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BIOLOGICAL POPULATIONS AS INDICATORS OF ENVIRONMENTAL CHANGE

Office of Policy, Planning and Evaluation
U.S. Environmental Protection Agency
Washington, DC 20460

This report, "Biological Populations as Indicators of Environmental Change - Volume I" is a review of scientific literature on biological phenomena frequently noted in the popular press, to determine the degree to which scientists are reporting that the phenomena may be indicators of environmental changes.

Noticing that reports of events, such as dwindling numbers of warblers in our forests and apparent reductions of frogs and salamanders observed worldwide, were appearing almost weekly in news features and science pages of major newspapers, the Environmental Results Branch (ERB) of the Office of Policy, Planning and Evaluation (OPPE), U.S. Environmental Protection Agency (USEPA) began an attempt to identify existing knowledge about these phenomena. Of particular interest was considering whether these phenomena, alone or in combination, might be indicators of environmental change at the regional, continental, hemispheric, or global scales.

The first volume reviews eight of these phenomena; planned future volumes will address additional occurrences and continue to monitor the literature on the topics in this volume. Selection of these eight topics is not an indication that we believe these to be the "best" indicators of environmental change; simply these appeared frequently in the popular press and data was more plentiful than for other topics. Likewise neither do we suggest that one can determine if these changes are from natural causes or are anthropogenic (induced by man). This is a scientific literature review "directed" by a screen of articles appearing in the popular press; we make no independent recommendations nor conclusions in regard to causes or selection of indicators of environmental change.

As part of this reference/educational document, extensive bibliographies are included. These bibliographies, the scientific references cited in the text and included within each chapter as "References", and popular literature cited as a "Popular Press Bibliography", should serve as tools for scientists and the general public alike.

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Global warming, acid rain, water pollution – how can the general public understand which issues are the most serious and which ones, if any, are overstated? What do we really know about the effects of these and other environmental problems on the health of ecosystems and plant and animal populations within ecosystems? What do news reports of unexplained (and sometimes previously unseen) occurrences such as large numbers of dead dolphins washing up on the Atlantic coast of the United States and in the Mediterranean, apparent reductions of frogs and salamanders observed worldwide, and dwindling numbers of warblers in our forests really mean? Are these occurrences induced by man, i.e., are they "anthropogenic?"

After noticing that such events and related phenomena began to be identified frequently in scientific journals and almost weekly in news features and the science pages of *The New York Times* and *The Washington Post*, the Environmental Results Branch (ERB) of the Office of Policy, Planning and Evaluation (OPPE), US Environmental Protection Agency (US EPA), began an attempt to identify existing knowledge about these phenomena. Of particular interest was considering whether these phenomena, alone or in combination, might be indicators of environmental change at the regional, continental, hemispheric, or global scales.

This first volume examines certain of these phenomena and attempts to distinguish those occurrences in the natural world that scientists believe to be anthropogenic from those phenomena for which so little is known that it is unclear whether these events result from man-made or natural causes. Following volumes will consider additional natural-world occurrences as potential indicators of environmental quality and will continue to monitor the literature on the topics in this volume.

The scientific literature and popular information sources were reviewed simultaneously, to determine the degree to which scientists are reporting that the phenomena may be indicators of environmental changes, and to develop some indication of public awareness and concern for these events. These bibliographies – the scientific references cited in the text are included within each chapter as "References" and a selected popular literature bibliography as "Popular Press Bibliography" – should serve as tools for scientists and the general public alike. The use of popular information sources as part of the screening process to identify biological phenomena of potential concern was a different approach than typically is used in developing a scientific literature review. However, such a "media scan" appears to be an appropriate tool to use on occasion. This is in keeping with the new emphasis at all levels of government of collecting the types of information that may be of particular interest to our "customers", the public. Such media scans are one type of tool to help us take into account what may be of special concern to the public in developing reference documents such as this.

Twelve potential biological indicators of environmental change of particular interest were identified in the initial literature review based on scientific merit and validity. The US EPA is addressing two of these topics elsewhere. This volume focuses on eight of the remaining initial topic areas. These eight topic areas were chosen because of their broad geographic extents. Additional topics may be addressed in future publications. Scientists with expertise in specific topics assisted in reviewing this document for technical accuracy are listed in the acknowledgements section.

D. Eric Hyatt and Otto Gutenson, Editors
EPA Office of Policy, Planning and Evaluation

EXECUTIVE SUMMARY

We live in an era of unprecedented loss of biological diversity, and possibly of certain life-supporting services provided by ecosystems. Recently, news reports of occurrences such as large numbers of dead dolphins washing up on the Atlantic coast of the United States and in the Mediterranean, apparent reductions of amphibian populations – such as frogs and salamanders – observed worldwide, and dwindling numbers of warblers in our forests, have been appearing with increasing frequency. But what do these observations really mean? Which are natural occurrences in response to variability in weather or other natural phenomena, and which are consequences of man's activities? What do these phenomena tell us about the condition of our environment? Which of man's activities are the most damaging to our biological heritage, and what, if anything can we do to reverse these losses?

The Environmental Results Branch (ERB) of the Office of Policy, Planning and Evaluation (OPPE), US Environmental Protection Agency (US EPA) is beginning an attempt to identify existing knowledge about these phenomena. Of particular interest is considering whether these phenomena, alone or in combination, might be indicators of environmental change at regional, continental, hemispheric, or global scales. To accomplish this, an analysis of the scientific literature and popular information sources was performed to determine the existing "state of the science" for such reported phenomena. Twelve potential indicators of environmental change of particular interest were identified in the initial review of news media and scientific journals (see page 4). US EPA is addressing two of these elsewhere (loss of wetlands and loss of biodiversity). This report focuses on eight of the remaining ten topic areas:

(1) Declining populations of neotropical migrant birds;

(2) Declining populations and increasing numbers of extinctions of North American fish species;

(3) Decreasing populations of North American ducks;

(4) Increased incidence of coral bleaching, degradation, and death worldwide;

(5) Declining populations of amphibians worldwide;

(6) Decreasing populations of turtles worldwide;

(7) Mass deaths of dolphins and declining populations of seals;

(8) Loss of forests worldwide and forest "dieback" in the north temperate zones.

Observed trends, hypotheses, and supporting evidence on causes of the trends for each topic are described in Section 2 of this report and summarized briefly below.

Neotropical migrant bird species. Fragmentation of North American forests is contributing to the decline of neotropical migrant bird species that breed in forest interiors. Forest fragmentation exposes larger proportions of the remaining forest to edge conditions and edge predators and parasites, and several characteristics of neotropical migrant species make them more vulnerable to these changes than short-distance migrants or resident species. The relative contribution of "island effects" of forest fragmentation to the decline of neotropical migrants on a regional scale has not been analyzed.

Tropical deforestation also might be contributing to the observed population declines of neotropical migrant species, but scientists do not agree on this issue. Whether or not tropical deforestation currently is contributing to the declining neotropical migrant bird populations, it is likely to become a more serious problem than fragmentation of habitat in North America in the near future. Obviously, continuing tropical deforestation *and* North American forest fragmentation are likely to cause continued population losses and eventual extinctions of neotropical migrant species.

North American freshwater fish. The rate of extinctions of North American freshwater fish has risen sharply in the last decade. Now, fully a third of the native species of North American freshwater fish are considered threatened, endangered, or of special concern. Physical alteration of surface waters (e.g., channelization, dams, reservoirs) and the introduction of non-native species are the major causes of population declines and extinctions among North American fish, although other factors have contributed to the decline of many species.

Ducks in North America. Several species of ducks have suffered significant declines in population levels in North America in recent years (i.e., mallard, American widgeon, blue-winged teal, northern pintail, and redhead), and several other species appear to be declining also (e.g., canvasback, northern shoveler, green-winged teal). Investigators believe that the declines are due primarily to drought and human activities that have severely reduced the abundance of wetland habitats required by ducks and other waterfowl for breeding, migration, and overwintering. Crowding of birds into the remaining areas may contribute to outbreaks of disease and increased mortality. Degradation of the remaining wetlands by acid rain and/or agricultural runoff may be reducing the reproductive success of ducks in the remaining habitats. Finally, uncovered oil pits contributed to the mortality of migratory waterfowl, but regulatory actions over the past few years have eliminated this source of mortality. Uncovered cyanide pits in the mid-west, however, continue to pose a threat.

Coral reef communities worldwide. For years, coral reef communities have been suffering from adverse effects of human activities, including physical destruction (e.g., boat anchors, coral mining), nutrient runoff and sedimentation, and coastal pollution from agriculture, industries, and sewage. In addition, during the 1980's, four coral reef community bleaching events occurred on an unprecedented geographic scale. Scientists believe that these wide-spread bleaching events occurred in response to elevated water temperatures, but as yet there is no conclusive evidence that the bleaching events are indicative of a global warming trend. John Ogden, director of the Florida Institute of Oceanography, has concluded that "virtually every reef system in the world is suffering."

Amphibians worldwide. Recently, numerous reports of declining populations and extinctions of amphibian species worldwide have raised the question of whether a worldwide decline is occurring that may be a result of human activities. Although it is not yet clear whether a true global decline is in progress, concern for that possibility continues to increase. Habitat destruction, introduced species, habitat acidification, and unusual climatic variations are known to have had adverse effects on several localized amphibian populations. Other potential factors, such as pathogens, pesticide exposure, and increased ultraviolet radiation, have not yet been studied. The cause(s) of many of the observed declines of frog populations have not yet been identified, and additional study is needed, particularly on the range of fluctuations that might be expected to occur naturally.

Turtles worldwide. Approximately one third of the world's species of land turtles (terrestrial and freshwater semi-aquatic) are now considered to require conservation attention. Essentially all of the world's sea turtle species are considered threatened or endangered. For the land turtles, habitat destruction and fragmentation, appear to be the primary causes. Juvenile and adult sea turtles suffer primarily from capture by shrimp trawlers, but other factors also cause excess mortality. Various human activities have restricted available nesting beaches and have reduced the survivorship of sea turtle eggs and hatchlings on remaining beaches.

Marine mammals. Two recent bottlenose dolphin mass mortalities have triggered public and scientific concern that pollution, in addition to incidental catches of dolphins by the tuna fishing industry, may threaten dolphin populations. Pathological examination of dolphins stranded in 1987 suggest a chronic immune system suppression. This could have been a consequence of sublethal exposure to a red tide and/or a consequence of unusually high concentrations of PCBs in the dolphin tissues. In addition, recent "epidemics" of a distemper-like virus have caused mass mortalities among several populations of seals. Some suspect that coastal pollution has increased the seals' susceptibility to the virus, but the cause of the outbreaks is as yet undetermined. Unusually warm temperatures also may contribute to outbreaks of the virus.

In addition to mass mortality events, many pinniped (i.e., seals, sea lions, and walruses) populations have been declining recently. Bioaccumulation of PCBs or other toxic substances are known to reduce reproductive success in seals, and may be contributing to these population declines in some areas.

Forests worldwide. Forests are declining and being damaged worldwide. In the tropics, clearing land for agriculture and other land uses is the most significant problem, whereas in the north temperate zone, forest dieback resulting from atmospheric pollution is an additional problem.

Clearing of tropical rainforest is proceeding at an unprecedented rate that could result in the complete loss of such forests by the year 2050. In North America, deforestation and reforestation are more balanced; however, old growth forests are at risk of being lost completely in the Pacific Northwest.

