DROWNING THE NATIONAL HERITAGE: Climate Change and U.S. Coastal Biodiversity

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FOREWORD

Say the words "extinction crisis," and what most likely comes to mind first is a tropical forest in flames—an apt image when deforestation is the main force behind a species extinction rate unmatched in 65 million years. But Americans concerned about saving tropical forests' vast biological wealth must not lose sight of losses much closer to home, including the degradation of U.S. seashores, coral reefs, barrier islands, estuaries, and coastal wetlands.

These coastal habitats are home to teeming communities of plant and animal species, including our own. Some of this diversity is far from secure: for instance, 80 species that are at risk of extinction can live *only* on the strip of coastline that lies within 10 feet of sea level. Beach-front development is already fragmenting coastal habitats, and rising population, temperature, and sea levels could compound these losses. The number of Americans living in coastal areas will probably reach 127 million by 2010, a 60-percent increase over a half-century of migration. Global warming could raise sea levels from two to five feet over the next century, in many cases outpacing particular ecosystems' landward march. What survival odds do species already in trouble have if their habitat keeps shrinking, squeezed on one side by a growing human presence and on the other by a rising sea?

What's left of our natural heritage can't be saved unless we awaken to the choices and trade-offs required. The loss of biodiversity may be a new concept to most U.S. policymakers, but together with global warming it tops the U.S. Environmental Protection Agency's list of high-risk threats. Yet, as EPA points out, more visible environmental problems—oil spills, toxic waste dumps, and the like—get the most attention from citizens and policymakers alike.

That must change, argue Walter V. Reid and Mark C. Trexler in *Drowning the National Heritage: Climate Change and U.S. Coastal Biodiversity*. If today's global warming forecasts are borne out over the next century, coastal zones face certain losses even under the most enlightened policies imaginable. Only instituting the right mix of policies now can prevent widespread biological impoverishment in the future, they contend.

Neither fleeing in droves from every coastline nor protecting all land from inundation is politically and economically feasible as a long-term solution, Drs. Reid and Trexler find. Instead, they counsel a middle way that would allow for coastal development over the next few decades and for conserving wetlands and other coastal systems in a hotter future.

The authors point out that curbing the rate and magnitude of global warming would do more to conserve coastal biodiversity than any after-the-fact measure could. But they also identify policy shifts that would help coastal ecosystems and species survive the warming that is already in store:

- Incorporating the protection of coastal ecosystems as a fundamental goal in federal and state policies.
- Eliminating federal and state subsidies that promote coastal development and coastal defense.
- Making wider use of such regulatory measures as coastal zoning and setbacks.
- Putting property owners on notice that sea level will rise and that large areas of what is now dry land will eventually have to be abandoned.
- Minimizing human stresses other than sea level rise on coastal ecosystems.
- Identifying appropriate policies for key coastal ecosystems.

The authors also suggest that nongovernmental organizations that buy land for conservation purposes should begin experimenting with easement and leasing options that would allow them to protect wetlands and other coastal ecosystems as the sea rises.

Many of these issues have been raised in discussions of land-use planning, global warming adaptation measures, and ways to stem species extinction. But *Drowning the National Heritage* represents the first attempt to weave the strands of data and analyses from these diverse disciplines into a coherent whole. This synthesis extends the analyses and policy recommendations of such previous WRI studies as *Keeping Options Alive: The Scientific Basis for the Conservation of Biodiversity, Conserving the World's Biological Diversity, Minding the Carbon Store: Weighing*

U.S. Forestry Strategies to Slow Global Warming, and *A Matter of Degrees: The Potential for Limiting the Greenhouse Effect*.

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James Gustave Speth
President
World Resources Institute

I. INTRODUCTION AND OVERVIEW

The world's ecosystems may undergo more profound changes over the next century than during any comparable span of human history. Global warming of the magnitude expected in coming decades, accompanied by changes in sea level, rainfall, and wind and ocean currents, will significantly affect species composition, community structure, and the function of ecosystems. Ecosystems continually evolve in response to natural climatic changes, but the rate of climate change in the century ahead, coupled with the existing pattern of human settlement and stresses on species and ecosystems, could overwhelm ecosystems' capacity to adapt, thus impoverishing the world's biological wealth. Biodiversity—the world's genes, species and ecosystems—could be an invaluable resource in humanity's efforts to adapt to climate change, but it may also become one of the first victims of that change.

To many, conserving biodiversity means protecting tropical rainforests and their unmatched species diversity. But biodiversity conservation ought to be of concern in species-poor ecosystems too. In fact, the best way to think of it is using biological resources in ways that deliver to future generations an environment rich in genes, species, habitats, ecosystems, and the knowledge needed to use them wisely. Put bluntly, no ecosystem can be used sustainably unless its basic components are maintained. By that measure, biodiversity conservation is a bottom-line necessity not only in tropical forests, but also in ecosystems much closer to home.

The status of biodiversity in coastal ecosystems stands out as a case in point. Coastal wetlands (salt marshes and brackish marshes), coral reefs, mangroves, barrier islands, and estuaries are facing an onslaught of development related pressures.[1] Although these ecosystems do not garner the public attention given rainforests, they deserve comparable protection. The species richness of coral reefs is unparalleled in marine environments, and the primary productivity of coastal wetlands and coral reefs ranks among the highest on earth. Adding to this case, growing and shifting human populations, and even more rapidly growing demands on resources, have placed these ecosystems under enormous stress. Barrier islands have become favorite sites for resorts and summer homes, coastal wetlands have been filled to make room for industry, estuaries bear the brunt of pollution released along miles of rivers and coastline, and sedimentation and pollution are killing coral reefs near cities and river mouths.

> "Biodiversity—the world's genes, species and ecosystems—could be an invaluable resource in humanity's efforts to adapt to climate change, but it may also become one of the first victims of that change."

In the United States, the struggle to conserve the biodiversity of coastal ecosystems has centered on wetland conservation. Prior to the 1970s, few federal or state programs actively encouraged the conservation of either coastal or interior wetlands. At the same time, numerous governmental incentives indirectly promoted the conversion of wetlands to agriculture or other uses. Within the contiguous United States, 53 percent of coastal and interior wetlands were lost between the 1780s and the 1980s; some 10 percent were lost between 1954 and 1974 alone (Dahl 1990).

Public outcry over the loss and degradation of the nation's wetlands, and the growing scientific understanding of their economic and biological importance, stimulated significant federal and state policy changes. As early as the 1970s, the Clean Water Act, the Coastal Zone Management Act, and state coastal zone legislation began to slow the loss of coastal wetlands. By the mid-1980s, annual rates of coastal wetlands conversion had dropped by half (OTA 1984), and by 1984 the Office of Technology Assessment declared that "coastal wetlands are reasonably well protected."[2] Interior wetlands still faced significant threats, but by the late 1980s the impressive achievements seemed to place a goal of "no-net-loss of wetlands" within reach. In 1988, the National Wetlands Policy Forum, made up of representatives of industry, conservation groups, farmers, ranchers, and government officials (including three state governors) recommended a goal of no-net-loss of wetlands.

> "**Coastal wetlands can withstand modest rates of change in sea level unless their landward movement is hindered by physical obstructions, but foreseen rates would almost certainly outpace the ability of many coastal ecosystems to move or adapt.**"

Has this goal become a verifiable reality? Unfortunately, various indicators of the status of coastal biodiversity demonstrate that this progress in wetland protection is insufficient to meet the long-term objectives for maintaining coastal ecosystems. Today's coastal natural resource policies don't ensure the maintenance of the foundations and continued productivity of coastal ecosystems even under current levels of stress. Add the likely additional stress of climate change and there is cause for considerable concern. The three- to six-fold increase in rates of sea level rise predicted by current climate-change models will have profound effects on the nation's coastal environment. Even by conservative estimates, sea level could be 66 cm higher by 2100, but a rise of nearly 2 meters over that time period may be equally plausible (Warrick and Oerlemans 1990, Titus 1991). Coastal wetlands can withstand modest rates of change in sea level unless their landward movement is hindered by physical obstructions, but foreseen rates would almost certainly outpace the ability of many coastal ecosystems to move or adapt.

Inundation is only one effect of climate change. As sea levels rise, coastal erosion and the severity of coastal flooding will increase, and coastlines will recede unless stabilized by dikes or through sand nourishment. Salt-water intrusion into groundwater, rivers, bays, and estuaries will increase. Changes in rainfall patterns and temperature will modify salinity gradients in estuaries and alter rates of river delta sedimentation, and coastal currents and upwelling patterns are likely to shift geographically and change in intensity. All of these "sea changes" will affect biodiversity in the nation's coastal zones.

Given these threats, what is the current status of coastal biodiversity (species, habitats, and ecosystems)? And what potential impacts can be expected from climate change? As the following review shows, the coastal ecosystems being affected by climate change are not healthy and resilient. Indeed, they are already under considerable stress.

The policies needed to respond to climate change so as to preserve coastal biodiversity differ from those normally considered to counter sea level rise. As spelled out below, addressing the needs of biodiversity conservation in coastal ecosystems demands rapid and anticipatory measures, all of them justified by the value of the coastal resources under threat.

II. COASTAL ECOSYSTEMS: THE FRAGILE LAND/SEA MARGIN

It is hard to characterize the structure and functioning of any ecosystem, but it is particularly difficult with the highly complex coastal marshes, coral reefs, mangroves, and estuaries located where land meets sea. It is still more difficult to probe beneath static descriptions of an ecosystem and assess its long-term "health." Habitats may persist but lose species, species may persist but lose the genetic diversity that enables them to adapt to future environmental change, and ecosystems may be visually unchanged but cease to perform valuable functions upon which we or other species have come to depend. The aim of biodiversity conservation is to ensure that these underlying components of the world's living resources are maintained. As straightforward as this goal may appear, it is another matter altogether to try to measure biodiversity or to translate biodiversity conservation into specific activities.

Although "biodiversity" is often equated with "number of species," there is no single measure of biodiversity. Rather, scientists rely on a set of indicators bearing upon the composition, structure, and function of habitats and ecosystems. This is not to downplay the importance of biodiversity as an issue. Many other concepts that provide the impetus for public policy development are equally abstract. For instance, the concept of "economic and social development" provides the framework within which most public policy is evaluated and promoted, but like biodiversity conservation it cannot be directly measured. We measure "development" through the use of such indicators as the Gross National Product (GNP), unemployment rate, and *per capita* income—all concrete components of the broad development agenda. Just as economists do not try to characterize the health of the economy with one indicator, so too biologists cannot evaluate biodiversity's status without examining a variety of indicators.

Biodiversity conservation should be an important objective of all land- and resource-use policies. Development that leads to continuing degradation of ecosystems and the loss of species and habitats cannot be sustained over the long term. By examining a variety of indicators of the long-term status of ecosystems, planners can anticipate problems, rather than simply react to situations that are almost beyond help. By forcing the examination of issues well upstream of a crisis, the anticipatory focus of biodiversity conservation gives policymakers the opportunity to respond while options to save species or ecosystem services still remain.

> **"Just as economists do not try to characterize the health of the economy with one indicator, so too biologists cannot evaluate biodiversity's status without examining a variety of indicators."**

The threat of extinction is one important indicator of the status of biodiversity and the ultimate indicator of the status of species diversity. But other indicators may be more useful from a planning perspective. Various indicators of the current status of coastal species, habitats, and ecological processes are examined here, along with trends in such practical attributes of coastal biodiversity as fishery productivity and waterfowl populations. Trends in populations of economically important species (such as fish and waterfowl) reveal the status of the ecosystem's underlying components in terms that economic planners can more readily grasp. Together, these indicators can be used to project the potential impact of climate change on the status of these ecosystems. *(See Chapter III.)* Understanding the current stress that coastal ecosystems face is crucial to fully appreciating how climate change may affect coastal biodiversity.

Coastal Species

Nearly half of the U.S. population, some 110 million people, lives in coastal counties (Culliton et al. 1990). This high density of settlement has been at the expense of habitat: a disproportionate share of rare and endangered species in the United States are now found in coastal counties.[3] But most of these species are associated with upland habitats. It has long been thought that few species right at the sea edge—in the zone most likely to be affected by sea level rise—are at high risk of extinction. Coastal wetlands and barrier islands have relatively few species, and the species occupying marine systems often have extremely large ranges.

These attributes of coastal species and ecosystems would seemingly insulate them from major threats of extinction. But a more careful examination of coastal ecosystems suggests otherwise. Our evaluation of the current threat to species utilizing, or restricted to, the zone below an elevation of 5 or 10 feet of sea level shows that a number of species in this coastal fringe will be squeezed between increasing development pressure from above and the rising sea from below. (The choice of these elevations is dictated by the resolution of the data available, but they also compare roughly with the range of estimates of sea level rise expected in the next century (roughly 1–6 feet).)

> **"Florida contains the overwhelming majority of the rare species restricted to the coastal fringe."**

Some 20 species that are federally listed as endangered or threatened are found only within the 10-foot coastal fringe of the contiguous United States, and another 33 are candidates for listing. *(See Table 1.)* These threatened and endangered species amount to only 3.4 percent of the nearly 600 listed species—scarcely surprising given that the land area in this zone is small. Considering only coastal wetlands, these ecosystems account for only 0.2 percent of surface area in the contiguous United States, but they are principal habitats for 15 federally listed or candidate species. The perception that coastal species may be less threatened with extinction is thus unfounded: the level of endangerment in coastal wetlands (3.5 species per million acres) is greater than the average for the United States as a whole (1.9 species per million acres).

In fact, these totals underestimate the true threat. The complexity of the federal listing process, combined with severe funding constraints faced by the Division of Endangered Species, has created a backlog of some 3,900 species waiting for classification. More up-to-date data on threatened and endangered species are maintained by The Nature Conservancy (TNC). According to TNC, 80 species and subspecies that are considered rare, imperiled, or critically imperiled on a range-wide basis are found only below the 10-foot contour of the contiguous United States.[4] *(See Table 1.)*

Moreover, these statistics refer *only* to species that are *restricted* to the area below the 10-foot contour. The picture is even more disturbing when species are included that utilize the coastal fringe, often for critical portions of their life cycle, but are not restricted to this zone. For example, TNC lists some 73 species in Maryland found only below the 10 foot contour as rare or imperiled. If all rare species *utilizing* this zone are included, however, the total grows to 122 species. Similarly, in California, the California clapper rail and the saltmarsh harvest mouse are the only federally listed endangered animals restricted in their habitat use to below the 10-foot contour, but the peregrine falcon, California brown pelican, light-footed clapper rail, California black rail, California least tern, Belding's savannah sparrow, and San Francisco garter snake are all rare species that live, among other places, in coastal wetlands.[5]

Florida contains the overwhelming majority of the rare species restricted to the coastal fringe. Forty-five of the 80 species (56 percent) classified by TNC as rare, imperiled, or critically imperiled in this zone are found in the contiguous United States only in Florida. The preponderance of species in Florida reflects both the low elevation of the state (consequently, the 10-foot contour includes more land than in many other coastal states) and the presence of tropical and subtropical habitat found nowhere else in the contiguous United States. Some Florida species that are rare in the United States and restricted to below 10 feet of sea level are found elsewhere in the Caribbean and may be found at higher elevations outside of the United States. Thus, not all of these species are threatened with *global* extinction.

Threatened and endangered species are those species in need of "critical care." But population trends of species not yet at risk of extinction are often equally useful indicators of biodiversity's status since these statistics provide policymakers with valuable information well in advance of any crisis. Only by monitoring trends in populations of all species and taking action to protect declining populations can a steadily growing list of endangered or imperiled species be avoided.

Recent population trends of coastal species are not encouraging. Consider the findings of the U.S. Fish and Wildlife Service, which monitors populations of

Table 1. Rare, Threatened, and Endangered Species in the United States Restricted to within 10 feet of Sea Level.

