, for instance).

■ *Increased transparency and accountability of government and private-sector performance in decisions that affect wetlands, including through greater involvement of concerned stakeholders in decision-making.* Laws, policies, institutions, and markets that have been shaped through public participation in decision-making are more likely to be effective and perceived as just. Stakeholder participation also contributes to the decision-making process because it provides a better understanding of impacts and vulnerability, the distribution of costs and benefits associated with trade-offs, and the identification of a broader range of response options that are available in a specific context. Stakeholder involvement and transparency of decision-making can increase accountability and reduce corruption.



Appendixes

Appendix A
Abbreviations, Acronyms, and Figure Sources

Abbreviations and Acronyms

CBD – Convention on Biological Diversity

COP – Conference of the Parties (of treaties)

DRIFT – Downstream Response to Imposed Flow Transformation

GRoWI – *Global Review of Wetland Resources and Priorities for Wetland Inventory*

ICZM – integrated coastal zone management

IRBM – integrated river basin management

IUCN – World Conservation Union

MA – Millennium Ecosystem Assessment

MDG – Millennium Development Goal

NGO – nongovernmental organization

OECD – Organisation for Economic Co-operation and Development

RBO – river basin organization

STRP – Scientific and Technical Review Panel (of Ramsar)

UNCCD – United Nations Convention to Combat Desertification

UNEP – United Nations Environment Programme

WWF – World Wide Fund for Nature

Figure Sources

Most Figures used in this report were redrawn from Figures included in the technical assessment reports in the chapters referenced in the Figure captions. Preparation of several Figures involved additional information as follows:

Figure 3.1

This Figure has been adapted with permission from H.M. MacKay, P.J. Ashton, M. Neal, and A. Weaver, *The Water Research Commission's Investment Strategy for the Crosscutting Domain: Water in the Environment,* WRC Report Number KV148/04 (Pretoria, South Africa: Water Research Commission, 2004).

Figure 4.1

This Figure has been adapted with permission from B.D. Ratner, Dong Thanh Ha, Mam Kosal, Ayut Nissapa, and Somphanh Chanphengxay, *Undervalued and Overlooked: Sustaining Rural Livelihoods through Better Governance of Wetlands,* Studies and Review Series (Penang, Malaysia: World Fish Centre, 2004).

Box 4.2

The information was derived from Chapter 20 in MA *Current State and Trends* and supplemented with information from N. Meyers and J. Kent, *Perverse Subsidies* (Washington, DC: Island Press, 2001).

Appendix B

Assessment Report Tables of Contents

Note that text references to CF, CWG, SWG, RWG, or SGWG refer to the entire working group report. ES refers to the Main Messages in a chapter.

Secretariat Support Organizations

The United Nations Environment Programme (UNEP) coordinates the Millennium Ecosystem Assessment Secretariat, which is based at the following partner institutions:

Food and Agriculture Organization of the United Nations, Italy

Institute of Economic Growth, India

International Maize and Wheat Improvement Center (CIMMYT), Mexico (*until 2002*)

Meridian Institute, United States

National Institute of Public Health and the Environment (RIVM), Netherlands (*until mid-2004*)

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CBD

CMS

GEF

ICSU
International Council for Science

IUCN
The World Conservation Union

UNITED NATIONS
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