Beyond the conclusion that general atmospheric pollution is leading to north temperate forest dieback in the developed countries, researchers have not been able to identify a more specific common cause across the continents. Because multiple pollutants are generally present in the forests of concern, attribution of forest dieback to specific direct or indirect effects of acid rain, ozone, or other atmospheric sources of pollution remains controversial. Current evidence implicates a variety of natural biotic and abiotic stresses upon which are superimposed physical and chemical stresses of anthropogenic origin that may have originated long distances from the affected sites.

Summary. Available evidence indicates that human activities are contributing to many of the observed population declines described in this report. The direct destruction, degradation, and fragmentation of habitats as lands and waters are converted and altered for human use appear to be the major contributors to declines in populations of neotropical songbirds, ducks, freshwater fish, and land turtles in North America. It is not yet clear whether the apparent decline in amphibian populations worldwide is real, and if so, what the cause(s) of the trend might be. Increasing environmental pollution is taking its toll on the surface water quality upon which our fish fauna depend, and may have contributed to the recent deaths and declines of dolphins and seals in the North Atlantic and the Mediterranean. Our deliberate and inadvertent introduction of non-native species of fish, frogs, and other organisms also has had a devastating effect on the diversity and abundance of our native fauna and flora. In addition to suffering from physical destruction, nutrient runoff and sedimentation, and pollution, coral reef communities may be suffering directly from a global ocean warming trend or increased variability in ocean temperatures. The clearing of tropical rainforests not only threatens global biodiversity, but also the services supplied by those forests in stabilizing our global climate.

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1. OVERVIEW OF BIOLOGICAL POPULATIONS AS INDICATORS OF ENVIRONMENTAL CHANGE

We live in a era of unprecedented loss of biological diversity and possibly life-supporting services provided by ecosystems (Myers, 1988; Wilson, 1989). The human population on the planet has more than doubled since 1954 (Mostafa, 1989). An estimated 25 percent of the world's species present in the mid- 1980s may be extinct by the year 2015 or soon thereafter (Raven 1988a,b). Various ecosystem services, such as the regulation of water discharge, soil generation, and the absorption and breakdown of pollutants, are being degraded in some areas as component species vanish from these ecosystems or as natural habitats are converted to other land uses (Reid and Miller, 1989). Our lives also are being impoverished by the loss in many areas of components of our planet's ecosystems that we have taken for granted in the past: hearing the song of a wood thrush in the spring, snorkeling to view coral reef communities, or spending a day outdoors fishing or hunting waterfowl.

Dead Mediterranean Dolphins Give Nations Pause (Washington Post, 1992)

The loss of biodiversity and ecosystem services as a whole are difficult concepts to grasp, and may not allow us to visualize easily how human activities impinge on the biological health of our planet. It may be easier for us to think in terms of specific indicators of changes, such as a decline in bird species that we can identify during spring and fall migrations or the failure of frogs to return to ponds in our favorite hiking areas. We are shocked to read of hundreds of dolphins found dead and dying on our Atlantic beaches, and wonder not only what has happened to these creatures, but also what the event may portend for our own future and well-being. Within the last decade, the frequency with which the news media (e.g., *The Washington Post*, *The New York Times*) have identified such occurrences has increased, and now can be found almost monthly. This frequency of reporting on such occurrences reflect the number of recent reports in the scientific literature.

From Minnow to Sturgeon, North American Fish are in Peril (NY Times, 1990)

But what do these changes really mean? Which are natural occurrences in response to variability in weather or other natural phenomena, and which are consequences of man's activities? We may wonder what these phenomena tell us about the condition of our environment. Which of man's activities are the most damaging to our biological heritage, and what, if anything can we do to reverse these losses? Which of these changes or indicators would be most representative of environmental conditions?

Coral Reefs Off 20 Countries Face Assaults from Man and Nature (NY Times, 1990)

1.1. Selection of Indicators: Technical and Popular Literature Scan

Different groups of organisms are vulnerable to different aspects of man's activities and the changes wrought on the environment by those activities. The health and welfare of "indicator" populations of organisms might serve as a barometer of different aspects of our changing environment and harbingers of consequences yet to come. As part of their strategic planning, the US Environmental Protection Agency's (US EPA) Environmental Results Branch (ERB) initiated an investigation into these phenomena in an attempt to determine which, alone or in combination, might serve as indicators of general environmental change at regional, continental, hemispheric, or global scales. ERB recognized that there are a number of potentially important environmental indicators outside those areas being considered by EPA's program offices (e.g., Office of Air and Radiation, Office of Water, etc.), indicators that might reflect the cumulative effects of human disturbances on many different components of our environment (e.g., water, soil, air).

Loss of Tropical Forests is Found Much Worse than was Thought (NY Times, 1990)

This report is based on an initial literature scan to identify and evaluate potentially useful ecological indicators of environmental quality. This included a review of popular literature to identify those phenomena that have caught the public's attention and of the scientific literature to determine the validity of the reported trends and what is known about natural and anthropogenic causes of these trends. The phenomena selected for this report are not necessarily considered of

Frogs, Toads Vanishing Across Much of the World; "Environmental Degradation" May be to Blame, Scientists Say (Washington Post, 1990)

greater importance by the scientific community than a number of biological phenomena not discussed here. But they appear to be of at least some concern to the public as indicated by the news scan. Therefore conducting a technical literature review to present the current state of scientific knowledge about these phenomena should serve a useful purpose in addressing the interests of our "customers", the public, in knowing more about the possible implications of the phenomena. Of the twelve topics that received the most coverage recently in the popular press (Exhibit 1), loss of biodiversity and loss of wetland habitats are the focus of major EPA research efforts and a number of other reports, and will not be covered in this volume. This report focuses on eight of the remaining ten topics. These eight topics were chosen based on scientific merit, quality of information available, and breadth of geographic scope. The remaining two topics (decrease in shellfish populations and increasing incidence of algae blooms) and other potential topics are not discussed in this report but may be addressed in future volumes.

This report summarizes the findings of the literature review in three sections. The remainder of Section 1 describes the literature review and acquisition strategy and identifies several potential biological indicators of environmental change. In Section 2, we describe each of the eight phenomena selected for review separately. For each, we describe level of applicability (e.g., regional to global), recent trends in the indicator, current hypotheses on the cause(s) of the observed trends, and the evidence available to support each hypothesis. In Section 3, we present an overview of all eight trends, and what they indicate concerning the impacts of human activities on environmental quality.

Seen any Warblers Lately? (NY Times Magazine, 1990)

1.2. Methods

To identify literature pertaining to biological populations as potential indicators of environmental change, we conducted a screen-level online computer search of popular and scientific literature and contacted academic experts and other professionals and organizations known to be involved in research or publications concerning biological trends (see Acknowledgements). Using these approaches, we identified several potentially important population indicators of environmental change at regional, national, hemispheric, and global levels, that had received attention in the popular press in recent years. We selected eight of the twelve topics that not only receive heavy academic and popular press coverage, but also appear to exhibit the most technical merit and wide

Their Beaches Eroding, Threatened Sea Turtles Have Few Places to Nest (NY Times, 1992)

Exhibit 1. Biological populations as potential indicators of environmental change.

Addressed in This Report

(1) Declining populations of neotropical migrant birds;

(2) Declining populations and increasing numbers of extinctions of North American fish species;

(3) Decreasing populations of North American ducks;

(4) Increased incidence of coral bleaching, degradation, and death worldwide;

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(5) Declining populations of amphibians worldwide;

(6) Decreasing populations of turtles worldwide;

(7) Mass deaths of dolphins and seals and declining populations of seals;

(8) Loss of forests worldwide and forest "dieback" in the north temperate zones;

Not Addressed in this Report

(9) Increasing incidence of brown algal blooms and concurrent die-offs of marine animals;

(10) Decreasing populations of shellfish from pollution and disease;

(11) Continued loss of wetlands in North America; and

(12) Loss of biodiversity worldwide.

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ygeographic scope. We then conducted a thorough search of the scientific literature of the eight topic areas which are the focus of this report. This report, therefore, is a scientific review of the technical literature, with the selection of indicators influenced in part by public perceptions of potential importance as well as by scientific concerns.

1.3. References

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2. SYNOPSIS OF EIGHT POTENTIAL BIOLOGICAL POPULATION INDICATORS

In this section, we provide a synopsis of eight potential biological indicators of large-scale environmental change for ERB (Exhibit 1, Indicators number 1 though 8). We have focused more effort on the first four indicators (i.e., neotropical migrant birds, North American freshwater fish, North American ducks, coral reefs worldwide) because they appear to be more promising in the short-term as indicators of environmental change. These four potential indicators were included in EPA/OPPE's 1992 report on *Strategies, Goals, and Environmental Results*. They represent groups for which there is strong evidence linking specific types of environmental change with population trends. Three of the remaining four indicators (i.e., amphibians, turtles, and dolphins and seals) also show potential as indicators, but either clear trends or links have not yet been established or the trends result from a combination of many different problems. Loss and degradation of forests currently is receiving attention by numerous organizations, and is reviewed here because of its fundamental relationship to several of the other potential indicators.

For each potential indicator included in this section, we first summarize our findings. We then provide a brief background of the organism group and describe the recent trends or events for each group, e.g., declining populations, increased incidence of disease. We then review current hypotheses explaining the trends, available evidence in support of the trends, consensus of the scientific community on the hypotheses, and when possible, the relative magnitude of each cause's contribution to the trends. We conclude each section with a reference list and a bibliography of articles that have appeared recently in the popular press.[1]

2.1. Neotropical Migrant Bird Species

Summary. Fragmentation of North American forests is contributing to the decline of neotropical migrant bird species that breed in forest interiors. Forest fragmentation exposes larger proportions of the remaining forest to edge conditions and edge predators and parasites, and several characteristics of neotropical migrant species make them more vulnerable to these changes than short-distance migrants or resident species. The relative contribution of "island effects" of forest fragmentation to the decline of neotropical migrants on a regional scale has not been analyzed.

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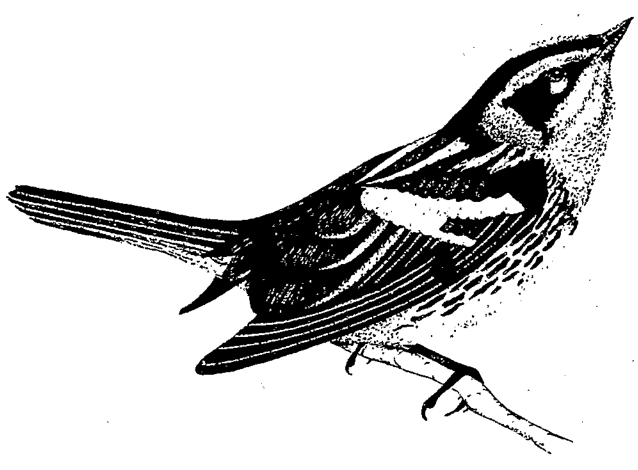
[1] *P following a citation year indicates that the reference is found in the Popular Press Bibliography section rather than in the Reference section.