Common Name	Name	TNC Designation[a]	Federal Designation[b]	Habitat
Plants				
Sensitive Joint-Vetch	*Aeschynomene virginica*	Imperiled	Candidate (2)	Marsh, Tidal marsh
Seabeach Pigweed	*Amaranthus pumilus*	Imperiled	Candidate (2)	Dunes
Suisun Marsh Aster	*Aster chilensis* var. *lentus*	Imperiled	Candidate (2)	Marsh
Seashore Saltbush	*Atriplex drymarioides*	Imperiled	—	Mudflats
Eaton Beggar-ticks	*Bidens eatonii*	Rare	—	Tidal Shore
Estuary Beggar-ticks	*Bidens hyperborea* var. *hyperborea*	Rare	—	Mudflats
Long's Bitter cress	*Cardamine longii*	Rare	—	Fresh Estuaries
Big Pine Partridge Pea	*Cassia keyensis*	Imperiled	Candidate (1)	Shallow soil over coral
Nodding Catopsis	*Catopsis nutans*	Imperiled	—	Dry knolls near marsh
Small-Flower Lily-Thorn	*Catesbaea parviflora*	Imperiled	—	Dunes, dry knolls
Key Tree-cactus	*Cereus robinii*	Critically Imperiled	Endangered	Thorn Scrub
Garber's Spurge	*Chamaesyce garberi*	Critically Imperiled	Threatened	Sand Pine rocklands
Porter's Hairy-Pod Spurge	*Chamaesyce porteriana* var. *keyensis*	Critically Imperiled	Candidate (1)	Coastal Scrub
Porter's Broadleaf Spurge	*C.p.* var. *porteriana*	Imperiled	Candidate (1)	Pinelands on limestone
Porter's Broom Spurge	*C.p.* var. *scoparia*	Imperiled	Candidate (1)	Pinelands on limestone
Geiger Tree	*Cordia sebestena*	Rare	—	Dunes
Bird's Beak	*Cordylanthus maritimus* ssp. *maritimus*	Imperiled	—	High Salt Marsh
Solf Bird's Beak	*C.m.* ssp. *mollis*	Critically Imperiled	Candidate (1)	Salt Marsh
Pt. Reyes Bird's Beak	*C.m.* ssp. *palustris*	Rare	Candidate (2)	Salt Marsh
Okeechobee Gourd	*Cucurbita okeechobeeensis*	Critically Imperiled	Candidate (2)	Swamp Forest
Narrow-leaved Carolina Scalystem	*Elytraria caroliniensis* var. *angustifolia*	Imperiled	Candidate (2)	Floodplain forest
Parker's Pipewort	*Eriocaulon parkeri*	Rare	—	Tidal Flats
Contra Costa Wallflower	*Erysimum capitatum* var. *angustatum*	Critically Imperiled	Endangered	Strand/Dunes
Blake's Gumplant	*Grindelia stricta* ssp. *blakei*	Imperiled	Candidate (2)	Salt Marsh
Johnson's Sea-Grass	*Halophila johnsonii*	Critically Imperiled	—	Sandy marine bottoms
Hairy Beach Sunflower	*Helianthus debilis* ssp. *vestitus*	Imperiled	Candidate (1)	Dunes, Sandy clearing
Manchineel	*Hippomane mancinella*	Rare	—	Dry knolls near marsh
Henry's Spider-Lily	*Hymenocallis henryae*	Critically Imperiled	—	Swamp
Broad-Leaved Spider-Lily	*Hymenocallis latifolia*	Rare	—	Mangrove, coastal swale
Inkwood	*Hypelate trifoliata*	Imperiled	—	Dry knoll near marsh
Delta Tule-pea	*Lathyrus jepsonii* ssp. *jepsonii*	Imperiled	Candidate (2)	Salt Marsh
Seabeach Pigweed	*Lechea maritima* var. *virginica*	Imperiled	—	Dunes
Panhandle Lily	*Lilium iridollae*	Critically Imperiled	Candidate (2)	Bogs, swamp
Sand Flax	*Linum arenicola*	Critically Imperiled	Candidate (2)	Pine rockland
Carter's Small-Flowered Flax	*Linum carteri* var. *carteri*	Critically Imperiled	Candidate (1)	Pinelands
Carter's Large-Flowered Flax	*Linum carteri* var. *smallii*	Imperiled	Candidate (1)	Disturbed soil, limestone
Humbolt Owl's Clover	*Orthocarpus castillejoides* var. *humboldtiensis*	Imperiled	Candidate (2)	Salt Marsh

Table 1. Continued

Common Name	Name	TNC Designation[a]	Federal Designation[b]	Habitat
Semaphore cactus	*Opuntia spinosissima*	Critically Imperiled	Candidate (2)	Dry knolls near marsh
Big Pine Key Prickly Pear	*Opuntia triacantha*	Imperiled	Candidate (2)	Sand, back beach
Florida Five-Petal	*Phyllanthus pentaphyllus* ssp. *floridanus*	Rare	Candidate (2)	Pinelands on limestone
Boykin's Few-Leaved Milkwort	*Polygala boykinii* var. *sparssifolia*	Imperiled	Candidate (2)	Pinelands on rock
Sea-Beach Knotweed	*Polygonum glaucum*	Rare	—	Beach
Alkali-Grass	*Puccinellia laurentiana*	Rare	—	Gravel Shore
Florida Royal Palm	*Roystonea elata*	Imperiled	Candidate (1)	Woodlands
Miami Palmetto	*Sabal miamiensis*	Critically Imperiled	—	Pinelands/scrub
Florida Water-Parsnip	*Sium floridanum*	Critically Imperiled	Candidate (2)	Woodlands
Mammals				
Duke's Salt Marsh Vole	*Microtus pennsylvanicus dukecampbelli*	Critically Imperiled	Candidate (2)	Salt Marsh
Key Largo Woodrat	*Neotoma floridana smalli*	Critically Imperiled	Endangered	Woodland
Key Deer	*Odocoileus virginianus clavium*	Critically Imperiled	Endangered	Woods, Mangroves
Southeast Beach Mouse	*Peromyscus polionotus niveiventris*	Critically Imperiled	Threatened	Beach/Dune
Anastasia Beach Mouse	*P.p. phasma*	Critically Imperiled	Endangered	Salt Marsh
Perdido Key Beach Mouse	*P.p. trissyllepsis*	Critically Imperiled	Endangered	Sand Beach
Florida Mouse	*Podomys floridanus*	Rare	Candidate (2)	Pine/Scrub
Key Vaca Raccoon	*Procyon lotor auspicatus*	Imperiled	Candidate (2)	Streams
Salt-Marsh Harvest Mouse	*Reithrodontomys raviventris*	Imperiled	Endangered	Salt Marsh
Mangrove Fox Squirrel	*Sciurus niger avicennia*	Imperiled	Candidate (2)	Pineland
Lower Keys Cotton Rat	*Sigmodon hispidus exsputus*	Imperiled	—	Woodland/Fresh marsh
Insular Cotton Rat	*S.h. insulicola*	Imperiled	—	Saltmarsh, Pine woods
Lower Keys Marsh Rabbit	*Sylvilagus palustris* ssp. *hefneri*	Imperiled	Endangered	Salt and fresh marsh
West Indian Manatee	*Trichechus manatus*	Imperiled	Endangered	Warm brackish/salt water
Birds				
Roseate Tern	*Sterna dougallii*	Rare	—	Sand Beach
Cape Sable Sparrow	*Ammodraums maritimus maritimus*	Critically Imperiled	Endangered	Fresh/Brackish marsh
Florida Prairie Warbler	*Dendroica discolor paludicola*	Rare	—	Mangroves
Florida Clapper Rail	*Rallus longirostris scottii*	Rare	—	Sandy Areas/Shoreline
California Clapper Rail	*Rallus longirostris obsoletus*	Critically Imperiled	Endangered	Salt Marsh
Mangrove Clapper Rail	*Rallus longirostris insularum*	Rare	Candidate (2)	Mangroves
Reptiles/Amphibians				
Loggerhead Sea Turtle	*Caretta caretta*	Rare	Threatened	Marsh, Beach
Green Sea Turtle	*Chelonia mydas*	Rare	Endangered	Sand Beach
American Crocodile	*Crocodylus acutus*	Imperiled	Endangered	Mangrove, bays
Leatherback Sea Turtle	*Dermochelys coriacea*	Rare	Endangered	Sand Beach

Table 1. Continued

Common Name	Name	TNC Designation[a]	Federal Designation[b]	Habitat
Hawksbill Sea Turtle	*Eretmochelys imbricata*	Rare	Endangered	Sand Beach
Lower Key Striped Mud Turtle[c,d]	*Kinosternon baurii*	Imperiled	—	Fresh/Brackish marsh
Kemp's Ridley Sea Turtle	*Lepidochelys kempii*	Critically Imperiled	Endangered	Sand Beach
Lower Key Brown Snake[c]	*Storeria dekayi*	Critically Imperiled	—	Woodlands to salt marsh
Lower Key Ribbon Snake[c]	*Thamnophis sauritus*	Critically Imperiled	—	Forests, swamps
Fish				
Mangrove gambusia	*Gambusia rhizophorae*	Rare	—	Mangrove
Florida Keys Sailfin Molly[c,d]	*Poecilia latipinna*	Imperiled	—	Swamps
Key Blenny	*Starksia starcki*	Critically Imperiled	—	Coral reef
Insect				
Northeastern Tiger Beetle	*Cicindela dorsalis dorsalis*	Imperiled (Var.)	Threatened	Sand Beach

a. The Nature Conservancy classifies a species as "Rare" (G3) if it is either very rare and local throughout its range, or found locally in a restricted range, or because of other factors making it vulnerable to extinction throughout its range. A species is designated as "Imperiled" (G2) if there are only 6 to 20 occurrences or few remaining individuals, or because of some factor(s) making it very vulnerable to extinction throughout its range. A species is listed as "Critically Imperiled" (G1) because of extreme rarity (5 or fewer occurrences or very few remaining individuals) or because of some factor(s) making it especially vulnerable to extinction (Morse 1987).

b. Federal candidate species designation: (1) Substantial information supporting listing has been assembled, (2) Additional information needed to clarify status.

c. Lower Florida Keys population only.

d. Questionable taxonomic designation.

both game and non-game birds by censuses during the breeding season. Of the 21 non-passerine (non-songbird) bird species exhibiting significantly declining population trends between 1980 and 1989, 4 (19 percent) are associated with coastal wetlands during some seasons (green-backed heron, northern pintail, common moorhen, and American avocet). The populations of several coastal species have declined significantly over even longer periods of time. Over the past 25 years, some 30 percent of the 20 non-passerine species with significantly declining populations are associated with coastal wetlands or estuaries during some seasons (American bittern, American black duck, northern pintail, northern harrier, common tern, and black tern; S. Droege, U.S. Fish and Wildlife Service, Personal Communication, 10 September, 1990).

In sum, the coastal fringe already contains a significant number of rare and endangered species, and population trends suggest that other species may be headed toward endangerment. It is against this background that the potential increased threats associated with climate change must be examined. *(See Chapter III.)*

Coastal Habitats

One of the chief causes of species endangerment is the loss of habitats (Reid and Miller 1989), and habitat destruction also results in the loss of important ecological services. A complete analysis of the status of coastal habitats would include discussions of wetlands, barrier islands, coral reefs, mangroves, sea grass beds, estuaries, rocky intertidal, marine benthic communities, and other habitats. Unfortunately, sufficient data to provide a clear picture of status and trends exist only for coastal wetlands.

The loss of coastal wetlands (including salt and tidal marshes) provides a graphic picture of how coastal development in the United States affects biological diversity. Between the mid-1950s and mid-1980s, approximately 20,000 acres of coastal wetlands were lost per year in the contiguous United States, amounting to a conversion of 8.3 percent over this period (OTA 1984).[6] In the mid-1970s, 4.4 million acres of coastal wetlands remained in the United States. The losses of coastal wetlands were concentrated in the Gulf states (Louisiana, Florida, and Texas), but were also significant in New Jersey, New York, and California. During this period, New Jersey was losing 3,097 acres per year, and Chesapeake Bay some 500 acres per year (Tiner 1985, 1987).

“Between the mid-1950s and mid-1980s, approximately 20,000 acres of coastal wetlands were lost per year in the contiguous United States, amounting to a conversion of 8.3 percent over this period.”

Aggregate figures of coastal wetlands loss, however severe, obscure particularly dramatic changes in certain regions. For example, between 1950 and 1967, San Francisco Bay (and the adjoining Suisun Bay) lost 192,000 out of 294,000 acres of estuarine and wetland habitat (Jensen et al. 1990), and by the mid-1970s only 20 percent of the Bay's original wetlands remained (Tiner 1984). California as a whole lost nearly 53 percent of estuarine and wetland acreage during this time. Similarly, northern New Jersey lost 75 percent of its coastal wetlands between 1925 and 1975 (Tiner 1985). In Louisiana, an area of coastal wetlands greater than the size of Rhode Island was lost between 1900 and 1985.

In the 1970s, state wetlands protection acts and federal regulations associated with Section 404 of the Clean Water Act dramatically reduced the rate of loss of coastal wetlands. Before the Wetlands Act passed in 1973, Delaware was losing almost 450 acres of coastal wetlands each year. After 1973, losses dropped to 20 acres annually (Tiner 1984). In Massachusetts, where 20 percent of saltwater wetlands acreage was lost between 1951 and 1971, only five acres are thought to have been lost through human action in the decade beginning in 1978, when stringent coastal wetland regulations for salt marshes were adopted (McCreary and Adams 1988).[7]

By most accounts, wetlands on both the east and west coasts are now well protected by state laws from the threats they have faced in the past. All coastal states in the lower 48, except Texas and Georgia, have now adopted laws to protect coastal wetlands. Overall, the National Marine Fisheries Service estimates, by 1981 the loss of coastal saltwater wetlands had been reduced by 70 to 85 percent since the 1960s. However, by this time many states had already lost most of their coastal wetlands and the need for preservation of the remaining acreage was readily apparent. In Massachusetts, for instance, less than 6.5 percent of all coastal land is undeveloped.

Massive losses of coastal wetlands continue only in the Gulf states, where the hydrology of the Mississippi river has been altered and the coastal plain is subsiding. *(See Box 1.)* More than 50 square miles of coastal wetlands are being lost in Louisiana each year. Relative sea level rise in the Mississippi delta is approximately 12 to 13 mm per year, comparable to the predicted rate of sea level rise under global warming scenarios. *(See Chapter III.)*

The scattered information available on the status of other coastal ecosystems suggests that these too are under considerable stress. Barrier island ecosystems have changed from *de facto* wilderness to the focus of intense development pressure in a matter of decades. Prior to World War II, only 28 percent of all U.S. barrier islands were subject to development pressure, but by 1980 the figure had increased to 70 percent (Millemann 1988). Beach ecosystems, with their important nesting habitats for birds and sea turtles, have similarly been disturbed by pollution, recreational use, and the construction of jetties, groins, and bulkheads. And coral reefs have been lost to sedimentation and pollution. Coral reefs north of Miami have suffered from sedimentation caused by dredging, and sewage had similarly detrimental impacts on corals in Florida before more stringent water quality standards were put in place in the 1970s. The quantity and health of corals has also declined in response to increased recreational fishing, coral gathering, and contamination by sewage, as well as to the destructive impact of anchors.

Clearly, the nature of the problem affecting coastal habitats is changing. No longer is the primary threat to wetlands and other coastal ecosystems the massive habitat loss associated with the

Box 1. Wetlands Loss in the Mississippi Delta

The Mississippi River delta contains 41 percent of the coastal wetlands of the contiguous United States. The annual biological productivity of the delta is extremely high—each year Louisiana ranks first nationally in tonnage of fisheries landings, and the wetlands support the largest fur harvest in the United States, the largest concentrations of overwintering waterfowl, and most of the marine recreational fishing landings. Many people who live on the low natural levees of former river distributaries have traditionally made their living by harvesting the abundant natural resources of the delta's wetlands.

When sea level rise slowed about 6,000 years ago, the Mississippi River was depositing its sediments at approximately the latitude of Baton Rouge, which is now about 320 km (100 miles) upriver from the active delta. Over the last 6,000 years, the Mississippi River created seven major deltas by abandoning its channel seven times and switching to new, shorter routes to the Gulf. Once abandoned, each old delta began to subside below sea level, and its many wetlands reverted to open water.

> **"Between 1900 and 1985, an estimated 400,000 acres of coastal wetlands were lost in Louisiana, an area 1.3 times the size of Rhode Island."**

The long-term net gain of land that characterized the Mississippi River delta for 7,000 years reversed itself about 100 years ago. In 1980, the land loss rate was estimated to be 100 km^2/yr (40 mi^2/yr) within the delta itself and 130 km^2/yr (50 mi^2/yr) for all of coastal Louisiana. This amounts to a loss of some 100 acres per day. More recent studies have pushed the rate of loss up to more than 150 km^2/yr. Between 1900 and 1985, an estimated 400,000 acres of coastal wetlands were lost in Louisiana, an area 1.3 times the size of Rhode Island. This lost wetland area, worth at least $3,000/acre in terms of recreation and biological productivity, represents a loss in excess of $3 billion.

A major underlying cause of wetland loss in Louisiana is subsidence, or submergence of the land surface. But probably the single greatest reason for wetland loss in Louisiana is the reduction in sediment available to maintain accretion rates. As numerous studies have indicated, the suspended sediment load of the Mississippi River has decreased substantially since the early 1960s. This change stems from the damming of many Mississippi River tributaries, improved soil conservation practices which lessened rates of erosion, the mining of sand deposits along river for industrial use, and the dredging and on-land disposal of river sediments.

Adding insult to injury, artificial levees have confined the Mississippi along practically its entire length from Cairo, Illinois southward, and various control structures have blocked or restricted river flow in natural distributary delta channels. As a result, less sediment is available for deltaic sedimentation and barrier island nourishment while valuable delta-building sediments are being funneled out onto the slopes of the outer continental shelf. Coupled with subsidence and the sediment deficit, shoreline erosion has resulted in the loss of some 10 percent of the coastal wetlands, and such activities as dredging channels and land "reclamation" have also damaged wetlands area directly.

Wetlands loss in Louisiana has been greatest in more inland fresh-to-brackish marshes, which have historically depended upon overbank flooding from the Mississippi River and its former distributaries to supply sediments. Marshes closer to the ocean are subject to greater sedimentation because of the higher tidal energy; consequently, they have not lost as much area.

Although the rates of wetlands loss are truly alarming, and bode ill for New Orleans and other cities built on the deltaic plain, the human influence on this hydrological system is already so massive that few practical responses seem capable of stemming the loss. Declining rates of oil extraction may slow subsidence somewhat, as might regulating Mississippi River flow so as to increase sediment transport, but even with such changes substantial wetland area will continue to be lost in the Mississippi Delta with or without increased rates of sea level rise.

Source: Turner 1990, Meyer-Arendt 1990, Templet and Meyer-Arendt 1988.

development of coastal infrastructure in the 1950s and 1960s. Instead, the cumulative effects of continued habitat loss, pollution, overharvesting, and increased recreational use are now to blame. One of the most ominous trends affecting coastal habitats is the rapid growth of the human population taking place in coastal areas. *(See Box 2.)* Population trends indicate that coastal resource managers will be fighting an uphill battle to maintain biological diversity as pressures on coastal ecosystems mount.

National Monuments include significant coastal habitats (USFWS 1989). Federal and state protected areas and wildlife refuges now protect substantial fractions of some key coastal wetlands. For example, nearly 50 percent of San Francisco Bay wetlands are now under some form of protection, though this coverage amounts to only 10 percent of the original acreage of wetlands in the Bay. In addition, seven Marine Sanctuaries were established in the United States between 1975 and 1987 (with a total area of 2,350 square nautical miles), and a network of 17 Estuarine Research Reserves covering nearly 400,000 acres was established between 1974 and 1985 (CEQ 1989).

Box 2. Trends in Coastal Human Populations

By 2010, the coastal population of the United States will have grown 60 percent larger than it was in 1960 to more than 127 million people. *(See Figure 1.)* In Florida alone, coastal population will have increased more than threefold, from 5 million to 16 million, over the same period. Seventeen of the twenty states with the largest statewide population increases expected over the thirty-year period are coastal, and only 5 percent of coastal counties are expected to lose residents. In general, coastal population density is increasing strikingly. In 1960, the overall population density in the United States (excluding Alaska) was 61 people per square mile, compared to 248 persons per square mile in coastal counties. By 1988, population density in coastal counties reached 341 persons per square mile, more than four times the U.S. average in that year.

Not surprisingly, the growth in use of public lands in coastal areas has grown in step with the growing coastal population. Since 1979, recreational visits to the 24 National Parks, National Seashores, and National Monuments that include coastal ecosystems has increased by 63 percent. *(See Figure 2.)* This 5-percent annual growth rate in visitation is more than five times larger than the annual growth of population in coastal counties. In the ten National Seashores, visitation increased by 78 percent over the past decade.