Tropical deforestation also might be contributing to the observed population declines of neotropical migrant species, but scientists do not agree on this issue. Whether or not tropical deforestation currently is contributing to the declining neotropical migrant bird populations, it is likely to become a more serious problem than fragmentation of habitat in North America in the near future. Obviously, continuing tropical deforestation *and* North American forest fragmentation are likely to cause continued population losses of neotropical migrant species.

2.1.1. Description

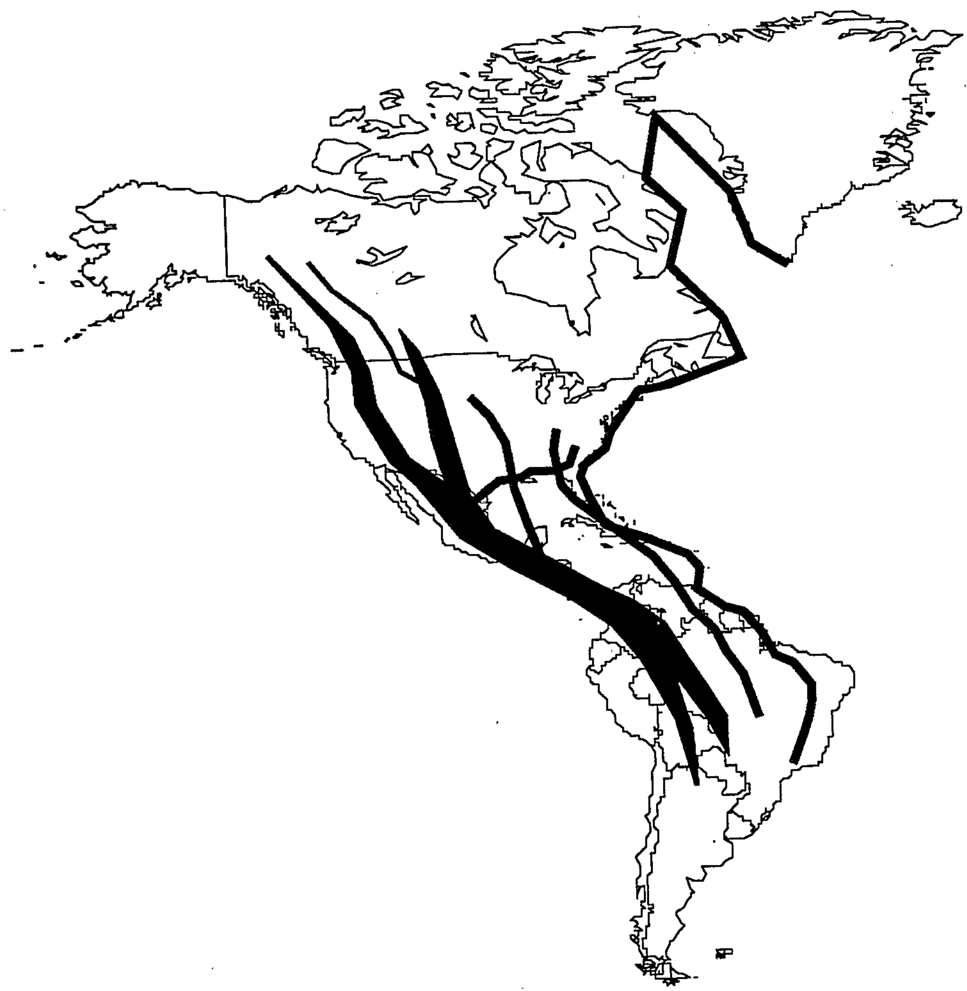
Background. Neotropical migrants are those species that breed mainly in the temperate region of North America and winter mainly south of the Tropic of Cancer in the Western Hemisphere (Terborgh, 1989). Of the bird species of the contiguous United States, 332 species (51 percent) migrate annually to the neotropics (Lovejoy, 1983). In large tracts of mature eastern deciduous forest, as many as 70 to 90 percent of the breeding birds are neotropical migrants (Terborgh, 1989; Whitcomb et al., 1979). This is because most forest-interior breeding birds are insectivorous and must follow the warm temperatures associated with their food supply. Exhibit 2.1.1 illustrates the migratory pathways of these birds.

Trends. Populations of many neotropical migrant bird species have reportedly been declining over the past 20 to 40 years (Aldrich and Robbins, 1970; Ambuel and Temple, 1982; Anderson, 1979; Askins and Philbrick, 1987; Briggs and Criswell, 1979; Butcher et al., 1981; Hall, 1984; Holmes and Sherry, 1988; Jones, 1986; Leck et al., 1988; Robbins, 1979; Serrao, 1983, 1985; Temple and Temple, 1976; Walcott, 1974; Whitcomb et al., 1981); however, most studies have concerned local populations, and the reported findings might have been unique to those particular sites (Hutto, 1988). Recent data analyses for the entire eastern region of North America indicate that most neotropical migrant bird species that breed in forest interiors of the eastern United States and Canada have recently (1978-1987) declined in abundance after a period of stable or increasing populations (Exhibit 2.1.2; Robbins et al., 1989). Between 1966 and 1978, increasing breeding population sizes were observed in 76 percent of neotropical migrant species (based on the US Fish and Wildlife Service (FWS) Breeding Bird Survey; Robbins et al.,



Blackburnian warbler (artist Kimberly Hall)

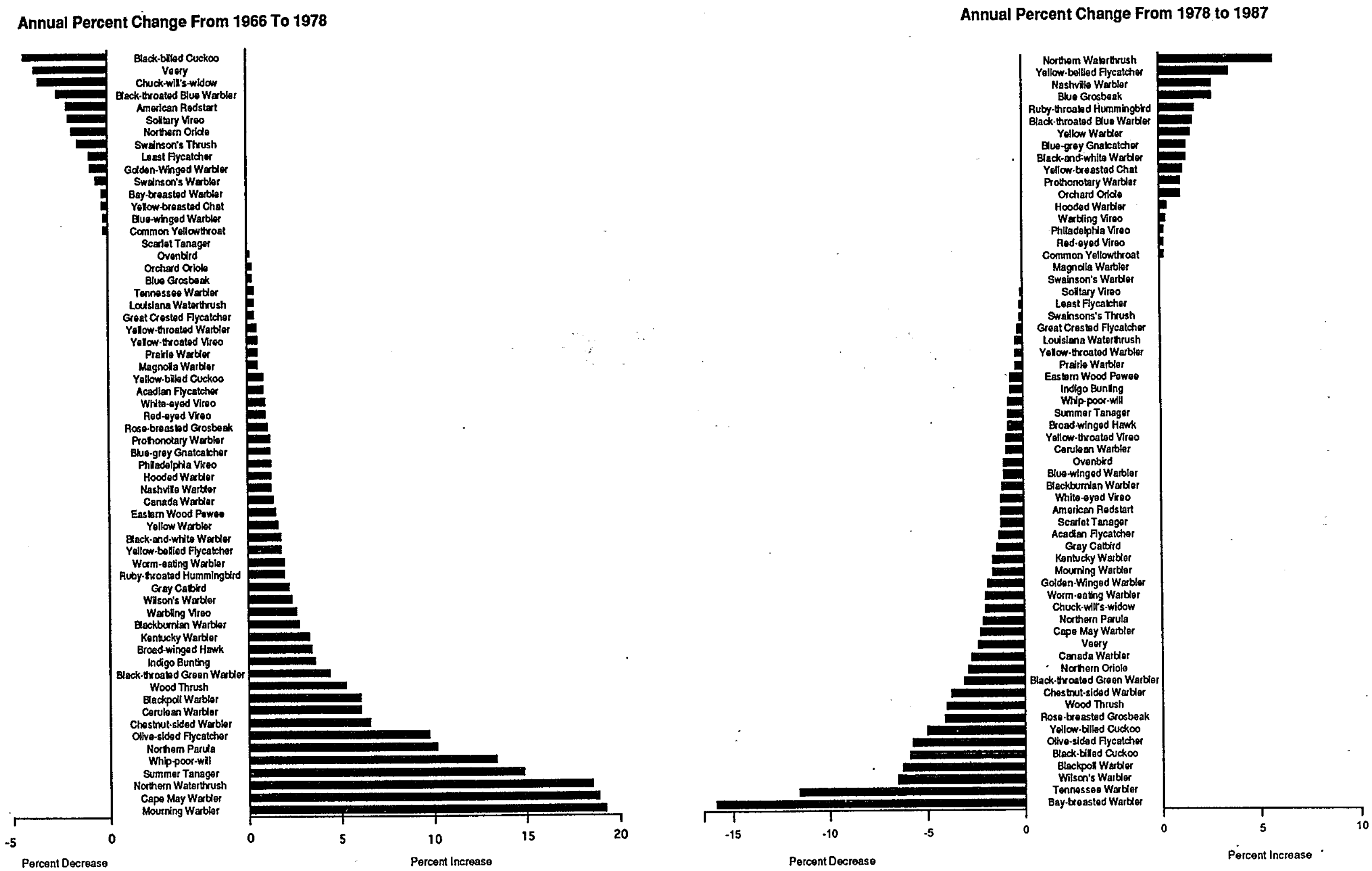
Exhibit 2.1.1. Migratory pathways of neotropical songbirds.



Neotropical migrant songbirds leave their breeding grounds in the United States and Canada to winter in subtropical and tropical areas of Central and South America.

Source: Greenberg, 1989.

Exhibit 2.1.2. Recent decline of neotropical migrant songbird populations.



Neotropical migrant songbirds have recently (1978 to 1987) declined in abundance after a period of stable or increasing populations (1966 to 1978). Graphs show trends for the 62 eastern populations of neotropical migrant bird species assessed in the National Breeding Bird Survey.

Source: Robbins et al., 1989

1989). In contrast, between 1978 and 1987, negative trends were observed in 71 percent of the species (Robbins et al., 1989). The fact that populations of most permanent resident and short-distance migrant bird species are not declining supports the hypothesis that phenomena unique to the neotropical migrants are at issue (Robbins et al., 1989; Terborgh, 1989).

2.1.2. Hypotheses

The decline of neotropical migrant bird species was initially perceived as a "forest fragmentation effect" in North America (Terborgh, 1989). Several species appeared to be "area sensitive", i.e., they could only be found in large tracts of forest and were absent from small patches of forest (Askins et al., 1987; Howe, 1984; Robbins, 1980; Terborgh, 1989). As forests continued to be fragmented by human activities and suburban developments, fewer forest tracts were sufficiently large to accommodate the "area sensitive" species. By the late 1970's, the area-sensitive forest-interior species recognized by Whitcomb et al. (1979) included not only the yellow-billed cuckoo, wood thrush, red-eyed vireo, black-and-white warbler and scarlet tanager recognized by Galli et al. (1976), but also the whip-poor-will, pileated woodpecker, Acadian flycatcher, veery, yellow-throated vireo, worm-eating warbler, northern parula warbler, ovenbird, Louisiana waterthrush, Kentucky warbler, hooded warbler, and American redstart (Robbins, 1979). Given the rate of tropical deforestation by the early 1980's, concern also developed over the loss of wintering habitat (Morse, 1980; Terborgh and Winter, 1980; Terborgh, 1989). We review the evidence available to support the hypotheses of breeding forest fragmentation and loss of wintering habitat in the tropics in Sections 2.1.2.1 and 2.1.2.2, respectively.

2.1.2.1. Forest fragmentation and loss of breeding habitat in North America

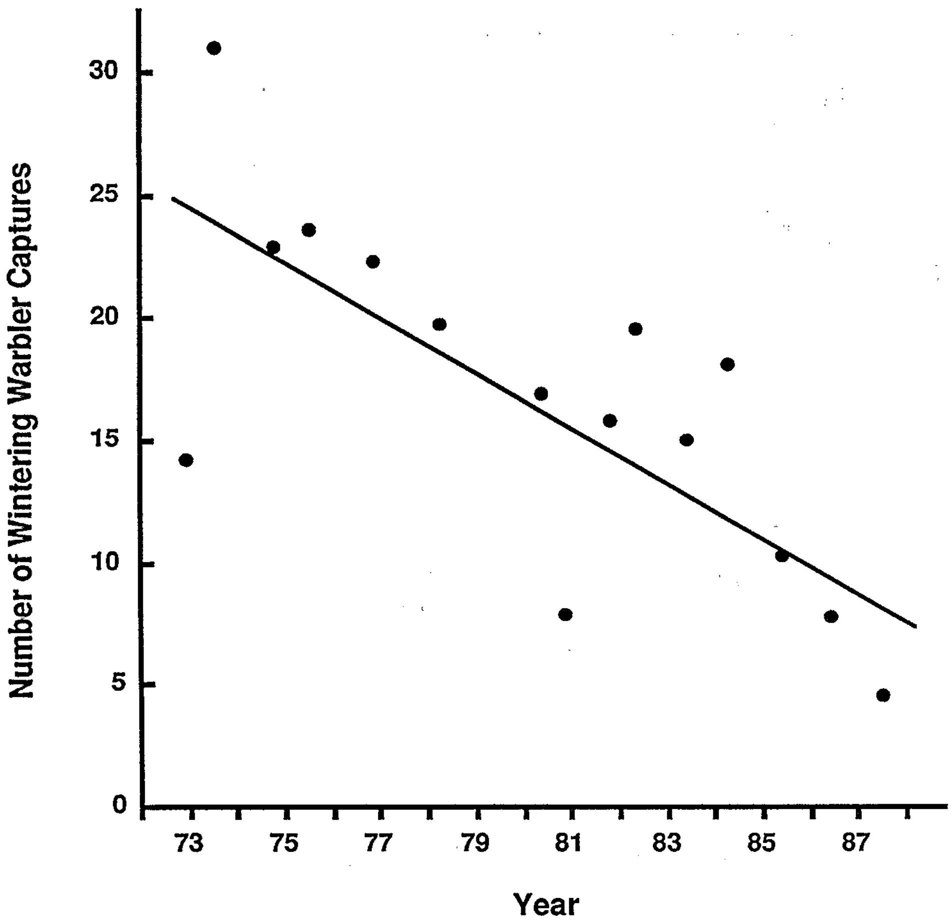
Causes of forest fragmentation include suburban development, super highways, transmission lines, reservoirs, and surface mining (Robbins, 1979). Many studies have indicated that fragmentation of forests adversely affects forest-interior species (Askins et al., 1987; Howe, 1984; Lynch and Whitcomb, 1978; Lynch and Whigham, 1984; Robbins, 1979; Whitcomb et al., 1981). Many species of neotropical migrants are found predominantly in large tracts of continuous forests and are found in much lower densities, or not at all, in isolated forests (Howe, 1984; Robbins, 1980; Terborgh, 1989). Recently, Faaborg and Arendy (1989) provided evidence supporting the hypothesis that problems in the North American forests are responsible for at least some of the declines. They found that the number of wintering migrants captured in the Guanica Forest of Puerto Rico between 1973 and 1988 has been steadily declining, even though this tropical forest is protected and has not appeared to change in vegetation or resident bird species over this time (Exhibit 2.1.3). Other evidence in support of this hypothesis comes from a 10-year investigation in the Hubbard Brook Experimental Forest in New Hampshire. Sherry and Holmes (1992) found that breeding populations of American redstarts in Hubbard Brook were significantly correlated with the previous year's fledging success regardless of how the population fared on their wintering grounds. Two major hypotheses have been offered to explain the sensitivity of the neotropical migrants to forest fragmentation in their breeding habitat: edge effects and island effects, as discussed below.

Edge effects. Forest fragmentation increases the ratio of forest edge to forest interior. Surveys of nesting success in North American deciduous forests indicate that nesting success is lower near the forest edge and in small forest patches than in the interior of large forests (Askins et al., 1990). For example, in Wisconsin, Temple and Cary (1988) found that nest success of 13 species was 70 percent in areas greater than 200 m from the forest edge (n = 82 nests); 58 percent in areas 100 to 200 m from the edge (N = 98); and only 18 percent in areas less than 100 m from the edge (n = 96). Forest edges support several generalist species of predators (e.g., bluejays, raccoons) that are absent or rare in forest interiors, as well as the brown-headed cowbird, which parasitize other birds nests. We review evidence that increased nest predation and parasitism rates account for the reduced nesting success at forest edges in the following paragraphs.

The abundance of some nest predators, such as the blue jay, American crow, and raccoon, have increased over the past few decades in areas of human disturbance (Terborgh, 1989; Wilcove, 1985b) and are more common along forest edges than in forest interiors (Terborgh, 1989). Using artificial nests supplied with quail eggs, Wilcove (1985a) demonstrated that nests located at forest edge experience higher predation rates than nests located in forest interior. Wilcove (1985a) also found that the percentage of nests preyed upon increased as the size of a forest patch decreased, to levels ranging from 30 to 95 percent in forests approximately 5 acres in size (Exhibit 2.1.4). In contrast, he found only 2 of 100 nests set out in the Great Smoky Mountains National Park to be raided. Similar results have been obtained using artificial nests in Maine (Small and Hunter, 1988) and Pennsylvania (Yahner and Scott, 1988).

Forest edges also support the brown-headed cowbird, a nest parasite of open and edge habitats that lays its eggs in the nests of other bird species (Brittingham and Temple, 1983; Bystrak and Robbins, 1977; Mayfield 1977a; Terborgh, 1989; Wilcove, 1985a,b; Whitcomb et al., 1981). Cowbirds forage in open fields, but female cowbirds concentrate host-searching activities along forest edge and may penetrate into the forest several hundred meters while searching for nests (Brittingham and Temple, 1983; Rothstein et al., 1984). Exhibit 2.1.5 indicates that cowbird parasitism can reach as far as 300 meters or more into the forest interior. The cowbird young hatch earlier than the host young and, being larger and noisier, get most of the food brought to the nest. As a result, fewer than normal, or often none, of the host's young fledge from a parasitized nest (Payne, 1977; Mayfield, 1977a,b; as cited in Brittingham and Temple, 1983). Forest-interior breeding species that have not coevolved with open habitat parasites such as cowbirds lack effective defense mechanisms (e.g., evicting the parasite's egg) (Rothstein, 1975).

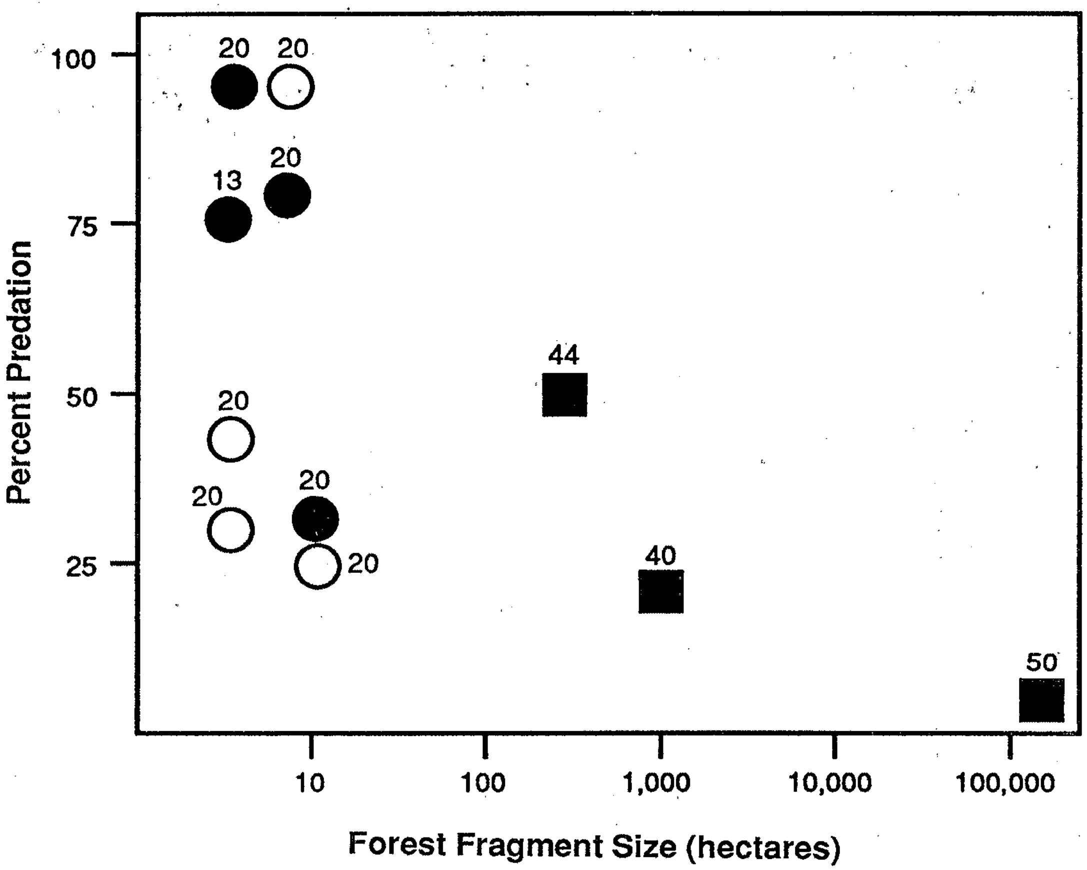
Exhibit 2.1.3. Decline in the number of winter resident warblers captured at the Guanica Forest, Puerto Rico, between 1973 and 1988.



The number of winter resident warblers captured each year in a protected forest in Puerto Rico declined significantly between 1973 and 1988, despite no obvious change in the forest over that time. The dots are the number of captures in 16 nets during 14 three-day samples each year. The line is a representation of the trend that statistically best describes the data.

Source: Faaborg and Arendy, 1989.