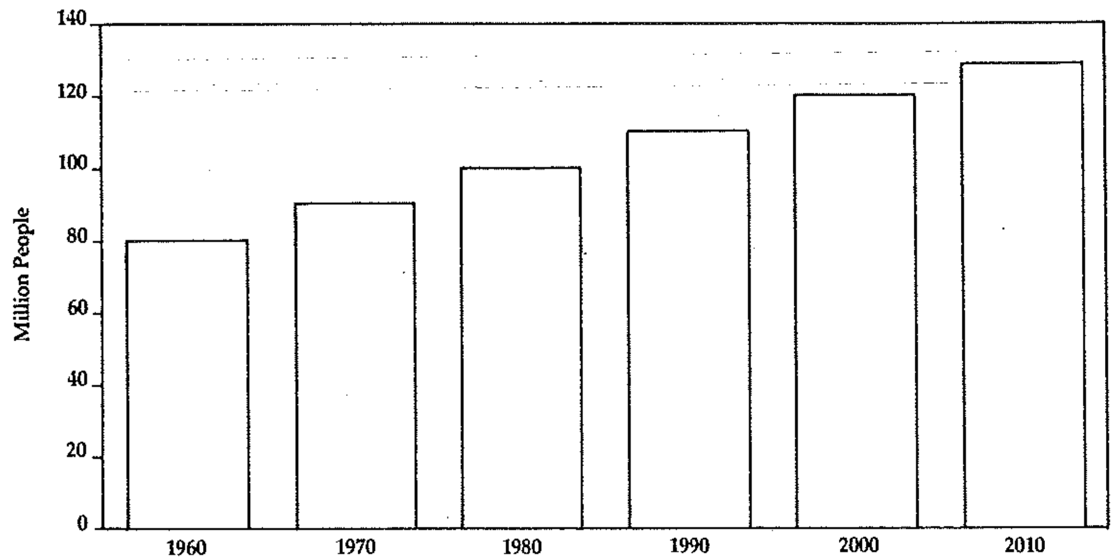
Source: Culliton et al. 1990, NPS 1981 to 1989.

> **"Federal and state waterfowl managers agree that another roughly 386,000 acres of coastal wetlands in Louisiana need to be protected to provide adequate waterfowl habitat."**

In recognition of the considerable threats to coastal areas, steps have been taken to protect key habitats. State or federal protected areas networks now include a significant acreage of coastal wetlands. *(See Figure 3.)* Some 117 Fish and Wildlife Service Refuges in coastal areas in the contiguous United States cover an area of 2,230 square miles, and 24 National Parks, National Seashores, and

But does this level of habitat protection meet real needs? By all accounts, the area of wetland habitat currently protected will not. Even though acquiring additional coastal wetlands has not been a high priority of federal legislation, federal and state waterfowl managers have determined that another roughly 386,000 acres of coastal wetlands in Louisiana need to be protected to provide adequate waterfowl habitat. Doing so could mean establishing parks or refuges but may instead involve land management practices other than land purchase, including regulatory and incentive-based interventions. Along the Atlantic Coast, another 50,000 acres of coastal wetland habitat must be protected to provide adequate migration and wintering grounds for the Black Duck (Chandler 1988). In California, the State Legislature has directed California Fish and Game to increase inland and coastal wetland acreage by 50 percent by the year

Figure 1. Population Growth Projections for Coastal United States Counties



Source: Culliton, (1990)

2000 so that wildlife populations can be maintained at present levels (Jensen et al. 1990).

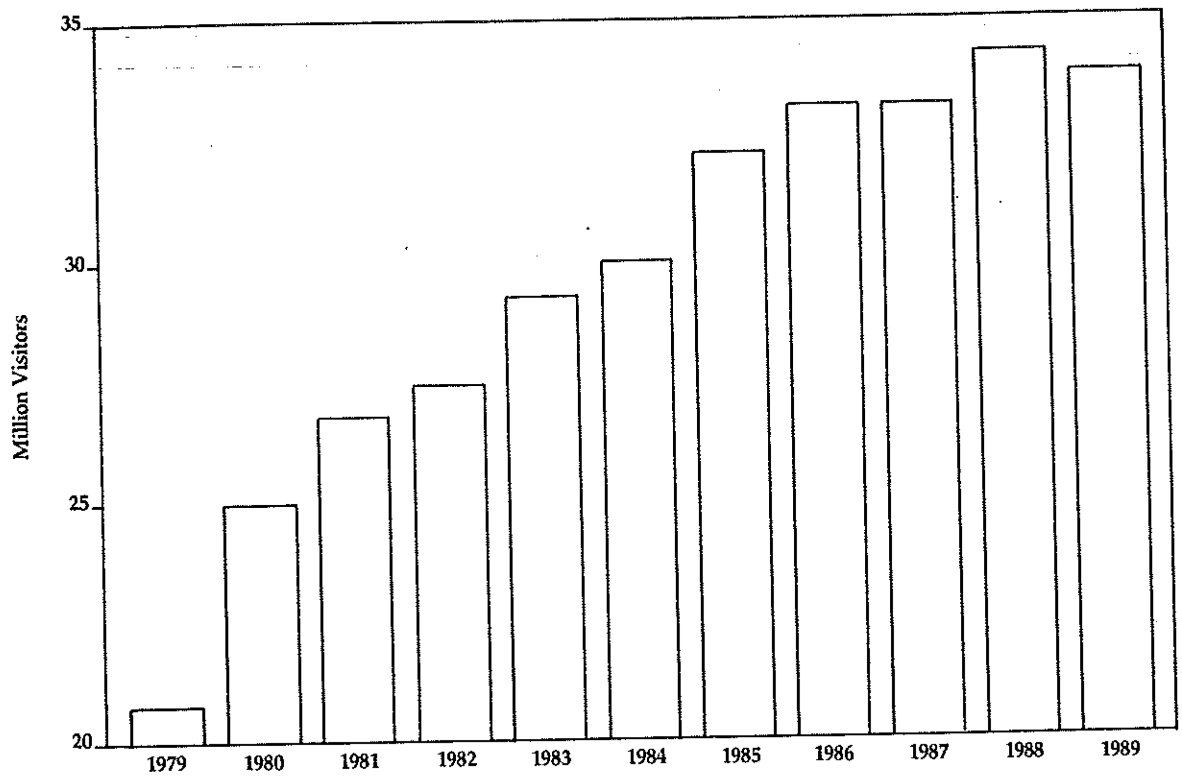
Moreover, as important as marine and coastal protected areas are for ensuring the conservation of biodiversity, protecting an area does not necessarily protect biodiversity. Management practices, the protected area's proximity to other areas of natural habitat, and the size of the protected area can all influence the odds of maintaining biodiversity. *(See Box 3.)* This is especially true in coastal ecosystems since harvests of fish or discharges of pollutants many kilometers away can affect a marine protected area and increased sedimentation or pollution from upstream land-use practices could damage protected wetlands or reefs.

Ecological Processes

Although seldom considered *components* of biodiversity themselves, ecological processes are certainly *products* of a region's biodiversity. Indicators of the status of ecological processes can thus shed light on the status of the underlying biodiversity. One of the most widespread impacts on coastal ecological processes is pollution, and despite gains made in past decades, pollution remains a serious threat today. Some 5 million to 20 million gallons of oil were spilled in U.S. waters each year in the 1980s. *(See Figure 4.)* In 1980, about 35 percent of sewage effluents generated nationwide were discharged into coastal and marine waters (CEQ 1989). In 1985, only 58 percent of the total U.S. coastal zone classified as shellfish growing area was unconditionally approved for shellfish harvest (CEQ 1989). In addition, although pollution controls have cut the amounts of such trace metals as lead and cadmium in coastal areas, copper contamination of oysters and mussels rose strikingly between the late-1970s and the late-1980s (Lauenstein et al. In Press). *(See Figure 5.)* Similarly, one study of trends in contaminant levels in mollusks since 1986 indicates that while concentrations of cadmium and chlorinated organic compounds such as PCBs are decreasing, contamination by mercury and selenium is growing (NOAA 1989).

One impact of these pollutants on ecological processes in coastal ecosystems can be seen in the apparent increase in the number of toxic algal blooms worldwide in recent years. These blooms are apparently caused by eutrophication resulting from the excess nutrients dumped into coastal waters. At a recent conference on Ocean Margins and Global Change, scientists noted that eutrophication seems to be taking place at the mouths of almost all of the world's rivers (Cherfas 1990). In 1988, a phytoplankton bloom was linked to mass deaths of dolphins off the Carolinas. The bloom

Figure 2. Recreational Visits to Twenty-Four National Parks, National Seashores, and National Monuments that Include Coastal Ecosystems



Source: National Park Service, (1980-1989)

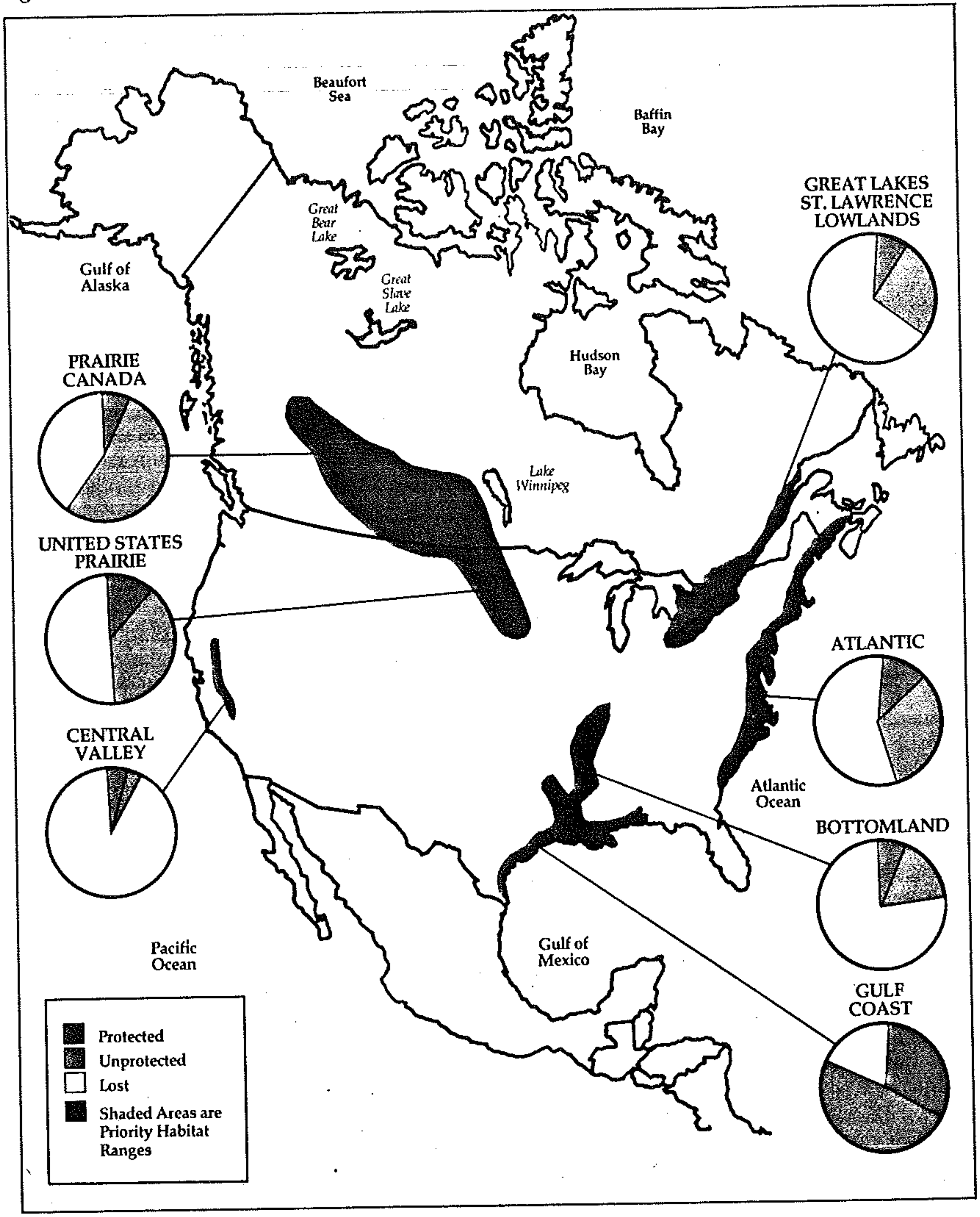
was caused by a species formerly restricted to the Gulf Coast of the United States and its spread to the East Coast may trace back to the increasing quantity of nutrients in these coastal waters.

For decades, coastal ecosystems, particularly wetlands, have been valued for their high productivity and for their contributions to the functioning of adjacent ecosystems. Wetlands were thought to export large quantities of nutrients to adjacent waters, and it was believed that these nutrients were largely responsible for the high fish and shellfish productivity associated with estuarine and coastal ecosystems. More recent evidence indicates that this "outwelling" phenomenon is a less important source of carbon and nutrients than had been thought (Nixon 1980). Finfish and shellfish production in estuaries without significant acreage of marsh can be at least as high as production in estuaries with such areas.

Yet, coastal wetlands do still contribute to nearshore productivity. For example, saltmarsh plants like cordgrass *(Spartina)* are an important source of carbon for estuarine consumers (Haines 1977, Peterson et al. 1986). Similarly, in a mangrove-dominated estuary in Malaysia, mangroves supplied more than 55 percent of the carbon in a commercially important species of clam, 30 to 100 percent of the carbon in a species of shrimp, and 60 percent of the carbon in the fishes inhabiting the inlets (Rodelli et al. 1984).

Besides the outwelling of nutrients to estuaries and coastal waters, nutrient transport also takes place via the food chain. For example, New Jersey's high intertidal marshes are the primary sites for the reproduction and growth of many saltmarsh killifishes, which move into intertidal creeks in the fall and become an important prey for larger estuarine and marine species (Talbot and Able 1984). Similarly, the Atlantic croaker *(Micropogonias undulatus)* and spot *(Leiostomus xanthurus)* accounted for 6 to 14 percent of the material flow out of a saltmarsh in the Gulf of Mexico (Currin et al. 1984).[8]

Figure 3. Status of Wetland Habitat in Key Waterfowl Wintering Areas



Source: North American Waterfowl Management Plan, (USDI, 1986)

Box 3. Does the *Area* Protected Equal the *Biodiversity* Protected?

Habitat conservation is an important component of biodiversity conservation, but it is misleading to consider the total "area" of habitat conserved a sufficient measure of the status of biodiversity. At least three other important considerations related to the habitat area conserved have direct implications for species diversity, an important component of biodiversity.

First, *management can profoundly affect the species present in an ecosystem and its functioning.* For example, many coastal wildlife refuges are managed primarily as wintering waterfowl habitat, but this management goal often conflicts with the management of the habitat for non-game species. Such conflicts are not restricted to game versus non-game species. Managing wetlands to save the endangered salt marsh harvest mouse in the San Francisco Bay makes it difficult to save the endangered clapper rail under scenarios of sea level rise since the mouse may need well-maintained dry diked areas while the rail may do better under more natural wetland conditions (Shellhammer 1989).

Second, *in any habitat, the number of species at risk of extinction increases exponentially with the loss in area* (Reid and Miller 1989). With, say, pollutant assimilation or fish production, the ecosystem function decreases in direct proportion to the amount of wetland area lost. But this guideline doesn't hold in the case of wetlands' role in providing viable habitats for plant and animal species. A rule of thumb is that losing 90 percent of a habitat will doom 50 percent of its species to extinction. But if the area of habitat lost is increased by another 5 percent, the percent of species at risk would increase by 15 percent.

Third, from the standpoint of maintaining viable species populations, *the extensive fragmentation of wetlands may be as damaging as the loss of habitat area itself.* Even though isolated pockets of wetland habitat along disturbed and developed coastlines have become critical reservoirs for biodiversity, the species they contain face significantly increased threats. Where previously a local population of a species that was wiped out by a serious storm would quickly be re-established by immigrants from adjoining wetlands, populations in isolated fragments may be permanently exterminated. Fragmentation also presents serious difficulties for migrant birds, which need suitable habitat to rebuild energy reserves during seasonal migrations.

Although the continuing degradation of coastal ecosystems will have somewhat less impact on adjacent ecosystems than scientists believed ten years ago, there remain important energy and nutrient linkages among coastal ecosystems that are influenced by habitat loss or degradation.

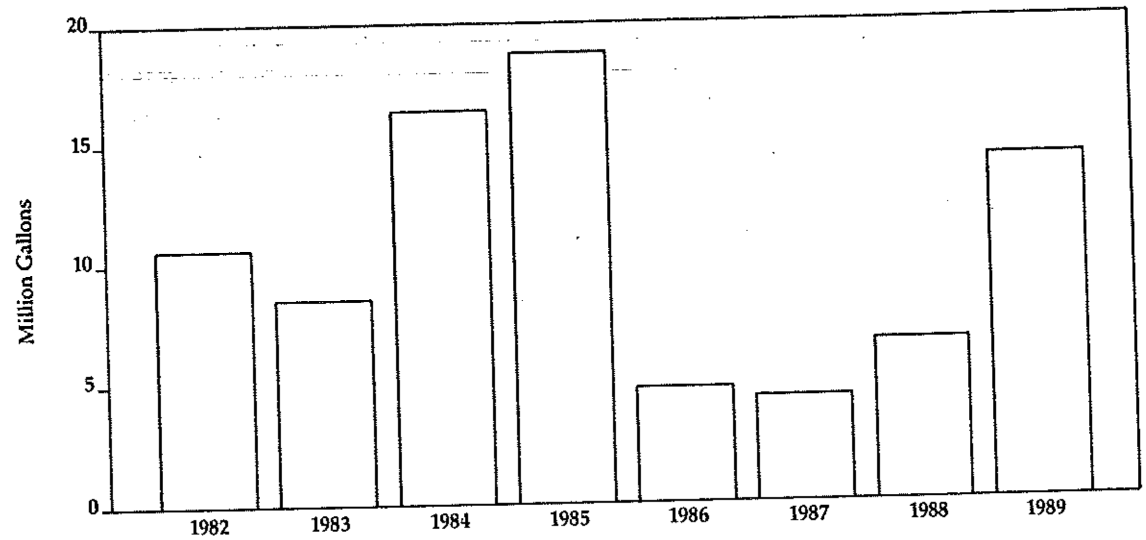
Economic Indicators of Coastal Biodiversity's Status

It is difficult to assign dollar values to the many benefits of coastal biodiversity. Biological resources traded in economic markets represent only the tip of the iceberg—many aspects of biodiversity are essential for the continued services we obtain from coastal ecosystems but they are not bought and sold. Nonetheless, where economic assessments can be made, they are valuable indicators of the status and trends of coastal biodiversity, particularly since relatively long-term data are often available for these indicators. Moreover, these ecological services directly benefit people—one principal reason for local concern and government action to maintain biodiversity.