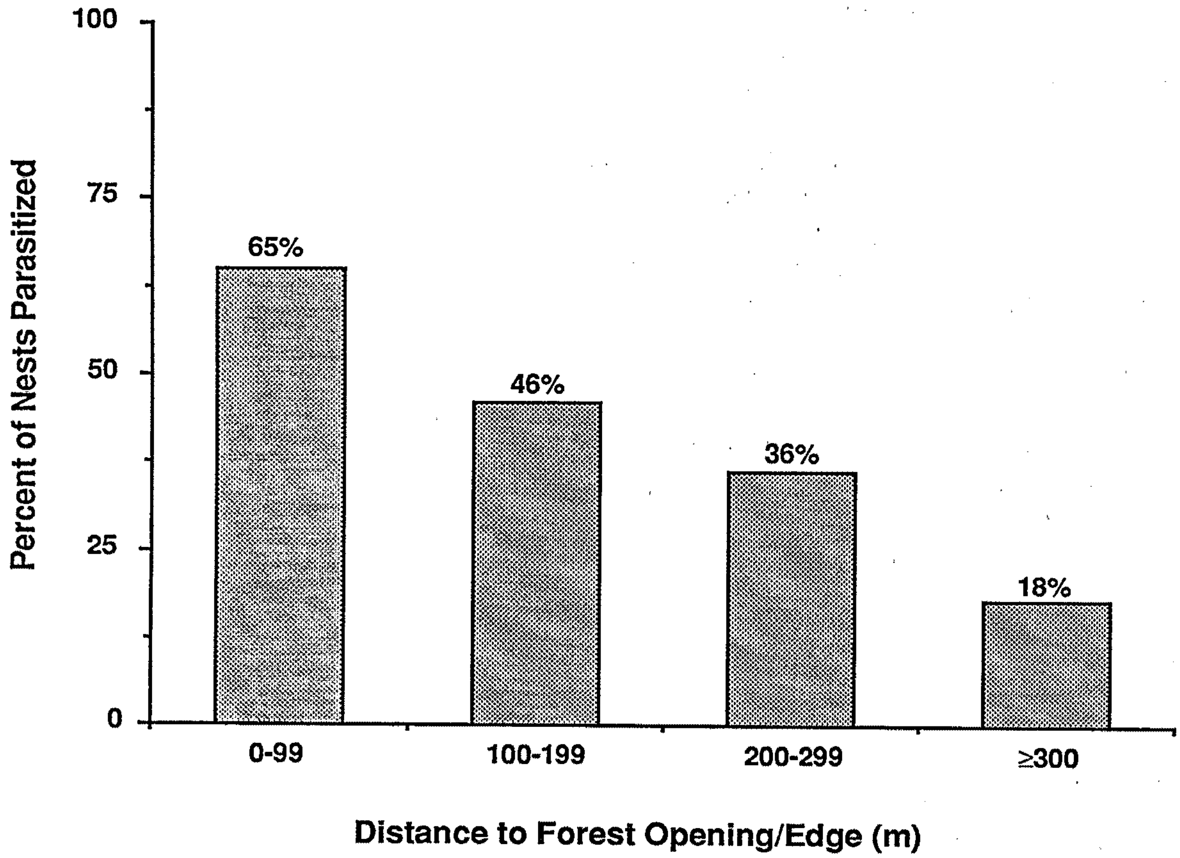
Exhibit 2.1.4. Increase in percentage of nests preyed upon with decreasing forest fragment size.



Nest predation is highest in the smallest forest fragments. Closed squares are large forest tracts, open circles are rural fragments, and closed circles are suburban fragments. The number above each point is the number of artificial nests placed in that forest. Since the experimental nests may be more conspicuous than natural nests, this experiment provides only a relative, not absolute, indication of predation rates with distance from the forest edge.

Source: Wilcove, 1985a.

Exhibit 2.1.5. Decreasing incidence of cowbird parasitism with increasing distance from forest openings.



Cowbird parasitism is highest at the forest edge; but is evident up to 300 meters into the forest interior. Cowbirds are the principal North American species of bird that parasitizes other birds by placing eggs in their nests. Some host species, such as robins, catbirds, and bluejays, recognize the cowbird eggs as alien and dispose of them. Almost all neotropical migrant species, however, do not distinguish a cowbird egg from their own and will feed a young cowbird as their own. This results in far fewer of the host species' young surviving because the cowbird egg tends to hatch first and, being larger and noisier than the hosts' own offspring, the young cowbird gets most of the food brought to the nest. The hosts' own young often starve or are crowded out. Analysis is limited to forest openings greater than 0.2 hectares. Host species were predominantly neotropical migrants: Acadian flycatcher (37 nests), wood thrush (N = 15), veery (N = 5), ovenbird (N = 15), hooded warbler (N = 4), least flycatcher (N = 5), red-eyed vireo (N = 1), American redstart (N = 4), mourning warbler (N = 1), Louisiana waterthrush (N = 1), scarlet tanager (N = 2), indigo bunting (N = 10), and rose-breasted grosbeak (N = 5).

Source: Brittingham and Temple, 1983.

Brown-headed cowbirds have increased dramatically in numbers and geographic range in the current century. As shown in Exhibit 2.1.6, the percent of Audubon Christmas Bird Count records that include the cowbirds has risen from less than 1 percent at the turn of the century to over 80 percent by 1980 (Brittingham and Temple, 1983). In 1985, the shiny cowbird, a brood parasite originally confined to South America and nearby islands (Perez-Rivera, 1986), reached the United States and has been expanding its range in Florida (Smith and Sprunt, 1987).

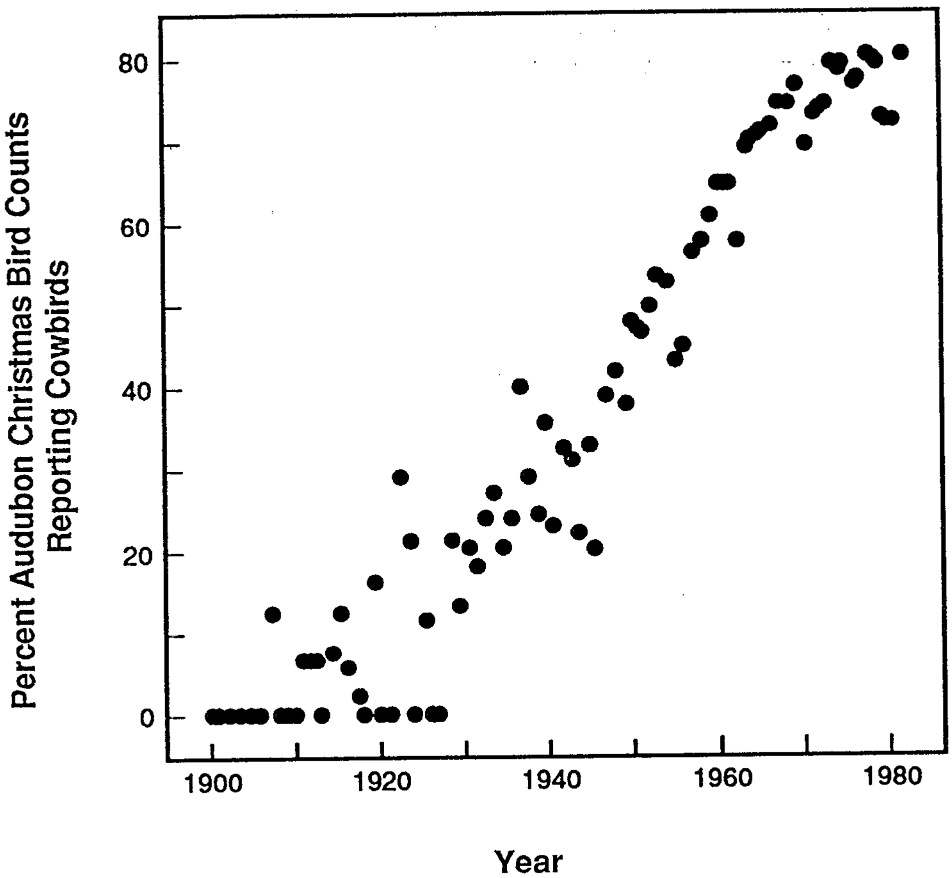
Many neotropical migrant bird populations are experiencing high levels of brown-headed cowbird parasitism (Terborgh, 1989), and, in some areas, virtually all nests of a species are successfully parasitized (Terborgh, 1989). The endangered Kirtland's warbler (*Dendroica kirtlandii*) provides a dramatic example of the potential magnitude of cowbird effects on a neotropical migrant species. Kirtland's warblers breeding habitat is restricted to Jack pine forests in central Michigan (Botkin et al., 1991). When cowbirds had unrestricted access to Kirtland's warbler nests, the warblers could not produce enough young to offset normal mortality (Walkinshaw, 1983; as cited by Terborgh, 1989). The existing populations of Kirtland's warbler declined by 60 percent from 1961 to 1971, apparently because of a high incidence of cowbird parasitism (i.e., up to 83 percent of all nests). With nest parasitism, the warblers fledged less than one young per nest. Beginning in 1972, cowbirds were trapped and removed annually from the warbler's breeding habitat, and parasitism rates dropped to below five percent (Kelly and DeCapita, 1982). With little nest parasitism, the warblers fledged nearly three young per nest, and the population has stabilized, although it is not increasing as had been hoped (Kelly and DeCapita, 1982; Mayfield 1977a,b; as cited by Brittingham and Temple 1983). Cowbird trapping programs also are being tried elsewhere (Beezley and Rieger, 1987; Wiley et al., 1991).

Susceptibility of neotropical migrant species to edge effects. Several life-history characteristics make the neotropical migrant species more susceptible to increased nest predation and parasite pressure than resident or short-distance migrant species (Askins and Philbrick, 1987; Lynch and Whigham, 1984; Robbins, 1979; Terborgh, 1989; Whitcomb et al., 1979; Wilcove, 1985a). Neotropical migrant species:

- are obligate inhabitants of forests (i.e., live only in forests);
- nest on or near the ground;
- tend to build open nests;
- raise only a single brood of young per year;
- have comparatively small clutch size; and
- have no defense mechanism against cowbirds.

Birds that reproduce successfully at forest edges have the following qualities (Lynch and Whigham, 1984; Robbins, 1979):

Exhibit 2.1.6. Increase in cowbird abundance in the United States from 1900 to 1980.



Brown-headed cowbirds, the principle parasitic bird species in North America, have increased sharply in numbers and geographic range in the United States since 1900. *Based on Audubon Christmas Bird Counts.*

Source: Brittingham and Temple, 1983.

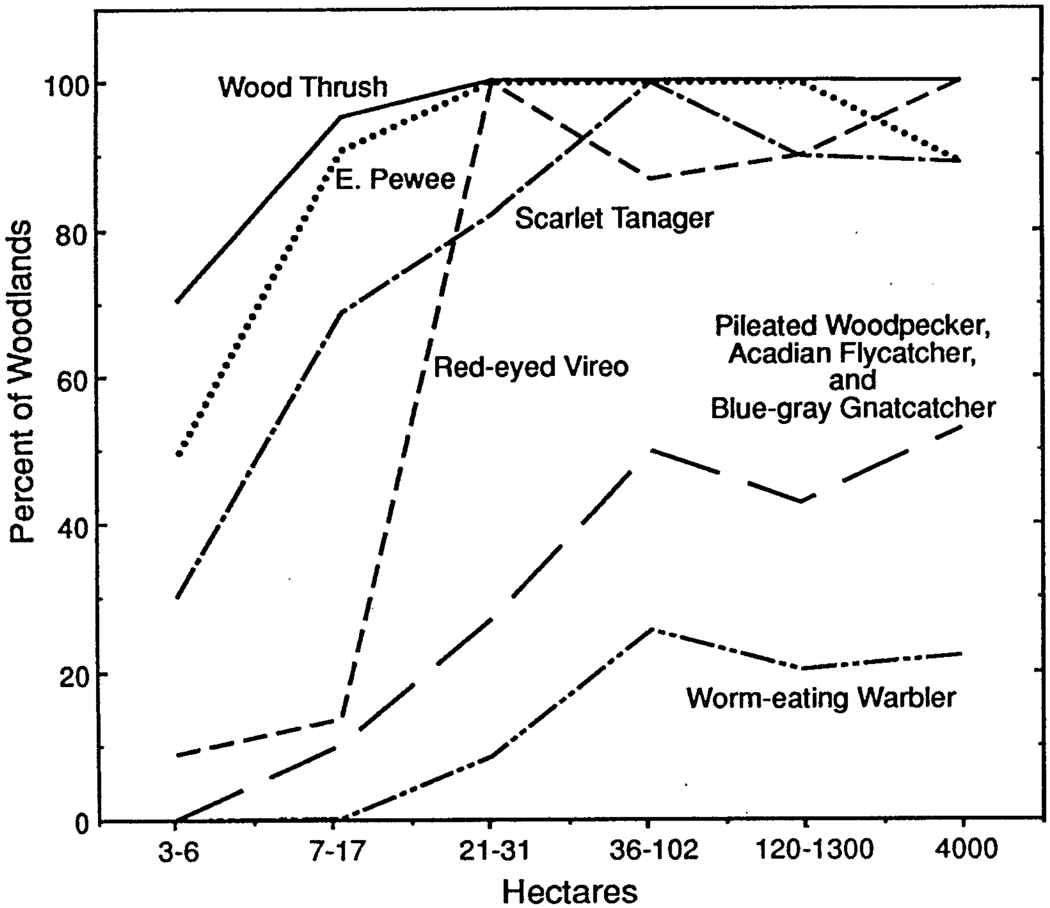
- are permanent residents or short-distance migrants;
- nest higher above the ground;
- build nests in protected cavities;
- often raise two or more broods per season;
- have relatively larger clutches; and
- may recognize a cowbird egg and eject or otherwise avoid it.

Because edge effects (i.e., increased nest predation and parasitism) can extend more than three hundred meters into a forest (Brittingham and Temple, 1983), areas in which forest fragments are only several hundred meters in width provide no true forest interior. Thus, none of the forest in many fragmented landscapes may be suitable for neotropical migrant birds that breed in forest interiors.

Island effects. MacArthur and Wilson's (1963, 1967) theory of island biogeography is relevant to understanding impacts of forest fragmentation on neotropical migrant birds. This theory states that the low species diversity characteristic of oceanic islands reflects a dynamic equilibrium, or balance, between rates of extinction and rates of colonization of individual species populations. The number of animal species found on a particular island at equilibrium is thought to depend on the island's productivity, its microhabitat diversity (e.g., variation in vegetation, topography, climate), and its size and degree of isolation from sources of potential colonists (as summarized by Whitcomb et al., 1979).

Forest loss and fragmentation has resulted not only in smaller patches of "undisturbed" forests, but also in increasing isolation of the forest "islands." As forest islands become more isolated from one another, locally rare species may become more vulnerable to local extinctions as a consequence of natural variation in mortality rates and reproductive success (Diamond, 1984; Howe, 1984; Terborgh, 1980; Terborgh and Winter, 1980; Whitcomb et al., 1979). Several studies have demonstrated that when a large forest is reduced in size, bird communities typically experience declines in species numbers (Ambuel and Temple, 1983; Butcher et al., 1981; Forman et al., 1976; Galli et al., 1976; Howe, 1984; Lynch and Whigham, 1984; Moore and Hooper, 1975; Robbins, 1980; Terborgh, 1989; Whitcomb et al., 1977; Whitcomb et al., 1981) and in breeding densities (Aldrich and Coffin, 1980; DellaSala and Rabe, 1987; Howe, 1984; Lynch and Whigham, 1984; Robbins, 1979, 1980). Robbins (1980) illustrated how the occurrence of neotropical migrant species increases with increasing forest patch size (Exhibit 2.1.7). Species such as the wood thrush, eastern wood pewee, and red-eyed vireo were found in most woodlands more than 20 hectares in size; the pileated woodpecker, Acadian flycatcher, blue-gray gnatcatcher, and worm-eating warbler were not found in any woods of less than 17 hectares (Exhibit 2.1.7). Thus, it may even be possible to develop "stress-response" curves to predict the effects of continued forest fragmentation on various species of neotropical migrants.

Exhibit 2.1.7. Proportion of woodlands of each size class in which the species indicated were found in the District of Columbia or Maryland.



The probability of finding given neotropical migrant bird species in a woodland increases with increasing size of the woodland. Also, more species are found in the larger woodlands.

Source: Robbins, 1980. The figure is based on the work of Briggs and Criswell, 1979; Lynch and Whitcomb, 1978; Galli et al., 1976; and data that Robbins collected in Maryland since 1951.

Other hypotheses. Another hypothesis to explain forest fragmentation effects considered by several investigators is that neotropical migrants may be competitively replaced by other species due to changes in habitat structure (Anderson, 1979; Aldrich and Coffin, 1980; Butcher et al., 1981; Ambuel and Temple, 1983; and Askins and Philbrick, 1987, as cited in Hutto, 1988). The necessary competitive exclusion experiments, however, have not been performed and would be very difficult (Terborgh, 1989). Moreover, none of the available evidence points strongly in this direction (Terborgh, 1989).

2.1.2.2. Loss of wintering habitat in the tropics

Several researchers have suggested that the recently increasing rates of tropical deforestation and consequent loss of wintering habitat for the neotropical migrants is responsible for the observed population declines (Ambuel and Temple, 1982; Briggs and Criswell, 1979; Hall, 1984; Howe, 1984; Lovejoy, 1983; Rappole et al., 1983; Terborgh, 1980). Morton and Greenberg (1989) reported that the rate of forest conversion in the neotropics ranges from one to four percent per year. This rate of change is "too great to allow for genetic adaptations of its [native bird species] through natural selection" (Morton and Greenberg, 1989).

The evidence for this hypothesis has been controversial, with some investigators finding no evidence of tropical deforestation effects (Holmes et al., 1986; Holmes and Sherry, 1988; Hutto, 1988; Wilcove, 1988), others finding no alternative explanation for the observed declines (Hall 1984; Leck et al., 1988; Marshall, 1988), and still others admitting that the evidence is suggestive, but not yet conclusive (Lovejoy, 1983; Wilcove and Terborgh, 1984; Terborgh, 1989).

Neotropical migrants have large breeding ranges in comparison to their small wintering ranges (i.e., winter densities are much higher than breeding densities) (Hall 1984; Morton and Greenberg, 1989). Terborgh (1989) has estimated on this basis that one acre of tropical forest may be equivalent to five to ten acres of north temperate forest. Wilcove and Terborgh (1984) suggested that the amount of habitat available in North America and in the wintering habitats was in balance in pre-colonial times. Initially, deforestation proceeded most rapidly in the north temperate zone. Subsequently, tropical deforestation rates increased (see Section 2.8). The ratio of summer and winter habitats may again be in balance, but the trend for the future will be of decreasing availability of forested wintering habitat in the tropics relative to breeding habitat in the north temperate zone. Several different patterns of population decline are possible under these circumstances, and Wilcove and Terborgh (1984) suggest that it may be unreasonable to expect unanimous agreement among investigators as to cause and effect at the early stages of species' decline.

Recently, however, using data from the US Fish and Wildlife Service (FWS) Breeding Bird Survey, Robbins et al. (1989) has provided strong evidence that tropical deforestation is contributing to a regional decline of neotropical migrant species. To avoid potential data biases associated with changing breeding habitat distributions in North America (e.g., increasing forest cover in New England, decreasing forest cover in the southeast), they compared population trends of neotropical migrants that overwinter in forested areas with those that overwinter in scrub habitats in the tropics. They found larger declines for the forest-wintering species than for the scrub-wintering species, many of which are in fact increasing in abundance. Robbins et al. (1989) concluded that in the last decade, tropical deforestation may be having a greater impact on neotropical migrants than is loss and fragmentation of forest habitats in North America.

2.1.3. Continued Monitoring

A variety of groups and organizations monitor bird populations, but the most comprehensive surveys in the United States are sponsored by the Audubon Society, the US FWS, and Cornell University.

The **National Audubon Society** sponsors three bird censuses: (1) the Christmas Bird Count, which started in 1900, (2) the Breeding Bird Census, which started in 1937, and the Winter Bird-Population Study, which started in 1947/48.

- The Christmas Bird Counts are conducted by tens of thousands of volunteers annually (Brody, 1989*P). Groups of bird watchers count all of the birds that they see in a day. The protocol is not scientific, and potential biases toward overcounting and misidentification cannot be ruled out. Moreover, the ratio of birds seen to birds present depends on many uncontrolled variables such as weather, observer density, duration and timing of observation periods, and variation in observer skills. Recently, the National Audubon Society has instituted more stringent counting rules and data checks to help counter biases (Brody, 1989*P).

- The Breeding Bird Census is a monitoring program in which the density of territorial males is estimated on a plot of homogeneous habitat. The vegetation in the plot also may be sampled (Temple and Wiens, 1989). Again, the protocol is not scientific, and some biases may result.

- The Winter Bird-Population Study is the winter analogue of the Breeding Bird Census, but the bird-habitat data have not been used extensively (Temple and Wiens, 1989). Due to the volunteer nature of the data collection effort, biases may be present in the data.

The **US FWS** Breeding Bird Survey (BBS), established in 1966, is an annual roadside survey of United States and Canadian birds. The surveys are conducted each June along approximately 2,000 roadside "routes." Experienced volunteers recruited by state and provincial coordinators sample bird populations at 50 stops at 0.8-km intervals along secondary roads. This survey relies upon singing males, however, which may constitute only a fraction of the total male population. Nonbreeding "floaters" may be an important component of the population (Morton and Greenberg, 1989). Thus, the FWS Breeding Bird Surveys may not show a population decrease when one is really occurring, which makes the recent results of the BBS even more dramatic.

The **Cornell** Laboratory of Ornithology manages several computerized databases on North American birds, including the North American Nest Record Program, the Colonial Bird Register, and two new programs, Project Birdwatch and Project FeederWatch. In addition, the Cornell Laboratory maintains the computerized databases for Audubon's three survey programs (Temple and Wiens, 1989).

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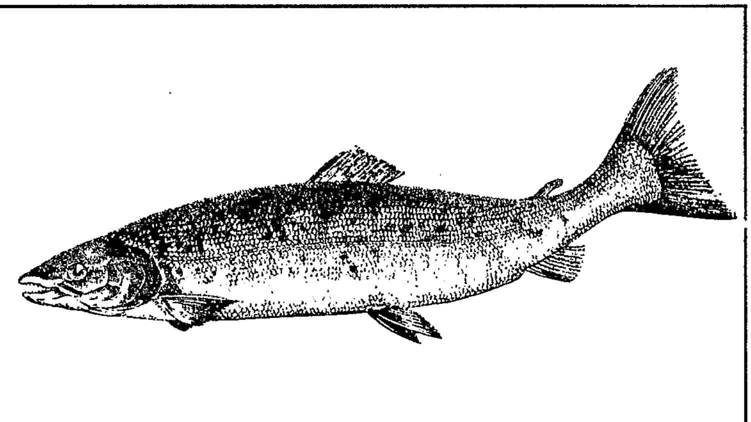
2.2. North American Freshwater Fish

Summary. The rate of extinctions of North American freshwater fish has risen sharply in the last decade. Now, fully a third of the native species of North American freshwater fish are considered threatened, endangered, or of special concern. Physical alteration of surface waters (e.g., channelization, dams, reservoirs) and the introduction of non-native species are the major causes of population declines and extinctions among North American fish, although other factors have contributed to the decline of many species. Native North American anadromous fish[2] (e.g., salmon, steelhead) also are at increasing risk of extinction, but we restrict our discussion here to fish that inhabit only freshwater.