Commercial fishing and waterfowl hunting are two important industries that rely heavily on healthy coastal ecosystems. Commercial fishing is a major U.S. industry, with landings valued at $3.2 billion in 1989. Nine of the 20 most important U.S. fisheries involve species that depend on coastal ecosystems for at least some part of their life cycle. *(See Table 2.)* These species account for 51 percent of the value of harvest from these 20 fisheries and 44 percent of the tonnage.

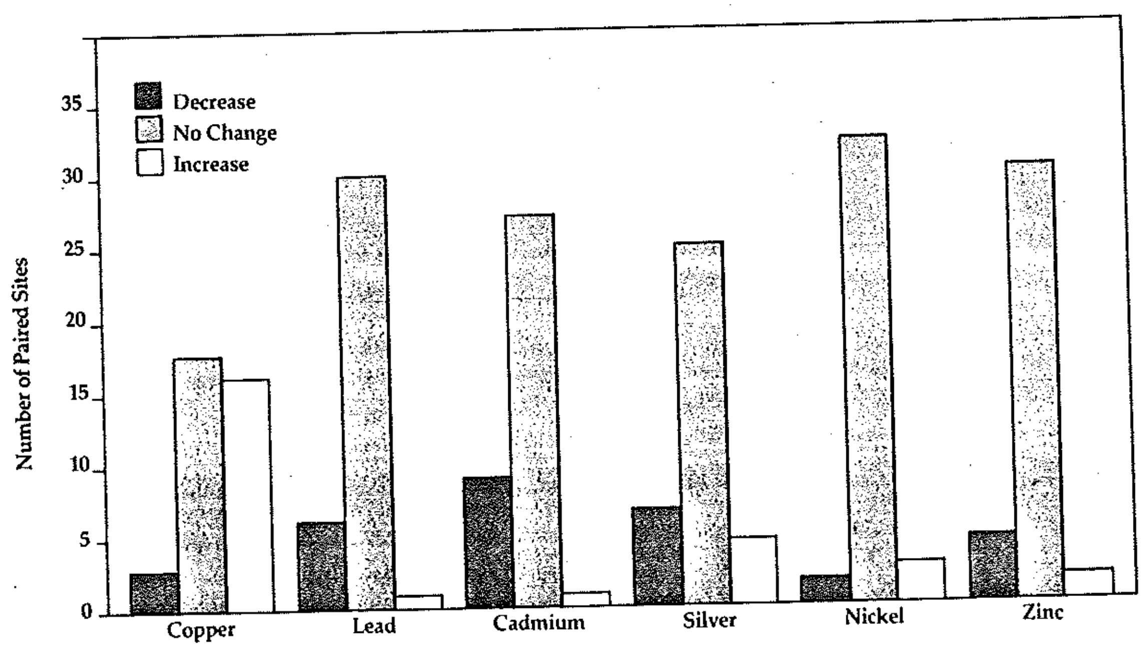
Trends in coastal fish harvests present a disturbing picture of the status of coastal ecosystems. Serious population declines of many commercially important coastal species are significantly reducing their contribution to human economies. Between 1970 and 1989, the harvest of oysters dropped by 44 percent and landings of spiny lobster declined by 34 percent. *(See Figure 6.)* Similarly, commercial landings of striped bass have declined continuously since 1973, with a fall of 92 percent since 1982.[9] Landings are not equivalent to population trends, since they reflect both population size and fishing effort. But in both the oyster and lobster fisheries, the price offered per pound to fishermen

Figure 4. Gallons of Oil Spilled in United States Waters



Source: United States Coast Guard, D.A. Lentsch, personal communication, (August 29, 1990)

Figure 5. Trace Metal Contamination in Coastal Ecosystems



Each bar represents the number of paired coastal sampling sites in which a comparison of tissue metal concentrations in samples of mussels or oysters between samples taken in the late-1970s and the late-1980s exhibited a significant decrease or increase or no significant change. A total of 36 paired sites was used for the study.

Source: Lauenstein, *et al.*, (in press)

Table 2. 1990 Commercial Fish and Shellfish Harvest—Top Twenty Species by Value.

Species	Coastal Dependent	Quantity (1000 lb)	Value ($1000)
Salmon (5 species)	yes	785,868	591,234
Shrimp (spp. all coasts)	yes	351,514	467,571
Pollock (Atlantic and Alaska)	no	2,385,237	196,843
Lobster (American and Spiny)	yes[a]	61,051	175,562
Snow (tanner) crab	no	164,643	160,082
Sea Scallops	no	33,757	132,594
Flounder (spp. all coasts)	yes[b]	202,489	119,831
King Crab	no	26,391	106,204
Tuna (all species)	no	89,413	103,543
Cod (Atlantic and Pacific)	no	450,560	103,147
Halibut	no	75,168	85,145
Menhaden (Atlantic and Gulf)	yes	1,988,726	84,462
Oyster	yes	29,926	83,585
Blue Crab	yes	206,720	80,989
Sablefish	no	97,590	73,272
Dungeness Crab	yes	40,984	45,534
Hard Clams	yes	9,278	44,925
Rockfish	no	133,623	42,338
Swordfish	no	11,768	38,321
Sea Herring (Atlantic and Pacific)	no	209,003	29,432
Total Coastal Dependent		2,890,688	$1,102,459
Total Oceanic		3,677,153	$1,070,921

Notes:
a. Species utilize near-shore coastal areas, but not wetlands or estuaries.
b. Species vary considerably in their use of coastal and estuarine habitats.

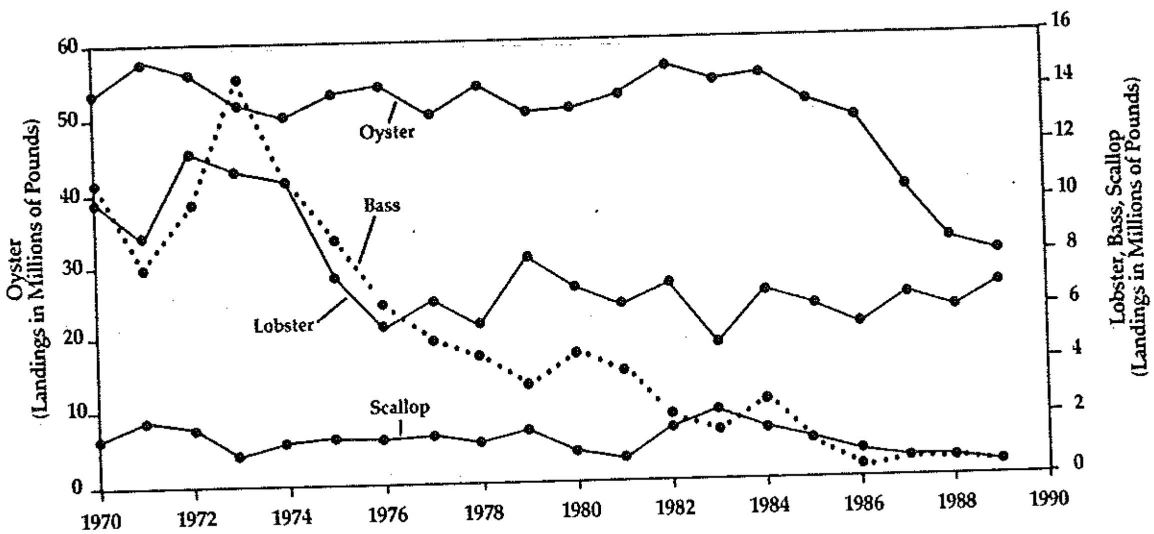
has increased over the last decade (adjusted for inflation) and so fishing intensity is unlikely to have decreased.

> **“Declines of fish and other populations have many causes and in no case is habitat loss or degradation the only one.”**

Other fisheries dependent on coastal ecosystems show similar declines. Between 1983 and 1989, landings of bay scallops fell by 88 percent. For all three species of scallops (bay, sea, calico), landings declined by 50 percent between 1975 and 1985, with catch per unit effort in 1985 also reaching historically low levels (CEQ 1989).

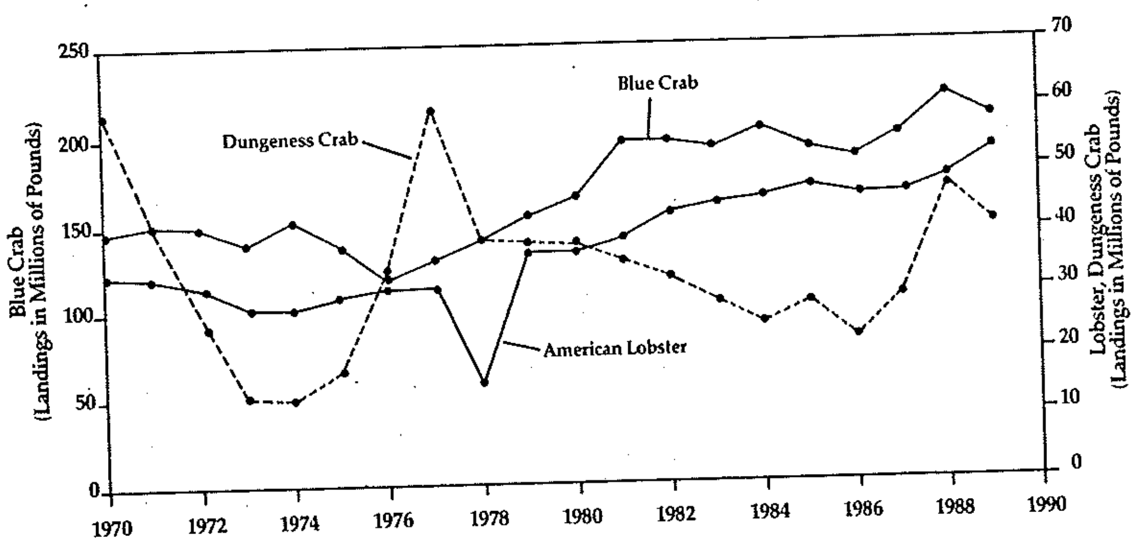
Declines of fish and other populations have many causes and in no case is habitat loss or degradation the only one. Oyster harvest is thought to have declined due to a combination of drought, disease, hurricane, water pollution, loss of coastal habitat, and overharvesting. Factors implicated in striped bass population declines include overharvesting, chemical contamination, habitat loss, and hybridization with other species. Further evidence that habitat loss and degradation is not solely to blame for these trends can be seen in the fact that several other coastal-dependent fisheries are apparently holding their own or even increasing in population. Landings of the American lobster have increased by 56 percent over the past two decades, and both blue crab and dungeness crab yields have increased or at least remained constant. *(See Figure 7.)* Such differences in population trends may exist

Figure 6. Trends in Landings in Fisheries Dependent on Coastal Ecosystems (Oyster, Spiny Lobster, Striped Bass, Bay Scallop)



Source: National Marine Fisheries Service, (1980-1989)

Figure 7. Trends in Landing in Fisheries Dependent on Coastal Ecosystems (Blue Crab, American Lobster, Dungeness Crab)

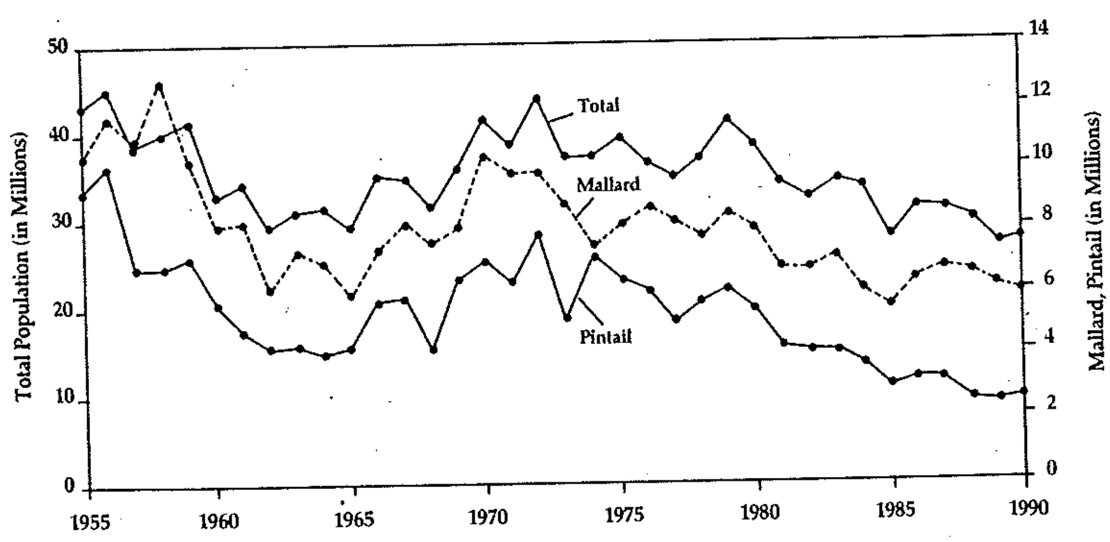


Source: National Marine Fisheries Service, (1980-1989) in part because not all marine species depend equally on coastal ecosystems. Nevertheless, clear evidence indicates that many coastal-dependent fisheries are under stress.

The coastal species whose declining populations have received most attention are ducks, many of which winter in coastal wetlands or estuaries. Among ten species accounting for over 97 percent of the North American breeding duck population, populations declined by 34 percent between 1970 and 1989 (Reynolds 1990). *(See Figure 8.)* Species in the Atlantic flyway have declined particularly dramatically, with populations dropping by nearly 50 percent since the mid-1960s (Flather and Hoekstra 1989). Although all ten species use coastal wetlands and estuaries in the winter, the canvasback, redhead, and scaup are particularly dependent on coastal ecosystems. The canvasback population declined significantly from 1980 to 1985—apparently because of habitat degradation and a decline in its preferred winter food (wild celery and other submerged aquatic vegetation) through much of its range—but has recovered somewhat since. *(See Figure 9.)* Redhead populations increased somewhat from the early-1960s to the early-1980s, but since 1986 populations have fallen by over 30 percent. Scaup populations too have declined over the past decade, falling by 38 percent from their recent peak in 1979.

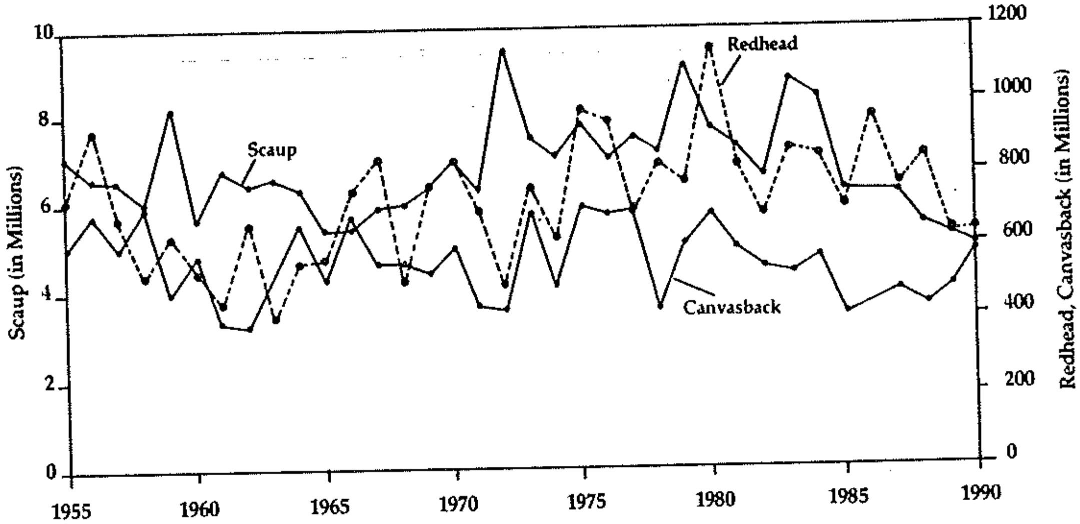
Not all waterfowl have shown such striking population declines. Goose populations, for example, have actually increased by nearly 75 percent between 1966 and 1982, apparently because conditions on their more northerly breeding grounds have improved. In addition, geese have benefitted from the expansion of cropland acreage: they forage in fields during winter and now breed in previously unused nesting habitat (Flather and Hoekstra 1989). But as with fisheries populations, the significant population declines among many species that utilize coastal ecosystems demonstrate that components of the biodiversity of coastal ecosystems are under serious stress.

Figure 8. Waterfowl Population Trends 1955 to 1990. Total Populations of Ten Most Abundant Ducks, Populations of Mallards and Pintails



Source: Reynolds, *et al.*, (1990)

Figure 9. Waterfowl Population Trends 1955 to 1990. Population Trends for Three Species Highly Dependent on Coastal Ecosystems During Winter



Source: Reynolds, *et al.*, (1990)

III. GLOBAL WARMING: AN ADDITIONAL STRESS ON COASTAL BIODIVERSITY

Undisturbed ecosystems can often "absorb" surprisingly large impacts without changing dramatically, but for ecosystems that are already threatened—among them, U.S. coastal ecosystems—added pressure may prove disastrous. The potential impacts of climate change represent such an "added pressure." A solid scientific consensus exists that the human-caused increase in concentrations of "greenhouse gases" in the atmosphere will commit the planet to an increase in global temperatures of some 1° to 3°C during the next century (Schneider 1989, IPCC 1990a). *(See Box 4.)* Given the already considerable pressures on coastal biodiversity, what will the added impact of climate change be?

Even after decades of research that should help clarify the ecological impacts of changes in sea level, precipitation, or coastal currents, answers to this question remain speculative. Nonetheless, the basic indicators used in the previous chapter can be employed again to assess the impacts on coastal biodiversity of global warming—especially sea-level rise and changes in ocean temperature.

World sea level has changed continually through geological history. Some 120,000 years ago, global temperatures were 1° to 2°C warmer than they are today and the sea was about 6 meters higher. At the last glacial maximum, when glaciers reached as far south as Illinois (15,000 years ago), the Earth was 5°C colder and sea level was some 100 meters below its level today (Titus 1990). As the glaciers retreated, sea level began to rise rapidly until about 6,000 years ago, when the rate of change slowed significantly. Measurements in the Caribbean indicate that sea level rose at an average rate of only 0.4 millimeters per year for the past 3,200 years, allowing shorelines to stabilize or expand and allowing many shallow marine environments to build (UNEP 1988).