2.2.1. Description

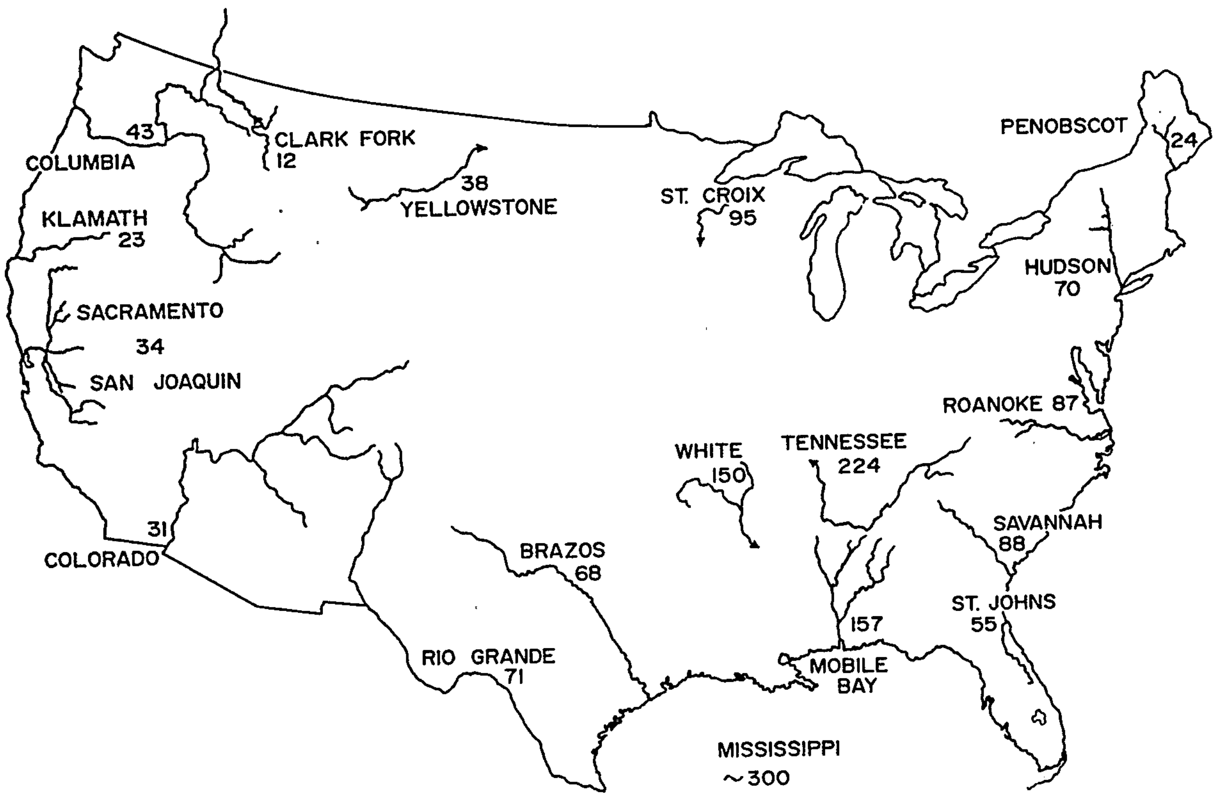
Background. North America has a rich freshwater fish fauna, exhibiting the greatest diversity in the central and southeastern United States (Exhibit 2.2.1). Many fishes have limited ranges, particularly in the arid southwestern states and in Mexico. Habitat characteristics that limit the distribution of species include water temperature, water depth, flow rate, bottom type, presence and type of aquatic vegetation, turbidity, and physical barriers between habitats.

Trends. The American Fisheries Society (AFS) Endangered Species Committee (ESC) has identified documented extinctions of 40 taxa of freshwater fish (i.e., 3 genera, 27 species, and 13 subspecies) in North America in the past 100 years, half occurring since 1965 (Miller et al., 1989) and 10 occurring in the last decade (Williams et al., 1989) (Exhibits 2.2.2 and 2.2.3). The regions of North America that have lost "a substantial proportion" of their native fish fauna are the Great Lakes, Great Basins, Parras Valley, Valley of Mexico, the Rio Grande, and other North American southwest desert areas (Miller et al., 1989). The minnow family (Cyprinidae) has lost more taxa (16) than any other family of fishes, and salmonids and cyprinodontids have each lost 7 taxa (Miller et al., 1989).



[2]Anadromous species inhabit both marine and freshwater ecosystems at different stages in their life-histories. The adults live in the ocean, but ascend rivers for breeding. The juveniles then descend the river to enter and mature in the ocean.

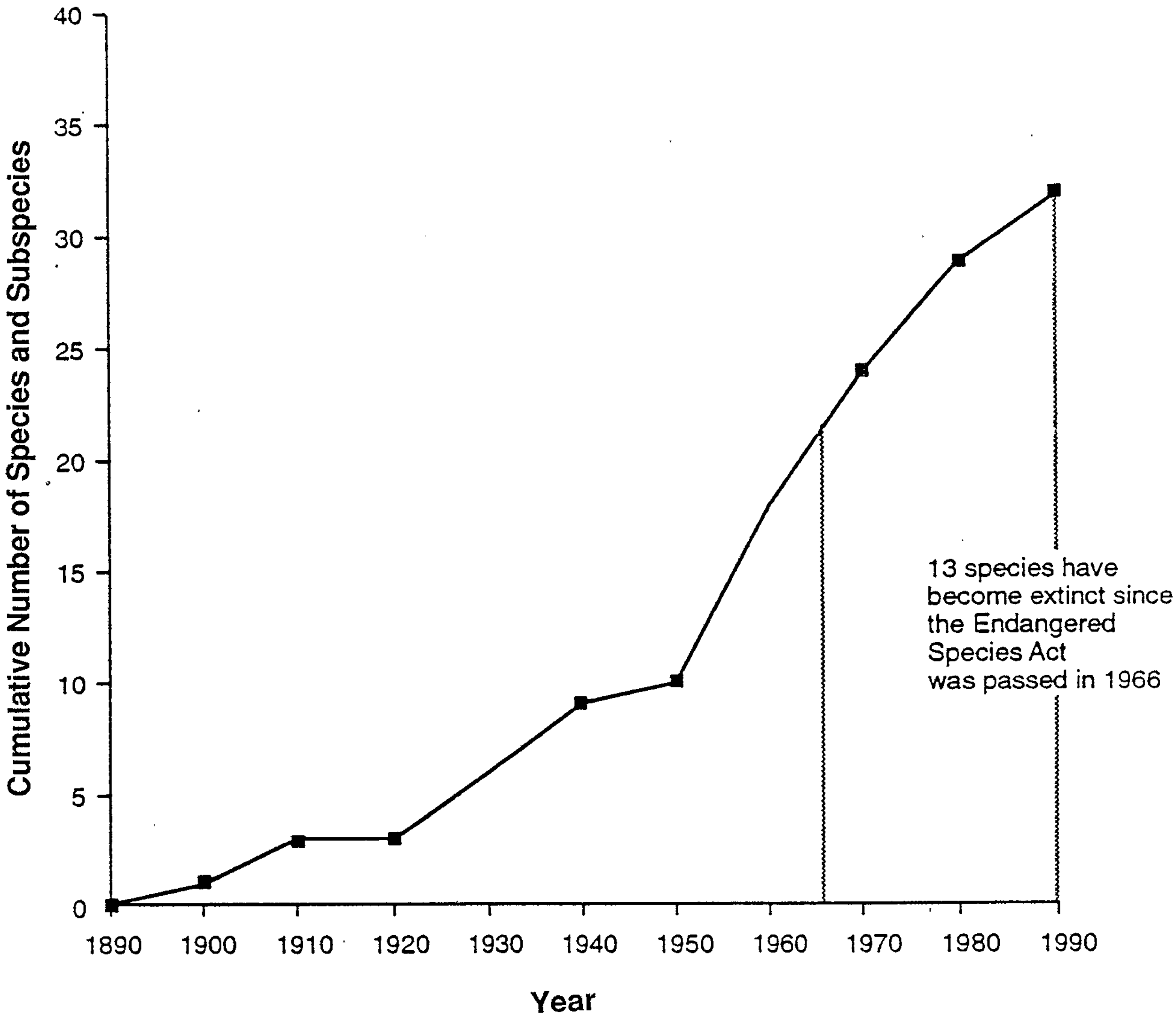
Exhibit 2.2.1. Numbers of taxa of native freshwater fishes of selected river systems.



North America has a rich freshwater fish fauna, with the greatest diversity found in the central and southeastern United States. Rivers selected to illustrate regional trends in fish species diversity.

Source: Reprinted from Sheldon (1988) with permission of Blackwell Scientific Publications.

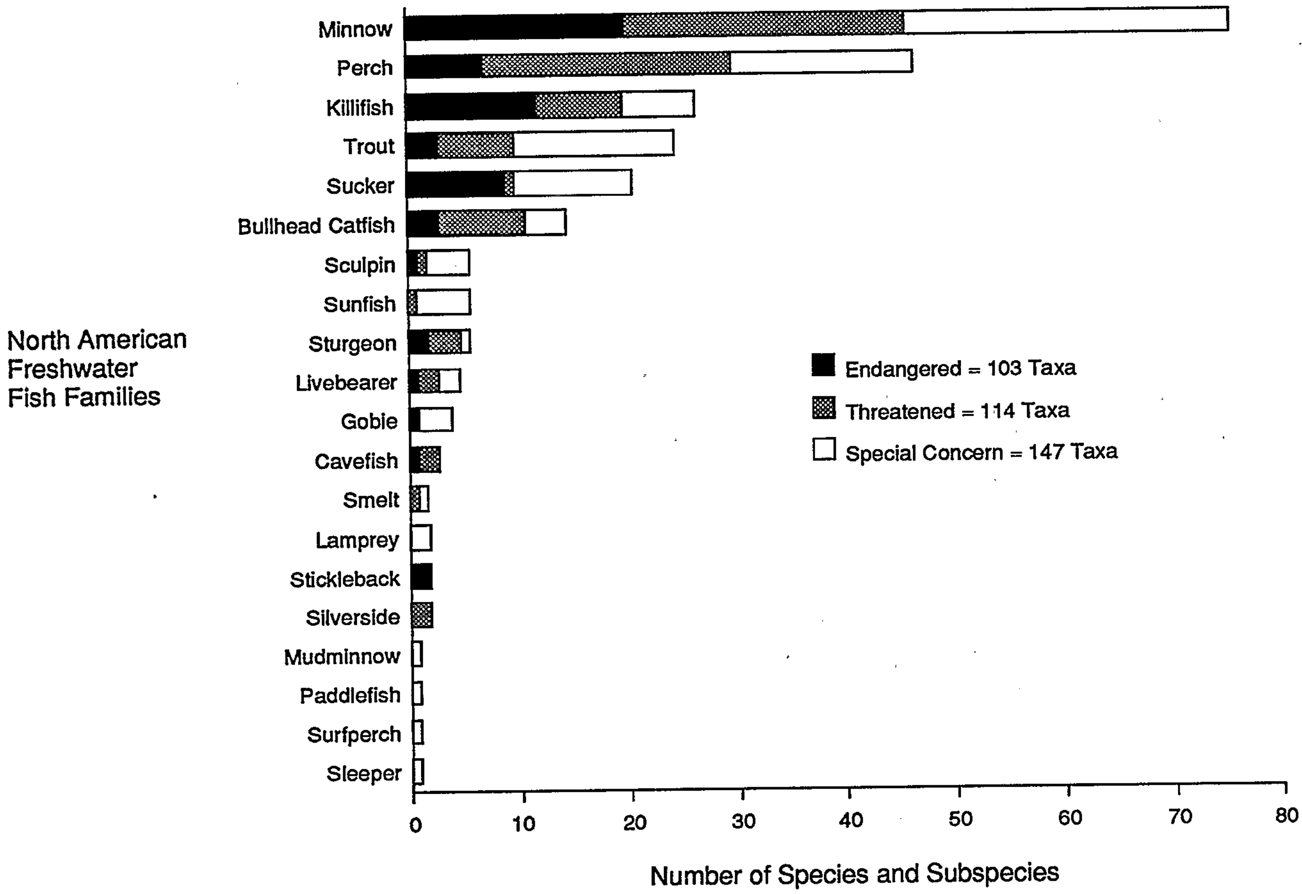
Exhibit 2.2.2. Cumulative number of fish extinctions by decade in the United States during the past century.