In the last century, global sea level has risen at a rate of 1.0 to 2.0 mm per year (Warrick and Oerlemans 1990), with one estimate suggesting that the rate of rise may have increased between 1920 and 1970 to 2.4 ± 0.9 mm per year (Peltier and Tushingham 1989). The rate of sea level rise in the past century appears to be somewhat greater than average rates over the prior two hundred years, but as yet no firm evidence links the apparent acceleration in sea level to human-caused global warming (Warrick and Oerlemans 1990).

Future rates and magnitudes of sea level rise under scenarios of global warming, though easier to predict than many aspects of climate change, are still surrounded by considerable uncertainty. Estimates of the sea level rise expected by the year 2100 range from 10 cm to nearly 3.4 meters (Hoffman et al. 1983, PRB 1985). The Intergovernmental Panel on Climate Change (IPCC) predicts that by 2030 global-mean sea level will be 8 to 29 cm higher than it is today, with a best estimate of 18 cm; by 2100, sea level is expected to be 31 to 110 cm higher, with a best-estimate of 66 cm (Warrick and Oerlemans 1990, Oerlemans 1989). Many researchers nevertheless consider the IPCC predictions of sea level rise conservative (Pugh 1990, Titus 1991). The IPCC assumes that some glaciers, particularly in the Antarctic, will actually increase in size as temperatures rise and thus partly offset any sea level rise, but many glaciologists believe that the glaciers will instead shrink and that a net contribution to sea level rise is not only possible, but likely. These experts believe that a sea level rise of as much as 200 cm by 2100 is entirely possible. Over the next few centuries, this means, the sea could rise by some six meters (Titus 1991).

"Policies for responding to sea level rise must take into consideration not only the magnitude of the expected sea level rise but also the uncertainty associated with the estimates."

Policies for responding to sea level rise must take into consideration not only the magnitude of the expected sea level rise but also the uncertainty associated with the estimates. The costs of underestimating sea level rise are likely to be high; accordingly, Edgerton (1991) argues that policymakers

Box 4. A Primer on Global Warming

Life on earth is dependent on the so-called "greenhouse effect," which keeps the planet about 59°F warmer than it would otherwise be. It was the French mathematician and physicist Jean Fourier who first described in 1827 how Earth's thin atmospheric blanket warms the earth. The atmosphere, Fourier suggested, possesses special greenhouse-like properties that permit solar energy to enter and strike the earth as visible light, but which then impede the energy's return into space as infrared heat. These "properties" are in fact the so-called greenhouse gases, which permit solar energy as visible light to pass through the atmosphere, but which absorb and re-radiate a portion of the same energy as it leaves Earth's surface as infrared heat. The net effect is a warming of the atmosphere. The relative warmth of a cloudy versus a cloud-free night sky is an accentuated example of this effect, since the water vapor making up clouds is itself a greenhouse gas.

Global warming becomes a threat only when the normal—and necessary—greenhouse effect is amplified by human activities. By increasing atmospheric concentrations of the naturally occurring greenhouse gases, primarily water vapor (H_2O), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and tropospheric ozone (O_3), and by adding new synthetic greenhouse gases, such as the chlorofluorocarbons and halons (CFCs), human activities are causing the atmosphere to trap an increasing proportion of the infrared heat that would otherwise escape back into space. All other things being equal, the additional heat-trapping capacity of the atmosphere will tend to raise global temperatures beyond those that would otherwise prevail.

As early as 1896, the great Swedish chemist Svente Arrhenius suggested that burning enough fossil fuels to double atmospheric CO_2 concentrations might raise average global temperatures by 10 degrees F. This is not far from the 3-to-8-degrees F increase that current climate models project for a doubling of atmospheric CO_2. If these models are correct—and they are the best that scientists can do for now—the unprecedented rise in atmospheric greenhouse gas concentrations during the last 40 years may have already committed the planet to an additional average temperature rise of 2 to 4 degrees F beyond the 1 degree F rise already observed over the past century. (This 1-degree warming cannot be conclusively attributed to human activities, but it is consistent with modelled predictions.)

Based on their relative abundance in the atmosphere, their radiative properties, and their atmospheric lifetimes, the relative contributions of the various greenhouse gases to future global warming can be estimated. Projected increases in atmospheric carbon dioxide concentrations are expected to account for roughly half of the global warming that occurs over the next several decades.

The actual pace and eventual magnitude of global warming will depend on variables as disparate as human population growth, the energy supply mix, the efficiency with which energy is produced and consumed, oceans' response to temperature change, deforestation rates, the emission rates of CFCs and other synthetic greenhouse gases, and both positive and negative climatic feedbacks. All projections are undermined by the significant uncertainties still surrounding most of these variables, and the nature and magnitude of climatic feedbacks remain particularly poorly understood and controversial. The increased cloudiness likely to be associated with global warming could accentuate or moderate the warming, depending on the type of clouds that become more common.

should plan for sea level rises that have only a 10 or 15 percent chance of being exceeded. Overall, Edgerton concludes, nations should plan for a 70-cm rise in sea level by 2050.

As noted earlier, one of the most important aspects of sea level rise from the standpoint of biodiversity is the rate rather than the magnitude of rise. The IPCC predictions suggest rates of sea level rise some three to six times higher than that experienced over the last century. By the year 2100, the rate of sea level rise could easily exceed 10 mm/year.

Impacts on Coastal Habitats

Can Wetlands Keep Pace With Rising Sea Levels?

The geologic record bears out the hypothesis that rates of sea level rise expected under conditions of global warming might well be at the very limit of wetlands' capacity to keep pace. The rate of sea level rise following the end of the Pleistocene (15,000 years ago until 6,000 years ago) is estimated to have been 10 to 20 mm/yr (Titus and Barth 1984, Grigg and Epp 1989). Little wetland development took place during this period and most present coastal marshes in the United States came after this period of rapid sea level rise (Stevenson et al. 1986). In general, little wetland formation is likely to take place at rates of sea level rise above 10 mm/yr. *(See Box 5.)*

How would the predicted three- to six-fold increase in rates of sea level rise affect coastal wetlands? Clearly, the loss of wetlands in Louisiana, already occurring at alarming rates, will increase. In addition, 11 of 14 wetland sites in the United States that are currently growing faster than the rise in sea level would probably begin to shrink if local relative sea level rise increased by 4.5 mm/yr to the average rate of 6.0 mm/yr (as predicted by IPCC) for the next century. *(See Box 5 and Table 3.)* (In fact, annual sea level rise would be less than this amount during the first half of the century and greater during the second.) If higher estimates of sea level rise prove true, *all* wetlands could on balance lose area. In some cases, marsh accretion rates may match the increase in sea level, but even such wetlands will be placed at the limit of their capacity to keep pace.

Although wetlands are clearly threatened by these rates of sea level rise, quantifying the actual areal loss of wetlands that would result is difficult. The change in areal extent depends not only on rates of relative sea level rise and accretion, but also on the composition and steepness of the shore, the presence of any such protecting structures as dikes or levees, and the presence of barrier islands. One study now under way at Butler University in Indiana has modelled impacts on coastal wetlands at 93 sites based on: elevation data from topographic maps, Landsat images of plant communities present at the sites, and measured or inferred rates of relative sea level rise and marsh accretion (Park et al. 1989).

Richard Park and his colleagues (1989) at Butler examined the potential impact of sea level rise

Box 5. The Growth and Evolution of Coastal Wetlands

How well coastal wetlands survive climate change and resultant sea level rise depends upon the rates of relative sea level rise and marsh accretion. Relative sea level rise is a function of both land submergence and real water level rise. Since both processes lower land surface relative to water levels, it is often difficult to separate the relative magnitudes of each. Global estimates of sea level rise conceal a significant variation in relative sea level change found in various regions of the United States, ranging from over 10 mm per year decline in the sea surface along the coast of southeastern Alaska to a 10 mm per year rise along the northeastern Maine and Louisiana coasts (Stevenson et al. 1986).

In Louisiana, a major underlying cause of wetland loss is subsidence, or submergence of the land surface. Subsidence stems partly from the added weight of the sediments that have been deposited, as well as from natural patterns of sedimentation. But the withdrawal of gas, oil, and water from subsurface deposits, as well as compaction by such man-made structures as levees, roads, and buildings, have also significantly increased rates of subsidence.

In marsh accretion, the marsh surface builds upward through sedimentation. In organic sedimentation, the decay of organic matter builds up the marsh surface; in inorganic sedimentation, the second principal mechanism of marsh accretion, mineral sediments carried by rivers or tidal action are added to the marsh.

In the face of rising relative sea level, coastal marshes may keep pace if vertical marsh accretion increases sufficiently. At the current rate of sea level rise, most coastal wetlands of the East and Gulf Coasts of the United States have kept pace with sea level rise (Stevenson et al. 1986). *(See Table 3.)* Out of 18 U.S. wetlands for which sufficient data on accretion rates and relative sea level rise are available, only four sites (encompassing the Mississippi River Delta and Blackwater Marsh in the Chesapeake Bay) have not accrued sediment fast enough to keep pace with relative sea level rise.

How well coastal wetlands keep pace with sea level rise depends on how high the tidal range is. In general, wetlands in regions with relatively small tidal ranges have lower rates of vertical accretion because less sediment is transported by tidal action (Stevenson et al. 1986). By the same token, coastal areas with higher tidal ranges are less vulnerable to sea level rise.

Table 3. Comparison of Coastal Wetland Accretion Rates with Current and Predicted Rates of Relative Sea Level Rise in the United States. (Modified from Day and Templet 1989, Stevenson et al. 1986)

Location	Wetland Type	Mean Accretion Rate (mm/yr)	Relative Sea Level Rise (RSL, mm/yr)	Net Gain/Loss (mm/yr)	Net Gain/Loss with 4.5 mm/yr Increase in RSL
Louisiana					
Deltaic Plain	Brackish				
	Streamside	14.6	11.0	+3.0	− 1.5
	Backmarsh	5.9	11.0	−4.1	− 8.6
	Saline				
	Streamside	13.7	13.0	+0.7	− 3.8
	Backmarsh	7.5	13.0	−5.5	−10.0
Chenier Plain	Brackish	7.0	12.0	−5.0	− 9.5
Georgia					
Sapelo Is.	Saline	4.0	2.5	+1.5	− 3.0
Savannah R.		11.0	2.5	+8.5	+ 4.0
South Carolina	Saline	2.5	2.2	+0.3	− 4.2
North Carolina		3.0	1.9	+1.1	− 3.4
Maryland					
Blackwater	Brackish	2.6	3.9	−1.3	− 5.8
Nanitoke	Brackish	6.1	3.2	+2.9	− 1.6
Delaware					
Lewes	Saline	4.7	2.2	+2.5	− 2.0
Lewes	Saline	>10.0	2.2	+7.8	+ 4.3
New York					
Fresh P.	Saline	4.3	2.2	+2.1	− 2.4
Flax P.	Saline	5.5	2.2	+3.3	− 1.2
Connecticut		5.0	1.9	+3.1	− 1.4
Rhode Island	Saline	4.3	1.9	+2.4	− 2.1
Massachusetts	Saline	5.5	0.9	+4.6	+ 0.1

under three likely scenarios for the next century: 50, 100, and 200 cm rise by the year 2100. They also examined three scenarios for protecting coastal lands from inundation. Under the first, all dry land is assumed to be protected from sea level rise by the establishment of dikes or levees. Under the second, only areas with residential and commercial development are sheltered. Under the third, only areas already served by dikes or levees are protected. These three scenarios for coastal protection parallel the types of responses that policymakers can use to address the likely impacts of sea level rise on coastal biodiversity.

If the primary goal is to minimize impacts on coastal biodiversity, coastal ecosystems should be allowed to migrate landward with rising sea levels unhindered by new physical obstructions (scenario three). In contrast, attempts to minimize impacts on existing coastal infrastructure by building dikes and levees (scenario two) or even to protect all dry land from inundation (scenario one) would reduce the area available for coastal ecosystems displaced by the rising sea.

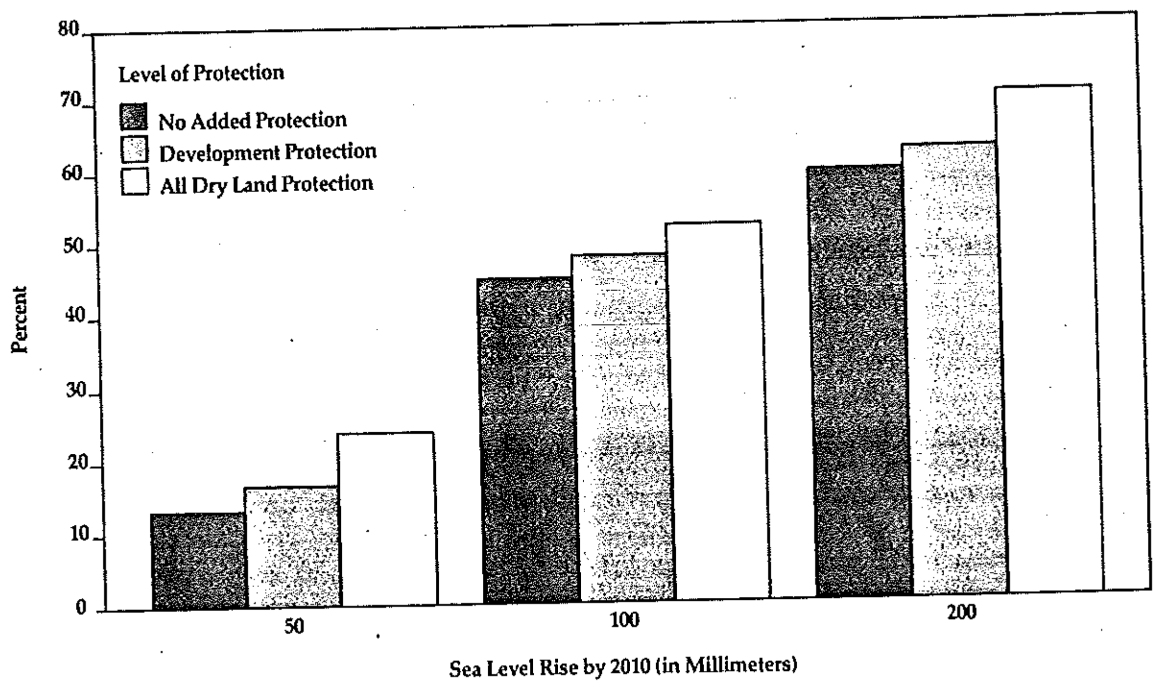
The results of Park's study show that under a conservative scenario of a sea level rise of 50 cm by 2100, over 26 percent of coastal wetlands in the East and Gulf states would be lost if all dry areas are protected from inundation, 17 percent would be lost if all residential and commercial areas are protected, and 14 percent would be lost if only currently diked areas are protected from inundation. *(See Figure 10 and Table 4.)* In comparison, their model predicts 11 percent of coastal wetlands will be lost over the same time at the current rate of sea level rise (primarily losses occurring in the Mississippi River delta).[10]

At the higher rates of sea level rise predicted by some climate models, Park's study indicates that the impacts on coastal wetlands would increase dramatically. With a 1-meter rise by 2100, 46 to 52 percent of coastal wetlands would be lost. While the impacts on Louisiana would be particularly devastating—where a loss of 84 percent of wetlands would be expected—most other regions would also lose roughly one-third of their coastal wetlands. With a 2-meter rise over this period, some 61 to 70 percent of wetlands would be lost. These estimates of wetlands loss compare roughly to estimates made by the U.S. Environmental Protection Agency (26 to 82 percent loss under the 100 cm scenario, 29 to 90 percent loss under the 200 cm scenario) (Titus 1991).

"Some regions will be hurt more than others if sea level rises."

Some regions will be hurt more than others if sea level rises. For example, if sea level rises by 50 cm by 2100, wetlands in southern and western Florida are likely to keep pace with sea level rise

Figure 10. Predicted Wetland Loss by 2100 Based on Three Scenarios of Sea Level Rise



Source: Park, *et al.*, (1989)

and may actually increase in area if not blocked from migrating landward. *(See Table 4.)* If no further barriers to landward migration are erected, wetland area could hold its own in the mid-Atlantic and Northeast states at this lower end of predicted sea level rise; but wetlands would be lost elsewhere, and in the northern Gulf states the area lost would increase 20-fold.

Regional differences are also apparent in the extent to which the construction of barriers will increase the loss of wetlands. In regions like Louisiana, where extensive wetlands project from a relatively short fixed coastline, the construction of barriers does not significantly increase the amount of wetlands that would be lost by 2100. In contrast, in the northeast the area of wetlands lost would increase nearly 5-fold under the 100-cm scenario if barriers were established around existing development. *(See Table 4.)* In general, Atlantic wetlands would be especially vulnerable to the protection of dryland by dikes while wetlands along the gulf coast would be affected less.

Table 4. Regional Estimates of Losses of Coastal Wetlands Expected by the Year 2100 under Various Scenarios of Sea Level Rise (Modified from Park et al. 1989). Areas in square miles.

Region / Area Protected	Current Area	Change in Wetland Area by 2100 with Sea Level Rise Indicated			
		Current Area (Percent)	50 cm Area (Percent)	100 cm Area (Percent)	200 cm Area (Percent)
Northeast					
All Dry Land Protected			−42 (− 9)	−77 (−17)	123 (−27)
Development Protected	453	−27 (−6.0)	−33 (− 7)	−74 (−16)	128 (−28)
No Added Protection			+7 (+ 1)	−15 (− 3)	157 (−35)
Mid-Atlantic					
All Dry Land Protected			−263 (−33)	−434 (−55)	611 (−78)
Development Protected	786	+177 (+22)	−17 (− 2)	−252 (−32)	492 (−63)
No Added Protection			−54 (+ 7)	−196 (−25)	452 (−57)
South Atlantic					
All Dry Land Protected			−486 (−13)	−1,377 (−37)	2,157 (−59)
Development Protected	3,673	+40 (+ 1)	−121 (− 3)	−1,103 (−30)	1,898 (−52)
No Added Protection			−25 (− 1)	−998 (−27)	1,777 (−48)
S & W Florida					
All Dry Land Protected			−258 (−11)	−959 (−42)	1,257 (−56)
Development Protected	2,257	+92 (+ 4)	+147 (+ 6)	−549 (−24)	788 (−35)
No Added Protection			+216 (+10)	−537 (−24)	730 (−32)
Louisiana					
All Dry Land Protected			−2,209 (−48)	−3,585 (−78)	4,350 (−95)
Development Protected	4,564	−1,804 (−39)	−2,036 (−45)	−3,856 (−84)	4,343 (−95)
No Added Protection			−2,006 (−44)	−3,857 (−84)	4,345 (−95)
Other N. Gulf					
All Dry Land Protected			−421 (−21)	−754 (−38)	1,090 (−55)
Development Protected	1,984	−13 (− 1)	−297 (−15)	−805 (−41)	1,055 (−53)
No Added Protection			−265 (−13)	−787 (−40)	1,043 (−53)
TOTAL: East and Gulf Coasts of United States					
All Dry Land Protected			−3,679 (−26)	−7,186 (−52)	9,588 (−70)
Development Protected	13,717	−1,535 (−11)	−2,453 (−18)	−6,639 (−48)	8,704 (−63)
No Added Protection			−2,019 (−14)	−6,390 (−46)	8,416 (−61)

Significant changes in community composition of wetlands may be in store under various scenarios of sea level rise (Park et al. 1989). Along the Mid-Atlantic Coast, vegetated wetlands are expected to decrease in area while tidal flats increase. In the southeastern states, from North Carolina to Texas, the relative (and absolute) area of mangroves is likely to increase, while saltmarsh and tidal freshwater marshes would decrease.

An important influence on wetlands loss in the United States, particularly on the East Coast, are ever shifting barrier islands. In theory, barrier islands migrate landward while maintaining their topographic profiles as sea level increases. Waves maintain the barrier island profile by redistributing sediments onto the back of the barrier as the seaward side erodes. However, on barrier islands experiencing development pressure, physical structures prevent the landward transport of sand and the sand that is transported landward tends to be bulldozed back to maintain the beachfront profile. Overall, efforts to stabilize barrier islands have not been highly successful, and such artificial structures as seawalls and groins have usually accelerated the removal of beach sediments by wave action (El-Ashry 1971, Meyer-Arendt and Davis 1988).

As barrier islands disintegrate and adjoining tidal inlets widen, marine wave action penetrates further into the formerly protected tidal marshes. While the increased wave action does increase tidal sedimentation rates, the erosion of wetlands caused by increased wave action is more than offsetting (Meyer-Arendt 1990). Moreover, positive feedback tends to speed barrier island erosion: as wetlands are converted to open water, the volume of water in the bay increases. Because more water is then moved in and out of the bay with the tides, the ends of the barrier islands are eroded and the tidal inlets are widened.

Can wetlands keep pace with sea level rise? Even conservative projections of the sea level rise expected during the next century imply strains on U.S. coastal wetlands' ability to maintain their area. Under the IPCC's conservative "best estimate" scenario, nearly twice as much coastal wetland area will be lost over the next century as would otherwise be the case. Over the range of plausible estimates for sea level rise by the year 2100 (0.5 to 2 meters), some 15 to 70 percent of the remaining coastal wetlands on the East and Gulf Coasts of the United States could be eliminated.

Coral Reefs

Both sea level rise and changing water temperatures will influence U.S. coral reefs located in southern Florida, on small isolated banks in the Gulf of Mexico off Louisiana and Texas, and off Puerto Rico and Hawaii. At current rates, sea level rise (1 to 2 mm/yr) does not inhibit coral reefs' upward growth, estimated to be roughly 10 mm per year (Grigg and Epp 1989). But sea level rise under scenarios of global warming is likely to equal or exceed these limits.

High rates of sea level rise during the Pleistocene deglaciation (estimated at 10 to 20 mm per year) prevented most corals from keeping pace with sea level, and many coral islands drowned (Grigg and Epp 1989).[11] Corals tend to be most sensitive at the northern end of their ranges, where cooler water temperatures and lower light intensity slow growth. Maximum rates of net reef growth decrease from 10 mm/yr near the equator to 1 mm/yr at higher latitudes (Grigg and Epp 1989). Because many corals in the United States are at the northern limit of their range, they tend to grow relatively slowly.

Accordingly, sea level rise of the magnitude now predicted, if maintained for several centuries, could cause a significant loss in the areal extent of corals in the United States. However, some scientists have argued that in the short term (50 to 100 years), sea level rise and sea temperature warming could actually benefit corals (Buddemeier and Smith 1988). They suggest that sea level rise will rejuvenate depauperate reef flats near the ocean surface and that higher coastal water temperatures could increase the range of U.S. and other high latitude corals.

Recent evidence of coral "bleaching" thought to be caused largely by unusually high water temperatures provides reason to doubt these putative short-term benefits of climate change and ample reason to believe that rapid climate change could seriously harm the world's corals. Coral bleaching—the loss of the mutualistic algae living with the coral—is believed to stem from such stresses as sedimentation, pollution, or unusually cold or warm water temperatures. During bleaching events, corals lack the primary energy needed to grow, and if bleaching is frequent or protracted, the coral ultimately dies (Goreau 1990a).

Coral bleaching has been observed sporadically around the world for decades, but all such cases involved such locally confined stresses as muddy river water plumes or high temperatures caused by poor water circulation. In the past decade, however, coral bleaching has taken place on an unprecedented scale. Major bleaching episodes at sites around the world have taken place in 1980, 1983, 1987–88, and 1990 (Goreau 1990a, Williams and Williams 1990, Williams 1990). In many cases, the corals died as a result (Goreau, Personal Communication, October 10, 1990). In the Caribbean, all of the major bleaching episodes in the 1980s have been associated with above-normal water temperatures (Goreau 1990b).

At any latitude, a water temperature rise of 2° to 3°C above normal can cause bleaching. If water temperatures increase slowly over a number of years, corals will probably adapt physiologically to the new environmental conditions. But a rapid elevation in sea temperature—a rise like that predicted to accompany global warming—may cause a coral die-off. Unfortunately, the pattern of the 1980s suggests that such a situation may already be upon us.

Impacts on Coastal Species Diversity

Rare and Endangered Species

As discussed in Chapter II, a significant number of rare, threatened, and endangered species depend on or use the coastal fringe. The Nature Conservancy (TNC) lists 80 species and subspecies restricted to below the 10 foot contour as rare, imperiled, or critically imperiled. *(See Table 1.)* Many of the animals and other species in this zone would have no physical problem dispersing to higher elevations at the pace of sea level rise, but plants and any species already threatened or endangered would. Many of these species are considered endangered precisely because their habitat has been lost, so further losses could prove disastrous. Moreover, coastal development adjacent to critical habitats for endangered species could block the dispersal of species if sea level rises. Thus, the impacts of sea level rise, particularly the loss of wetlands, will significantly increase extinction threats and will create new candidates for species to be listed as rare and endangered.

A more precise assessment of the potential impacts of sea level rise on coastal species diversity can be obtained by examining impacts state by state. *(See Table 5.)* Although the global extinction of a species represents an ultimate and irreplaceable loss, the loss of species from a portion of their range—known as extirpation—can undermine the region's local species diversity and the genetic diversity of the species more generally. Then too, local extirpation is a step toward global extinction. For this reason, examining trends in the loss of species from portions of their ranges can put threats to species diversity into perspective.

A substantial number of species are at risk of extirpation from individual states as a result of global warming. In Oregon, Massachusetts, Maryland, North Carolina, and Florida, some 41 species that utilize the coastal fringe are federally listed as *globally* endangered or threatened and another 128 are candidates for listing.[12] *(See Table 5.)* But the picture is more disturbing at the state level. In these five states alone, TNC has designated some 461 coastal species found beneath the 10-foot contour to be at risk of local extirpation (rare, imperiled, or critically imperiled) and has found that between 3 and 70 species considered rare at the state level are *restricted* in their habitat use to within 5 feet of sea level.[13] *(See Table 5.)* Within these states, Florida's vast area of low-lying wetlands holds the most species at risk, while Oregon's steep coast is home to the least.

As populations utilizing the narrow coastal band are subjected to the continuing threats of development from above while their habitat shrinks from sea level rise below, threats to species diversity grow. Sea level rise is certain to contribute to the extirpation of species in individual states and may well contribute to the extinction of some coastal species in the United States.

Coastal Plant Communities

While the status of individual species in coastal regions provides a good measure of threats to species diversity, judging threats at the level of plant and animal communities is far more difficult.[14] To begin with, the designation of a community or ecosystem is much more subjective than the designation of a species. Each species is a separate and unique entity, while communities are in continual flux as new species immigrate in or die out locally. Moreover, community processes and species interactions change continually as species evolve or co-evolve in each other's presence. In the absence of comprehensive data, the likely impacts on coastal communities nationwide cannot be evaluated confidently, but the following cases do indicate the range of impacts.

One end of the spectrum is represented by the plant community found on three bird rookeries off the coast of Maine. Machias Seal Island, Matinicus Rock, and Gull Rock are each small (less than 12 acres) islands, located 8 to 19 miles from shore. The plant community for the three islands amounts to only 110 species none of which are currently federally listed or candidate species. Only five are considered rare at the state level by TNC, and only three of these are restricted to within 10 feet of sea level. Accordingly, the impact of sea level rise on this community is likely to be fairly small.

At the other end of the spectrum are the barrier island communities common along the southern

Table 5. Federal Threatened and Endangered, and State Rare Species in Coastal Regions. State totals refer to the number of species determined by TNC to be "Critically Imperiled," "Imperiled," or "Rare or Uncommon" in that state. A species may be common in other states and still be listed if rare in the particular state. Superscript indicates the number of subspecies (or varieties) included in the total.

Region	Birds	Mammals	Reptiles Amphibians	Fish	Plants	Total
I. Federally Listed (Endangered, Threatened) Species Found Within 10 Feet of Sea Level (Candidate Species in Parentheses)						
Oregon	4 (2)	0	0	0	(2)	4 (4)
Massachusetts	0	0	0	0	0	0
Maryland	2	1^{1}	0	0	1(12)	4(12)
North Carolina	1	0	1	0	(7)	2 (7)
Florida	8^{2} (5^{2})	8^{7} (9^{7})	9 (9^{3})	1(2^{1})	12^{1}(83^{14})	38(108)
II. Rare Species Restricted to Within Five Feet of Sea Level						
Oregon	0	0	0	0	3^{2}	3
Massachusetts	11	0	0	0	9^{1}	20
Maryland	11	0	0	0	38	49
North Carolina	0	0	1	0	10	11
Florida	19^{3}	11^{9}	11^{4}	2^{1}	27^{4}	70
III. Rare Species Found Within 10 Feet of Sea Level						
Oregon	7^{1}	0	1	0	8	16
Massachusetts	17	1	1	1	22^{1}	42
Maryland	16	1^{1}	2	1	102^{2}	122
North Carolina	1	0	1	0	19	21
Florida	35^{8}	19^{15}	30^{14}	9^{1}	167^{18}	258

Atlantic seaboard of the United States. Assateague Island is a 37-mile long, 17,652-acre, barrier island off the coast of Maryland and Virginia with a maximum elevation of 25 feet. The island is not threatened with submergence from sea level rise in the coming century, but the rising sea level is likely to cause it to shift landward, which could reduce its size. Assateague and adjacent Wallops Island contain 589 plant species, of which 27 percent are non-native species introduced in recent decades. Among the plants on the islands, two species are candidates for federal listing and four species are considered by TNC to be very rare or imperiled nationally.

Using the greater resolution provided by an examination of the rarity of species at the level of the state, Assateague Island can be seen to be quite unique in its species composition. Some 23 percent (97) of the native species on Assateague and Wallops islands are considered rare, imperiled or critically imperiled in the state of Maryland or Virginia by TNC.[15] And many of these species live close to the sea, where they stand to be further threatened by sea level rise. Twelve of the rare and imperiled species are restricted to elevations of less than 10 feet throughout their range. Moreover, another 16 species that are currently not at risk in the two states are also restricted to these low elevations and could become rare if coastal habitats changed significantly.

If sea level rises at the high rates suggested by some scenarios of climate change, the species composition of Assateague's plant community is likely to change dramatically. Even if none of the species were to become globally extinct, the extirpation of a number of species from Assateague itself would mean that the community that now exists will be no more.

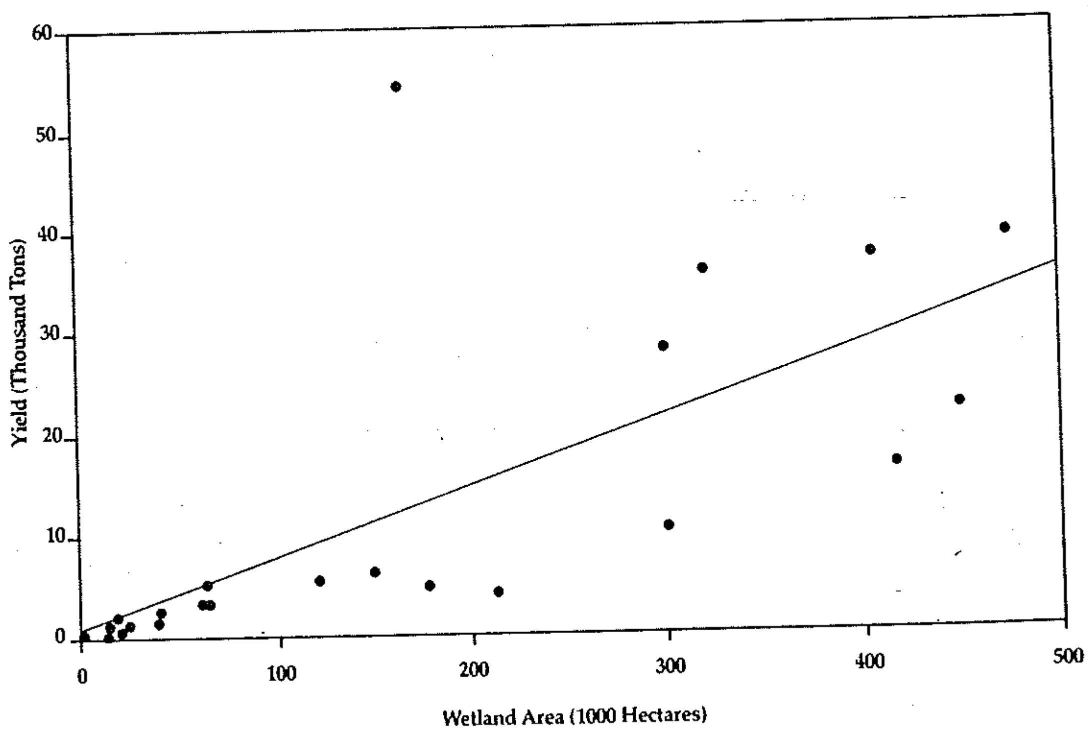
Fish and Wildlife Population Trends

Coastal fish and wildlife populations are influenced by a variety of factors, including both breeding and non-breeding habitat loss and degradation, pollution, harvesting, and reduction in food availability. Predicting the impact of climate change generally on these populations, or even the specific impacts of a loss of coastal wetlands on the populations, is thus fraught with difficulty.

> **“Predicting the impact of climate change on coastal fish and wildlife populations or even the specific impacts of a loss of coastal wetlands on these populations is fraught with difficulty.”**

For instance, the dramatic decline in wading bird populations in south Florida, from well over 1 million birds 100 years ago to the current population of 16,000 breeding birds, is due in part to habitat loss and degradation, but plume hunting also took its toll at the turn of the century and water management practices have been linked to the decline more recently (Harris 1988, Walters et al. In Press). Similarly, shrimp abundance tends to be greater in areas with more wetland vegetation (*See Figure 11;* Turner 1977, Turner and Boesch 1988), but this general trend doesn't help in predicting the impact of wetlands loss on shrimp abundance because the impact depends on the pattern of wetland loss. Despite the massive losses of coastal wetlands in Louisiana during the past 30 years, landings of such commercially important species as shrimp have increased. No doubt increased fishing effort is partly responsible, but another factor is the increased length of marsh shoreline that has resulted from canal construction,

Figure 11. Relationship of Wetland Area to Shrimp Yield in 23 Sites Worldwide



To remove the influence of latitude (temperature and sunlight) on productivity, yield was mathematically adjusted to a common latitude of 15° using the equation determined by Turner (1977) for the relationship of yield/acre with latitude.

Source: Adapted from Turner, (1977)

along with growing open areas in the back-marsh that has allowed shrimp access to a larger portion of the marsh (Browder and Rosenthal 1989).

Data relating wetland loss to productivity for other fisheries is largely anecdotal, though thought-provoking. For example, fish harvest declined in a Florida estuary following wetland loss to dredging, and the whiting fishery in Western Port, Australia declined by about 80 percent in size coincidentally with the loss of sea grass beds in the bay (Turner and Boesch 1988).

Despite the difficulties associated with calculating the impact of wetland loss on fisheries, the National Marine Fisheries Services has estimated that the loss of estuarine marshes between 1954 and 1978 (a loss of roughly 8 percent of marsh area) cost the United States fishing industry some $208 million per year (Tiner 1984). Using this as a benchmark, it can be seen that a reduction of coastal wetland area by a further 20 to 70 percent during the next century could amount to annual losses in excess of $1 billion.

Other Impacts of Climate Change

Besides sea level rise and ocean temperature changes, other changes associated with global warming are likely to have significant impacts on coastal biodiversity. However, since global climate models still do not agree on regional details of changes in precipitation, temperature, wind speed, and storm frequency, it is even more difficult to accurately predict the impacts of these factors than those of sea level rise.

Precipitation and Freshwater Runoff. Changes in precipitation patterns caused by global warming will alter salinity gradients in coastal estuaries. Freshwater inflow provides a direct source of nutrients to estuarine ecosystems, as well as a source of sedimentation. In six estuaries in Texas, for example, the major source of carbon, nitrogen, and phosphorous was freshwater inflow (Armstrong 1982). Moreover, the pattern of use of estuaries by finfish and shellfish is often a function of the seasonal pattern of freshwater inflow. Interannual variation in the harvest of a large number of estuarine-dependent fisheries has been correlated with variations in freshwater inflow (Cushing 1982).

Anticipating the effects of climate change on freshwater inflow is clearly problematic, not only because of the uncertainty inherent in climate models, but also because flow patterns into nearly every U.S. estuary are affected by upstream human uses, dams, and diversions. In general, though, increased freshwater runoff would increase productivity in coastal areas (especially if the normal timing of flows does not change) and decreased runoff would decrease productivity.

Temperature. Increased air temperature and associated water temperature will alter the range of a number of coastal species. For example, the northern limits to the distribution of mangroves in the southeastern United States are controlled by winter temperature (Markley et al. 1982, McMillan and Sherrod 1986). Similarly, the endangered West Indian (Florida) manatee *(Trichechus manatus)* needs water that is 22°C or warmer during winter. The ranges of other tropical plant and animal species will likely extend northward as a result of water temperature increases, while the ranges of northern estuarine species will contract.

Atmospheric Carbon Dioxide (CO_2). Atmospheric CO_2 concentrations are likely to double from pre-industrial levels by 2075. Because CO_2 is the base from which all plants build carbohydrates, increased concentrations may "fertilize" some plants, increasing their growth rate. Moreover, since not all plants follow the same chemical pathway in photosynthesis, elevated CO_2 is likely to favor growth in certain species more than others, perhaps altering community compositions. For example, the experimental CO_2 enrichment of a natural coastal wetland increased growth rates of both bulrush *(Scirpus olneyi)* and cordgrass (*Spartina patens),* but the effect was greater on bulrush, the species utilizing what is known as a "C_3" photosynthetic pathway, than on cordgrass, which uses a "C_4" pathway. Presumably, the bulrush could outcompete cordgrass if more CO_2 becomes available. More generally, this experiment suggests that changing CO_2 concentrations will further alter the species composition of coastal communities.

Ocean Currents. Ocean currents such as the Gulf Stream are likely to be affected by changes in temperature and wind patterns predicted to accompany global warming (Bakun 1990, Mikolajewicz et al. 1990). Because forecasting the magnitude or direction of such changes in ocean currents is fraught with uncertainty, even potential effects on coastal ecosystems are hard to gauge. One study has suggested, however, that by intensifying the alongshore windstress on the ocean surface, greenhouse warming could accelerate coastal upwelling (Bakun 1990). Such increase in windstress has been documented off California for the period 1946 to 1988. Increased intensity of an upwelling system is likely to increase productivity in those waters; it could also change the composition of nearshore marine communities.

Disturbance Patterns. Coastal wetlands are subject to a variety of episodic disturbances, including hurricanes, lightning, floods, and fire.

Other climatic influences on wetlands such as rainstorms, wave action, cold spells, or sustained strong on-shore or off-shore winds may also be considered "disturbances" when their intensity exceeds the standard ranges encountered over decades. A 100-year flood or a 100-year cold-spell, for example, would be considered a "disturbance" to an ecosystem.

Global warming may alter climatic variability, thus subjecting coastal ecosystems to higher (or lower) frequencies of disturbance. Although the expected rise in sea surface temperatures associated with global warming has stimulated considerable speculation that hurricanes may grow more fierce or numerous in coming decades, this conclusion has not been supported by climate modelling and scientists don't agree on how climate variability will change under global warming scenarios (EPA 1989).

Despite the lack of a consensus on what changes in disturbance patterns are in store, it is known that in almost all ecosystems, disturbance is a major determinant of species composition and ecological processes. Thus, even in the absence of a significant increase in temperature, coastal ecosystems could be profoundly affected by changes in the variability of climatic patterns.

For example, hurricanes, some with long-lasting impacts, are a part of coastal life in the southeast United States. The saline tide generated by Hurricane Audrey, which struck Louisiana in 1957 killing 160,000 ha of sawgrass *(Cladium jamaicense),* converted almost all of this habitat to open water by the following year (Valentine 1977). Much of this area was revegetated by 1972, but bulltongue *(Sagittaria falcata)* and water lily *(Nymphaea odorata)* became the dominant species, not sawgrass. In turn, these vegetation changes affected the animal community composition. Ducks that once fed on the sawgrass seeds used the marsh minimally for several years following the hurricane. Once annuals became established, ducks became more abundant than before, but as the perennial community took hold waterfowl use dropped.

Hurricanes also influence the deposition of sediments on coastal wetlands. A single small hurricane can deposit 22 mm of sediment some 7 km inland from the ocean shore (Rejmanek et al. 1988). Because the grasses and sedges that dominate coastal marshes in the United States can easily grow through the sediment deposits, community composition remains more or less the same after a hurricane. But in mangrove forests, sediment movement by hurricanes is a major cause of tree mortality. Hurricane Donna killed over 40,000 ha of mangroves in south Florida in 1960 (Craighead and Gilbert 1962).

The intense rainfall of hurricanes also affects ecosystems by washing tremendous amounts of organic matter into estuarine waters from freshwater and coastal marshes. Large-scale fish die-offs following the passage of hurricanes have been attributed to oxygen depletion caused by decomposing organic matter that was washed into the estuary. The frequency of extreme temperatures may also influence the species composition of coastal ecosystems, as for example, infrequent severe winter freezes in Florida Bay limit the development of coral reefs along the Florida Keys (Jaap 1984).

Major disturbances are already relatively frequent in coastal wetlands. Wind tides 1.5 meters above normal (generally associated with tropical storms or hurricanes) occur approximately every eight years in Louisiana delta marshes and account for major episodes of sedimentation (Gosselink 1984). In south Florida, coastal habitats experience hurricanes at regular intervals of about three to five years (Meeder and Meeder 1989). Any change in this disturbance regime may alter coastal community composition.

IV. PUBLIC POLICY AND THE CONSERVATION OF COASTAL BIODIVERSITY

Coastal ecosystems are vitally important to the United States. They provide the foundation of its fishing and sport-hunting industries, habitat for large numbers of species, pollution-filtration systems, flood control mechanisms, recreational destinations, and storm buffers. Apart from our ethical responsibility to ensure that species in coastal ecosystems are not driven to extinction, preserving these ecosystems makes sense from a practical standpoint as well: if their biodiversity is degraded they can't provide valued services. For this reason, concern over the conservation of biodiversity must go hand in hand with the design of sustainable patterns of use of these ecosystems.

From one standpoint, the history of protection of coastal ecosystems in the United States is a remarkable success story. Following two hundred years of destruction and alteration that culminated in the loss of nearly 10 percent of U.S. coastal wetlands in the twenty years prior to 1974 alone, losses of coastal wetlands have been sharply curtailed. Less pollution is discharged into coastal ecosystems now too, and the establishment of coastal protected areas has further reduced environmental threats.

Unfortunately, this sharp reduction in the rate of wetlands loss took place only after most coastal wetlands in some U.S. regions had already been lost. Moreover, trends in wetland acreage may understate the true impact on coastal ecosystems, including the degradation of wetland functions or the more pronounced loss of the ecologically important shoreline expanse of wetlands. And such ecosystems as barrier islands, mangrove swamps, beaches, and coral reefs, have not been closely monitored over this period and by all appearances have been significantly degraded. In future years, it will also be increasingly difficult for coastal ecosystems to hold their own: conventional pressures on coastal ecosystems will mount dramatically as both human populations and recreational use of coastal ecosystems grow.

If global warming exacerbates these threats, as predicted, wetland ecosystems and their associated species may not be able to keep up. Depending on how fast sea level rises and how much dry land is protected, 14 to 70 percent of the remaining coastal wetland acreage in the United States will be eliminated. And the impacts of climate change will not be restricted to sea level rise, but will also include changes in air and water temperatures, precipitation patterns and amounts, coastal currents, and the frequency of storms or fires. Some wetlands could benefit from some combination of these events, but the overall impact on U.S. coastal ecosystems will be negative. Climate change is likely to substantially elevate threats of extinction or extirpation of coastal species, and decrease populations of wetland-dependent species. It could also harm coral reefs. Even today, coral bleaching, tentatively linked to global warming, seems to threaten the nation's few coral reefs.

> **"Complacency in the face of prospects for coastal biodiversity in the United States is a mistake."**

Complacency in the face of prospects for coastal biodiversity in the United States is a mistake. Climate change will exacerbate already significant pressures on coastal ecosystems. A variety of indicators, including the numbers of threatened and endangered species reliant on coastal habitats, trends in productivity of coastal fisheries, trends in waterfowl populations, and trends in other wildlife dependent on coastal habitats, all suggest that while wetland acreage (outside of Louisiana) may be stabilizing, the biological diversity of coastal ecosystems already faces serious threats.

For nearly a decade, scientists and policymakers have studied the possible impacts of future sea level rise on coastal development and coastal ecosystems and debated how best to respond. Thus far, little of this work has been translated into changes in federal or state policy. Several states are beginning to consider policy changes in anticipation of a rising sea, and Maine has even enacted legislation. But, overall, the framework of policies guiding U.S. coastal development is changing rapidly enough to meet the challenge of coastal development, but too slowly to save coastal ecosystems.

Public Policy Options in the Face of Uncertainty

A range of options is available to decision-makers for responding to the impacts of climate change, particularly sea level rise, on coastal development and coastal ecosystems.[16] At one end of the spectrum is retreat—deciding to construct no more dikes, levees, or any other barriers to the sea. This is by no means a "do-nothing" policy option since no such retreat will be possible unless steps are taken today to prevent the development of land likely to be submerged in the future. At the other end of the spectrum is a policy of completely protecting coastal development against sea-level rise. Between these extremes are many other policy strategies. With a "do-nothing" approach, sea level rise and related climatic events lead to haphazard coastal abandonment and protection, with unknown economic and biological costs. Alternatively, prescribed coastal development could be accommodated to sea level rise over time. For example, buildings can be raised on pilings and moved back as the sea advances.

The various responses would have different impacts on coastal biodiversity, and each option also poses quite different legal, economic, and political problems. The pure retreat option would, in theory, best protect coastal ecosystems because those ecosystems would be free to migrate landward without human impediment. The economic and political costs of abandoning current and future coastal developments, however, make the pure retreat approach untenable. For all options, the substantial uncertainty surrounding the physical and biological impacts of climate change pose further obstacles to practical policy.

> **"Of the three general types of policy responses available, only one—acting now to make adaptation later possible—can ensure the protection of coastal ecosystems."**

Balancing such obstacles against a need to preserve coastal ecosystems, what are the most effective and politically realistic policy options? As the following review shows, of the three general types of policy responses available, only one—acting now to make adaptation later possible—can ensure the protection of coastal ecosystems.

Pay-as-You-Go Biodiversity Conservation

In 1987, a National Research Council study (NRC 1987) of the impacts of climate change on coastal engineering policy concluded that "Construction of almost any conceivable protection against sea level rise can be carried out in a relatively short period of time" and that, therefore, "if a substantial increase [in sea level] should occur, there will be time to implement protective measures." For several reasons, this "pay as you go" policy option is commonly suggested as an attractive way to respond to the many uncertainties involved in predicting how climate change will affect coastal development (NRC 1987).

The "pay as you go" option does have several advantages:

- Since economic impacts of sea level rise will be felt decades into the future, the costs of building dikes, levees, or other containment structures seem small when economically discounted back to the present.[17] These discounted costs often appear comparable to the perceived high costs of acting now to prevent development on coastal land, so economic discounting favors a do-nothing-now approach.[18]
- Preventing the expansion of coastal infrastructure now is politically difficult, while doing nothing now is par for the course in a policy-making system almost incapable of looking more than a few years into the future.
- Engineering "solutions" to the problems of sea level rise are relatively well understood, they are easy to plan, and their costs can be easily quantified.[19] Such alternatives as zoning restrictions, in contrast, are difficult and time consuming to carry out. Similarly, because it's easier to quantify the first-order costs of engineering solutions than their societal and economic costs (including the loss of biodiversity), a bias toward engineering solutions results.

For some coastal ecosystems, the pay-as-you-go approach might be implemented as a policy of "no net loss." For example, since wetland managers have had increasing success restoring or even creating wetland ecosystems, future wetland loss due to sea level rise could be offset by creating new wetland habitat. To work, however, actions to mitigate wetlands loss would have to extend well beyond existing project-related mechanisms, such as the issuance of a Section 404 permit under the Clean Water Act. Establishing a federal and state commitment to counter wetlands loss specifically resulting from sea level rise and global warming would require legislation.

More generally, though, the "pay as you go" approach to global climate change is not likely to help conserve coastal biodiversity. Few coastal ecosystems can be readily re-created, and artificially created wetlands or other coastal ecosystems may not be able to provide all of the services that natural ecosystems do. Adopting such a strategy would most likely result in a patchwork of "habitats" that meet some areal and composition requirements but lack rare species, continuity with adjacent ecosystems, and certain natural ecosystem functions.

An additional problem with the "pay as you go" approach is that the belief that engineering solutions will be available to address rising sea levels eventually becomes a self-fulfilling prophecy. Without anticipatory policies, development will proceed apace in coastal areas. By mid-century, when rising sea levels will become a significant threat to coastal development, the expensive coastal infrastructure added over six decades will increase the justification for physically protecting the shores. Already, along the Atlantic Seaboard, steps taken to protect developed coastal areas from sea level rise would significantly increase the expected loss of wetlands if climate changes as predicted. *(See Table 4.)* If coastal development is not restricted, wetlands loss will be even more severe. If it is decided to protect all dry land, for example, projected wetlands loss will double by 2100. *(See Table 4.)*

The impacts of engineering solutions on coastal biodiversity go beyond simply impeding the migration of coastal wetlands. Dams and saltwater intrusion barriers that might be constructed to reduce impacts on water supplies and coastal development would exacerbate the harm to coastal ecosystems. Since such barriers would retain riverborne sediments, they would slow the growth (accretion) of deltaic wetlands. Similarly, channeling rivers for flood control in the face of rising sea levels would block the flow of sediments to wetlands.

Clearly, the "pay as you go" policy response to sea level rise, while highly desirable from the standpoint of deferring costs until events categorically prove them necessary, does not meet needs for biodiversity conservation. Biodiversity cannot be conserved by means of the relatively quick technological fixes that may protect cities and other coastal developments. Needed instead are policies that meet current threats to coastal ecosystems and enable wetlands and other coastal ecosystems to adapt to expected shifts in the nation's coastline.

Fleeing the Rising Sea

The option of pure retreat clearly offers coastal biodiversity the most opportunity to adapt to changing environmental circumstances. Without human interference, ecosystems could move landward and enjoy the greatest likelihood of remaining intact. Even retreat, however, would not leave coastal ecosystems unscathed: if sea level rises relatively rapidly, some 14 to 60 percent of wetland area on the East and Gulf coasts—an area larger than Rhode Island and potentially as large as Massachusetts—would still be inundated. *(See Table 4.)* Nevertheless, only policies designed to slow the rate of climate change itself would do more to minimize the impact on coastal ecosystems.

Yet, however great their conservation potential, the zoning, landuse, and land ownership changes needed to make large-scale retreat possible are both economically and politically infeasible. Three problems stand out in particular:

- Governmental and non-governmental organizations lack the financial resources needed to condemn or purchase the tens of thousands of square kilometers of land that might be needed for future wetlands or other coastal ecosystems.
- Preventing the development of private lands, or denying owners the right to protect their property through seawalls or other measures, might well be seen as an unconstitutional taking of property, even if it were politically palatable (Fischman 1990). Similarly, regulating landowners' freedom to develop their property, thus lowering its future purchase price for the government, could also constitute an unconstitutional taking (Sax 1989).
- Preventing development on many coastal lands decades in advance of possible ocean encroachment is perceived as an economically inefficient use of a scarce resource (shoreline) with high opportunity costs and few economic benefits (Titus 1991). In principle, these lands could be used prior to inundation and still provide suitable habitat when the time came for them to be abandoned.

Even if pure retreat appears infeasible on a large scale and economically inefficient over the long term, it would probably go farther than any other option toward maintaining certain critical coastal habitats since it avoids the problem of later having to abandon coastal property developed now. It thus makes sense for policymakers and conservancy organizations to block the further development of areas landward of important coastal wetlands, including the habitats of endangered or rare species.

> **"Even if pure retreat appears infeasible on a large scale and economically inefficient over the long term, it would probably go farther than any other option toward maintaining certain critical coastal habitats since it avoids the problem of later having to abandon coastal property developed now."**

Acting Now to Make Adaptation Later Possible

The most politically and economically efficient way to conserve biodiversity while meeting other policy objectives is neither protection nor retreat. Far preferable to either are innovative policy options that meld the goal of short- to mid-term coastal development with the long-term goal of conserving wetlands and other coastal ecosystems. All such options currently attempt to institutionalize the assurance that current and future development will make way as necessary for migrating ecosystems (Titus 1991). Proponents of these so-called "presumed mobility approaches" argue that they allow continuing economic use of coastal drylands, while simultaneously keeping them available for coastal ecosystems when the time comes. The various approaches being discussed include:

- ***Not interfering with the development of coastal property, but simply prohibiting the construction of bulkheads or other measures to impede ocean advance*** (Titus 1986, Titus 1991, Fischman 1990). Current landowners might not object to such restrictions considering that property loss would occur far into the future, if ever.[20] Of course, future landowners could argue many years from now that such a regulation constituted a regulatory taking and should be overturned—a definite problem with this approach.[21]
- ***Combining discretionary permitting processes with bans of bulkheads and other landuse restrictions.*** To the extent that building a beach house or other structure is a privilege rather than right,[22] governments would certainly be able to impose conditions on building, remodelling, or repair permits. A "presumed mobility" clause could, for instance, legally prevent the landowner from taking steps that might impede ocean encroachment. Under these circumstances, developers would have incentives to design houses that could be easily moved, thus lowering the future costs of adaptation.
- ***Fundamentally changing the nature of land ownership along coastal zones.*** Ownership could be taken through governmental eminent domain and then leased back to the original landowners for a specified period on condition that no steps would be taken to counter sea level rise. Landowners would be in a much weaker position to object to the end of the lease than if they still owned the land (Titus 1991), though the governmental acquisition of the land in the first place poses daunting problems of legal authority and entails high compensation costs (Fischman 1991). Since leasing has never been attempted at this scale, it would also pose major informational, legal, and organizational problems of its own in coming years.
- ***Large-scale purchasing of upland wetland conservation or "flowage easements" by governments or by conservation groups.*** Considering the landowner's discounted cost of losing land in the distant future, the purchase of such a right ought to be inexpensive, probably less than 1 percent of the current market value of the land (Titus 1991). Taking ownership of the easement out of governmental hands could make the process significantly less susceptible to political and legal reversal at later dates. Courts rarely interfere with legally drafted deed provisions, so forced abandonment when the time comes ought to be largely immune to court challenges.
- ***Use the public trust doctrine to enforce the public's right to wetland conservation on private property.*** The public trust doctrine holds that the public retains certain rights with respect to tidal and other periodically or sometimes submerged lands, including coastal shorelines. It is not clear, however, whether

government has a responsibility to act to safeguard public trust wetland rights, or whether private responsibilities under the public trust doctrine extend to ensuring that wetlands do not disappear under rising seas (Fischman 1991).

The success of most of these options depends on two key assumptions. One is that landowners and courts will discount the future value of coastal property. If so, measures can be put into place to protect coastal ecosystems (prevention of bulkheads, purchase of easements) at a relatively low cost today (both politically and economically) since the net present value of the action is low. The second assumption is that future landowners faced with losing the land will not succeed in reversing the policies established today. Both of these assumptions are somewhat tenuous given the political pressure that can be brought to bear on land-use planning in a crisis.

To some extent, the nature of climate change itself is likely to influence future political decision-making significantly. If sea level rise is incremental, claiming a house here and a house there over time, political constituencies might have difficulty forming around the issue of reversing policies against protecting the land being lost. But if climate change is experienced as, say, intense storms and tidal surges, political pressure could easily be brought to bear to protect property interests. In Chatham, Massachusetts, a small group of determined landowners got policies against coastal defenses overturned when it became clear they were about to lose their houses through coastal erosion (Fischman and St. Amand 1990). In the aftermath of Hurricane Hugo, political pressure that had already been building to reform South Carolina's strict Beachfront Management Act of 1988 quickly succeeded in making the law considerably more flexible from the standpoint of landowners (Fischman 1990).[23]

One innovative idea for overcoming future political opposition has been put forward by Joseph Sax (Sax 1989). His proposal involves the "purchase" of an "insurance policy" against the day that sea level rise requires abandonment of private property. Property owners today would sell the conservation or flowage easement to their land to the government, but instead of being paid in cash they would receive the insurance policy. This insurance policy would stay with the property over time, helping maintain its value and reducing landowner incentives to take protective measures. The money itself would be invested so that a pre-set sum could be paid to the landowner when the property has to be abandoned. By providing a financial benefit at the time of actual impact, the policy would presumably be far less likely to come under attack by landowners. Although it clearly presents challenging implementation problems, not the least of which is the size of the fund needed to compensate the entire class of coastal property owners, this approach does appear to reduce the uncertainties surrounding the effectiveness of many of the other measures.

> **"If sea level rise is incremental, claiming a house here and a house there over time, political constituencies might have difficulty forming around the issue of reversing policies against protecting the land being lost."**

Underlying all of these policy options is the presumption that policymakers and the public know how important these coastal ecosystems and their biodiversity are. As always, the basic political facts of life in the United States make public education an important component of any effective response. As Fischman and St. Amand note: "[t]he most effective strategy today for encouraging this evolution in the doctrine [of presumed mobility] is to put private landowners on notice of the importance that the public places on coastal wetlands and of the role that fastlands will play in the future viability of marsh ecosystems." (Fischman and St. Amand 1990).

The Status of U.S. Policy

Various state and federal policies for protecting wetlands and other coastal ecosystems have existed in the United States for some time. In particular, Sec. 404 of the 1972 Clean Water Act and the Coastal Zone Management Act contain legal mechanisms for slowing or mitigating the loss of coastal wetlands and for addressing other impacts on coastal ecosystems, including pollution. Most states also now have coastal zone management laws regulating coastal development and discharges into coastal ecosystems. In general, federal and most state policies on coastal ecosystems provide a "reactive" policy framework. Such policies reflect the assumption that the coastline would be unchanging in the absence of identifiable development projects, and they provide a mechanism for mitigating or denying development proposals.

This reactive policy framework provides no mechanism for dealing with the anticipated impacts on coastal ecosystems of sea level rise induced by climate change. Yet, for several reasons, some progressive measures are being put into place. Governments are coming to grips with the problems created by seawall and bulkhead construction in response to even current rates of sea level rise and coastal erosion. Awareness of the importance of coastal wetlands is also growing.

Existing measures that will help provide a biological buffer in the face of future sea level rise include:

- Most coastal states restrict seawalls and bulkheads to protect recreational beaches and in some cases to help mitigate negative impacts on wetlands (Edgerton 1991).
- Maine has adopted "presumed mobility" as a guideline for areas developed after 1987. Permits for construction are issued only if the proposed development will not unreasonably affect wildlife habitat, interfere with natural water flow, or interfere with the natural supply or movement of sand within the coastal system. Buildings are allowed only if the developer demonstrates the site will remain stable after a three-foot sea-level rise. These rules have survived legal challenges, though they have not yet faced public pressures for rebuilding after, say, a major storm. The rules have not stopped coastal development, but they have influenced the location and type of development (Fischman and St. Amand 1990).
- In North Carolina, the Coastal Area Management Act of 1974 frames the need for regulatory intervention in terms of the danger that "uncontrolled or incompatible development could unreasonably endanger life or property." The law requires particular setbacks for new construction and prohibits erosion-control structures. Applicants for development permits have to sign acknowledgments that they understand the hazards of building permanent structures in essentially unsuitable areas. The apparent success of the Act, some regulators say, stems from its emphasis on protecting property and life, rather than preserving the beach or environment per se. This wording, they contend, gives them a stronger tool in seeking compliance with the Act and raises fewer "takings" issues (Fischman and St. Amand 1990). Other observers note, in addition, the particularly effective working relationship state and local landuse agencies have established to implement the Act.
- In South Carolina, a construction setback zone extends landward from the first primary dune for forty times the length of annual erosion (Edgerton 1991) *(See Note 23)*.

These state policies are a start in the right direction. Still, experience with honoring legal provisions when they really start to hurt casts their long-term ability to maintain coastal ecosystems into doubt. More innovate strategies need to be tested and applied to achieve this aim.

Conclusions and Recommendations

Surveying the policies available to respond to sea level rise and thereby minimize impacts on coastal biodiversity, it is easy to forget that climate change will seriously harm coastal biodiversity in the United States even with the most enlightened policy response. Virtually nothing can be done to mitigate some of the impacts of climate change on some coastal ecosystems. Even under the option of full retreat, rapid sea level rise will substantially reduce coastal wetland area, exacerbate threats to coastal species, and, along with increased water temperatures, threaten coral reefs. Accordingly, the highest priority now should be slowing the rate and ultimate magnitude of global warming. Even for coastal systems that may be able to adapt to a changing environment, the most obvious prescription for "pro-active" policy is still to slow future global warming. Regardless of which policy is relied upon to respond to rising sea levels, its implementation will be made much easier and cheaper if the rate of climate change is slowed.

Several types of policies will no doubt play important roles as the nation responds to sea level rise. Engineering solutions will be deployed in densely populated and developed coastal regions to protect the financial investment already made there. Where coastal uplands appear particularly important to the migration or formation of wetlands in the face of sea level rise, and where those coastal uplands can be purchased at modest cost, retreat makes sense. But the single most important influence on the fate of coastal biodiversity in coming decades will be success in implementing adaptive solutions.

Some of these adaptive (or "presumed mobility") solutions seem more promising than others. For example, if the funds can be amassed, the purchase of flowage easements by non-governmental organizations (instead of governments) should work well. In contrast, zoning restrictions on bulkhead construction may be overturned when the reality of sea level rise becomes apparent. Nevertheless, the ultimate success of policies based on the concept of presumed mobility will depend heavily on how and how fast climate change manifests itself and on how much effort is spent preparing landowners and others for sea level rise and its impact on current land uses.

In sum, five fundamental conclusions arise from this analysis:

1. ***Most policies proposed for mitigating the impacts of climate change neglect the need to conserve biodiversity.***
2. ***Some detrimental impacts on biodiversity can't be prevented by any policy response to climate change.*** In these cases, the need is to slow the rate and reduce the ultimate magnitude of global warming and its eventual impacts on coastal ecosystems. Reliance on technological fixes in these cases is ill founded.
3. ***Biodiversity conservation requires coastal development policies that promote accommodation to sea level rise, rather than defend against it.***
4. ***Success in conserving biodiversity as sea level rises depends on how fast response policies are implemented.*** It could take decades before the need to take action to protect coastal development would make itself evident, and by then it could be technically too difficult or too costly to make many changes that are feasible now.
5. ***Long-term environmental education is needed to make the adaptive responses intended to promote long-term biodiversity conservation politically acceptable.***

In light of these conclusions, the following eight policy options would help conserve coastal biodiversity in the face of climate change:

1. ***Slow the Rate and Magnitude of Global Warming.***

Although often overlooked in technical discussions of response to sea level rise, slowing global warming in the first place would do more than any after-the-fact measures could do to conserve biodiversity.

2. ***Incorporate the Protection of Coastal Ecosystems as a Fundamental Goal in Federal and State Policies.***

Legal findings that coastal wetlands migration is in the interest of human health, safety, and welfare can help defend against future charges of regulatory taking (Fischman 1990). Federal and state commitment to biodiversity conservation could be promoted through policy declarations. A model might be "It is a [State][Federal] policy to promote the conservation of biological diversity on public and private lands."

At the federal level, Executive Order 11990 should be reissued to establish a no-net-loss goal for coastal wetlands. A broad doctrine of no-net-loss should be adopted for coastal wetlands based on the length of the wetland/water interface and the functions of the wetlands, as well as on total wetland area. To the extent possible, the same criterion should be applied to other coastal ecosystems. The no-net-loss criterion should specifically include climate-change-induced sea level rise as an action to be mitigated by the government given the role of human activities in contributing to global warming.

3. ***Eliminate Federal and State Subsidies that Promote Coastal Development and Coastal Defense.***

The pooling of risk through federal flood insurance, for example, can encourage coastal development.[24] So can federal or state beach nourishment or seawall construction projects.

4. ***Make Wider Use of Such Regulatory Measures as Coastal Zoning and Setbacks.***

Public policymakers and analysts must come to accept that the coastline is not, nor will it ever be, a stable entity. An important policy goal, therefore, is maintaining greater flexibility in the face of an ever-changing coastline.

5. ***Put Property Owners on Notice that Sea Level Rise Will Occur and that Public Policy Goals Will Dictate the Abandonment of Large Areas of Dry Land.***

The sooner property owners are put on notice, the more likely that eventual abandonment of the land will be seen as a foregone conclusion, rather than as a public infringement of private property rights.

6. ***Minimize Anthropogenic Stresses on Coastal Ecosystems Other Than Sea Level Rise.***

Beach maintenance, groundwater pumping, flood prevention, sedimentation, and pollution discharge are just several of the activities whose implications for coastal ecosystems need more careful consideration during planning processes.

7. ***Based on the Distribution of Key Coastal Ecosystems, Identify Where Different Policy Options Should be Pursued.***

Where does land purchase or condemnation make sense? Where is defense against the ocean acceptable from a biodiversity standpoint? Where should "flowage easements" or other approaches be used? This identification process will require considerable site-specific research over the next several years.

8. ***Non-governmental Organizations Interested in Land Acquisition for Conservation Purposes Should Begin to Experiment with the Various Easement and Leasing Options Described Above, Focusing on Lands of Particular Conservation Importance.***

Given their experience with procuring and protecting lands already of conservation concern, through easements and other means, such organizations are in an excellent position to undertake experimental programs looking at lands likely to be of conservation importance in the future.

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NOTES

1. Coastal wetlands refer to coastal salt and brackish marshes. This more commonly accepted definition differs from the Convention on Wetlands of International Importance especially as Waterfowl Habitat (known as the Ramsar Convention) which defines any flooded area as a "wetland."
2. Inland wetland loss has continued to be a serious problem, but even here the "swampbuster" provisions in the 1985 farm bill (the Food Security Act of 1985, P.L. 99–198), as well as the repeal or alteration of several tax code provisions providing incentives for wetland conversion through the 1986 Tax Reform Act (P.L. 99–514) have made significant inroads into the rates of loss in the 1980s.
3. Although the average county in the contiguous United States contains only 3–4 federally listed threatened and endangered species, coastal counties tend to contain many more listed species with nearly half containing as many as 10–20 listed species (Flather and Hoekstra, 1989).
4. The Nature Conservancy classifies a species as "Rare" (G3) if it is either very rare and local throughout its range, or found locally in a restricted range, or because of other factors making it vulnerable to extinction throughout its range. A species is designated as "Imperiled" (G2) if there are only 6 to 20 occurrences or few remaining individuals, or because of some factor(s) making it very vulnerable to extinction throughout its range. A species is listed as "Critically Imperiled" (G1) because of extreme rarity (5 or fewer occurrences or very few remaining individuals) or because of some factor(s) making it especially vulnerable to extinction (Morse 1987). The Nature Conservancy, in cooperation with the various state Natural Heritage Inventory Programs, has the most complete data on threatened, and endangered species, but data on the species elevational ranges are accurate only to within 10 feet (5 feet for species threatened within the state), and thus greater resolution in coastal areas is not possible.
5. Scientific names: peregrine falcon *(Falco peregrinus anatum)*, California brown pelican *(Pelecanus occidentalis californicus)*, light-footed clapper rail *(Rallus longirostris levipes)*, California black rail *(Laterallus jamaicensis coturniculus)*, California least tern *(Sterna antillarum browni)*, Belding's savannah sparrow *(Passerculus sanwichensis beldingi)*, San Francisco garter snake *(Thamnophis sirtalis tetrataenia)*.
6. Of the actual loss of coastal wetlands between 1954 and 1974, more than 90 percent was due to human activities related to dredging for port development, filling related to the spread of urban areas, and disposal of dredged material. However, the causes of coastal wetland loss differed considerably among states. Sixty-three percent of wetlands loss in Delaware and 43 percent in Virginia was due to urban development. In contrast, the primary cause of wetlands loss in Maryland was coastal impoundments, dredging projects, and rising sea level, which accounted for 73 percent of the wetlands lost over this period. In coastal Louisiana, the overwhelming cause of wetlands loss relates to the drowning of wetlands due to the combination of land subsidence and reduced marsh accretion rates.
7. New Jersey was losing coastal marshes at a rate of 3,097 acres per year prior to passage of state coastal wetlands protection laws, and the rate dropped to only 50 acres per year subsequently. Similarly, in Maryland, rates of loss dropped from 1,000 acres per year to 20.
8. However, in some cases significant organic material returns to wetlands through this same process, since anadramous fish, which live as adults in salt water but breed in freshwater, return large quantities of nutrients when they return to spawn and often to die.
9. In part, the recent decline is exacerbated by more stringent harvest restrictions put into place as the population declined.
10. The study also analyzed west coast marshes, but due to apparent errors in determination of elevations the estimates of wetlands loss were highly uncertain.
11. Not all coral reefs were unable to keep pace with these rates of sea level rise. One study of coral reefs in Papua New Guinea suggests that growth kept pace with a 13 mm/yr relative sea level rise over a span of 1000 years following the Pleistocene deglaciation (Chappell and Polach 1991).

12. The total for the five states does not equal the sum of the totals in Table 5 because some of the listed species are found in more than one of the states. The coastal fringe refers to the area below the 10-foot contour.
13. The choice of 5-foot and 10-foot contour elevations in this discussion is dictated by the availability of data. The mapping of species occurrences is accurate only to these ranges. This coastal band slightly exceeds the area that will be affected by sea level rise in the next century (1–6 feet) but is, in fact, the band at greatest risk from the combined pressures of development and sea level rise.
14. A community is an integrated group of species inhabiting a given area. The organisms within a community influence one another's distribution, abundance, and evolution.
15. These species fall into categories S1, S2, S3, and SH as used by The Nature Conservancy. The number corresponds to the G-ranks described in Note 4, but refers to distribution and status at the state rather than global level. SH indicates a species of historical occurrence but not verified in the past 20 years, thus it may be either critically imperiled or extinct.
16. Almost no studies have examined the impacts of sea level rise on ecosystems other than coastal wetlands, such as barrier beaches, mangroves, or coral reefs.
17. Discounting is an economic concept that accounts for the time value of money (or other assets). Most individuals would prefer to receive any given amount of money today rather than ten years hence, and would even be willing to accept less money if they could get it right away. The amount of difference a person is willing to accept will depend both on the length of time involved, and on the specific benefit they perceive by receiving the payment immediately rather than tomorrow (their discount rate).
18. Although economic discounting clearly biases the decision-making process against taking actions that impose significant immediate costs either on the landowner or the government, the principle of economic discounting may be able to be turned to the advantage of wetlands conservation under certain scenarios. Purchasing the discounted rights to land that might later be submerged, for example, should in principle be quite inexpensive. This option is discussed later in the text.
19. The Intergovernmental Panel on Climate Change estimates that 1 meter rise in global sea level would require defense of 360,000 km of coastline around the world at a cost of close to $500 billion dollars over and above existing costs associated with coastal protection around the world. In the United States the cost is put at $106.2 billion, or $306 per person. This is equivalent to 0.03% of GNP for the United States, a seemingly modest figure. (IPCC 1990b)
20. In the case of a landowners' interest in coastal property, he or she may feel that what happens to the property in 50 or 60 years is of relatively little practical interest, and that events that far in the future are unlikely to significantly affect short-term real estate prices. As a result, he or she may be willing to simply accept the regulation, or may be willing to take a modest payment today in exchange for giving up certain rights to protect their property if it eventually becomes threatened by sea level rise.
21. The perceived robustness of this policy option is dependent on one's own perceptions of how the political and legal systems are likely to function in a situation in which large numbers of affluent landowners are suddenly faced with loss of their coastal property. Some observers argue that regulations or agreements implemented decades before are unlikely to be successfully challenged (Fischman 1991, Titus 1991), and that the regulations and agreements can be specifically tailored to minimize such risks. Indeed, there are many cases where conceptually similar provisions are successfully implemented, as in the case of conditional leases within National Parks. Nevertheless, the question as it applies to the coastal zone, where property loss could be dramatic and sudden under some scenarios, will in some sense remain open until it is actually tested.
22. To the extent that it is considered a right, such restrictions may be considered a taking.
23. The 1988 Beachfront Management Act provided for a "deadzone" in which no new construction would be allowed, and in which destroyed buildings could not be replaced. The law would have prevented rebuilding approximately 20 of the 150 coastal structures damaged by the hurricane. Amendments to the law in June, 1990 eliminated the "dead zone" and provided for variances to other provisions of the law including construction setbacks. Some regulators argue that the 1990 incorporation of the variance process into the law, along with stronger provisions prohibiting bulkhead construction or rebuilding, actually made it possible to more effectively implement the law than

had previously been the case. Nevertheless, elimination of the "deadzone" and the development of variance procedures will certainly increase the political pressure for shoreline protection in future years as sea levels rise.

24. The Coastal Barriers Recovery Act (CBRA) is an example of legislation to eliminate such subsidies. The goal must be to ensure that no federal subsidies encourage development in areas up to the limit affected by *relative* coastal sea level rise under the most likely scenarios of climate change.

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