The number of North American freshwater fish extinctions that occur each decade has been increasing steadily since the turn of the century. In the United States alone, 32 species and subspecies of fish have become extinct since 1900, 13 since the Endangered Species Act was passed in 1966.

Source: Based on 27 species extinctions plus 13 subspecies extinctions as described by Miller et al. (1989).

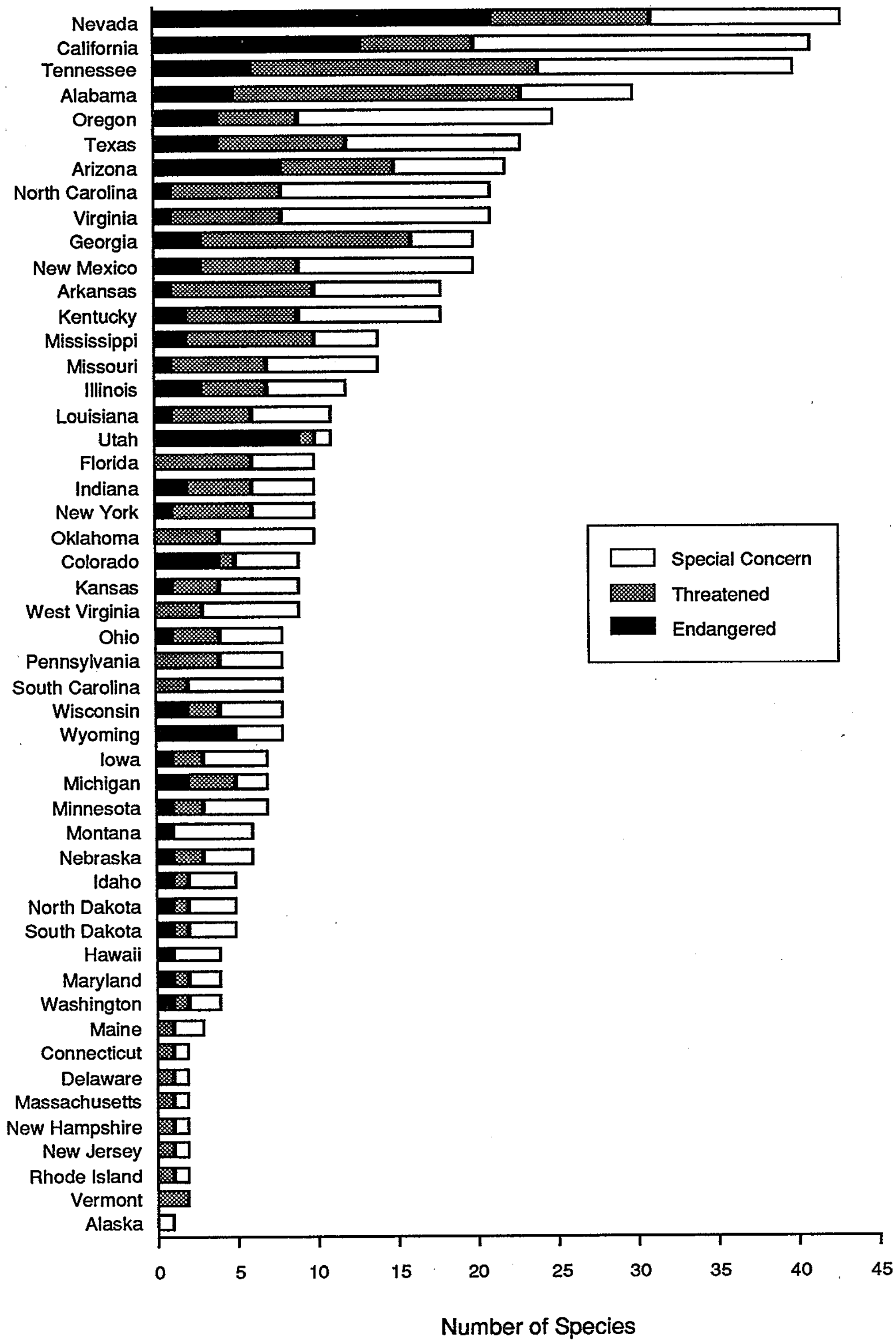
Exhibit 2.2.4. AFS/ESC list of freshwater fish taxa in North America that are endangered, threatened, or of special concern.



Of approximately 1,000 species and subspecies of freshwater fish in North America, the American Fisheries Society lists approximately 36 percent as endangered (i.e., facing extinction in all or a significant portion of their range), threatened (i.e., likely to become endangered in the near future), or of special concern (i.e., for which minor disturbances to their habitat could place them in danger).

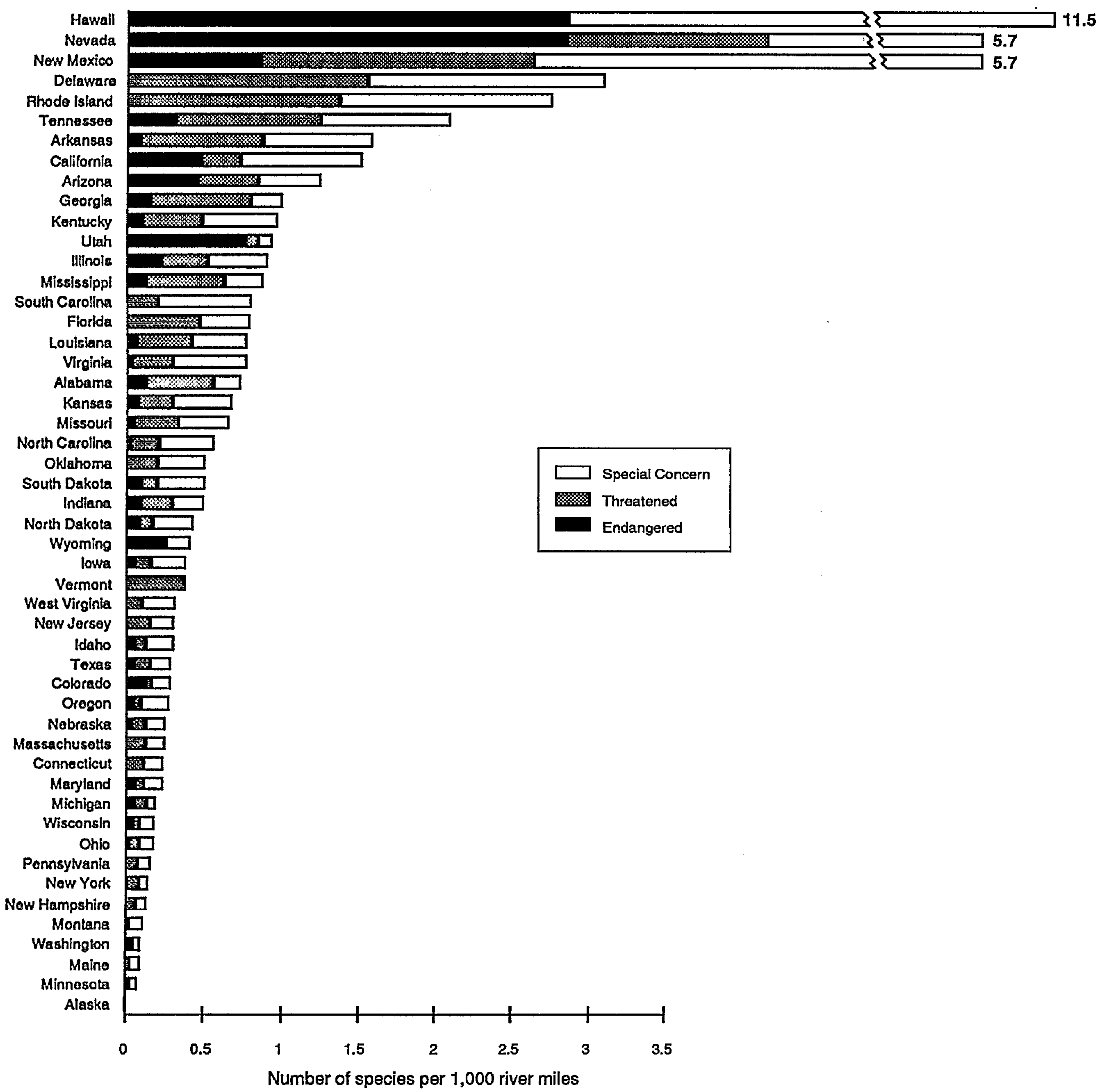
Source: Williams et al., 1989.

Exhibit 2.2.5. Number of fish species endangered, threatened, or of special concern by state.



Source: Adapted from Williams et al., 1989.

Exhibit 2.2.6. Proportion of freshwater fish species per 1,000 river miles classified by AFS as endangered, threatened, or of special concern, by state.



Source: Adapted from Williams et al., 1989.

Exhibit 2.2.7. Causes of extinctions and population declines in North American freshwater fish.

Cause	% Contribution to Species Extinctions[a]	% Contribution to Population Declines[b]
Habitat destruction/modification	73%	98%
Introduced species	68%	up to 37%
Hybridization	38%	--
Pollution, chemical alteration	38%	up to 37%
Overfishing	15%	3%
Disease	--	2%
Acidification	--	increasing

Habitat destruction and modification is the leading cause of extinction and population declines in North American freshwater fishes. Introduced species, hybridization, and pollution or chemical alteration are the next most significant problems.

[a] Source: Miller et al., 1989

[b] Source: Williams et al., 1989; Deacon et al. 1979

2.2.3. Continued Monitoring

The AFS/ESC compiles a list of endangered, threatened, or species of special concern in North America from other lists, original data, and discussions with pertinent agencies and knowledgeable individuals. AFS/ESC has published three lists to date: in 1972, 1979, and 1989 (Miller, 1972; Deacon et al., 1979; Williams et al., 1989). The lists are circulated to each state or provincial fish and game department for review and then revised and published.

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2.3. Ducks in North America

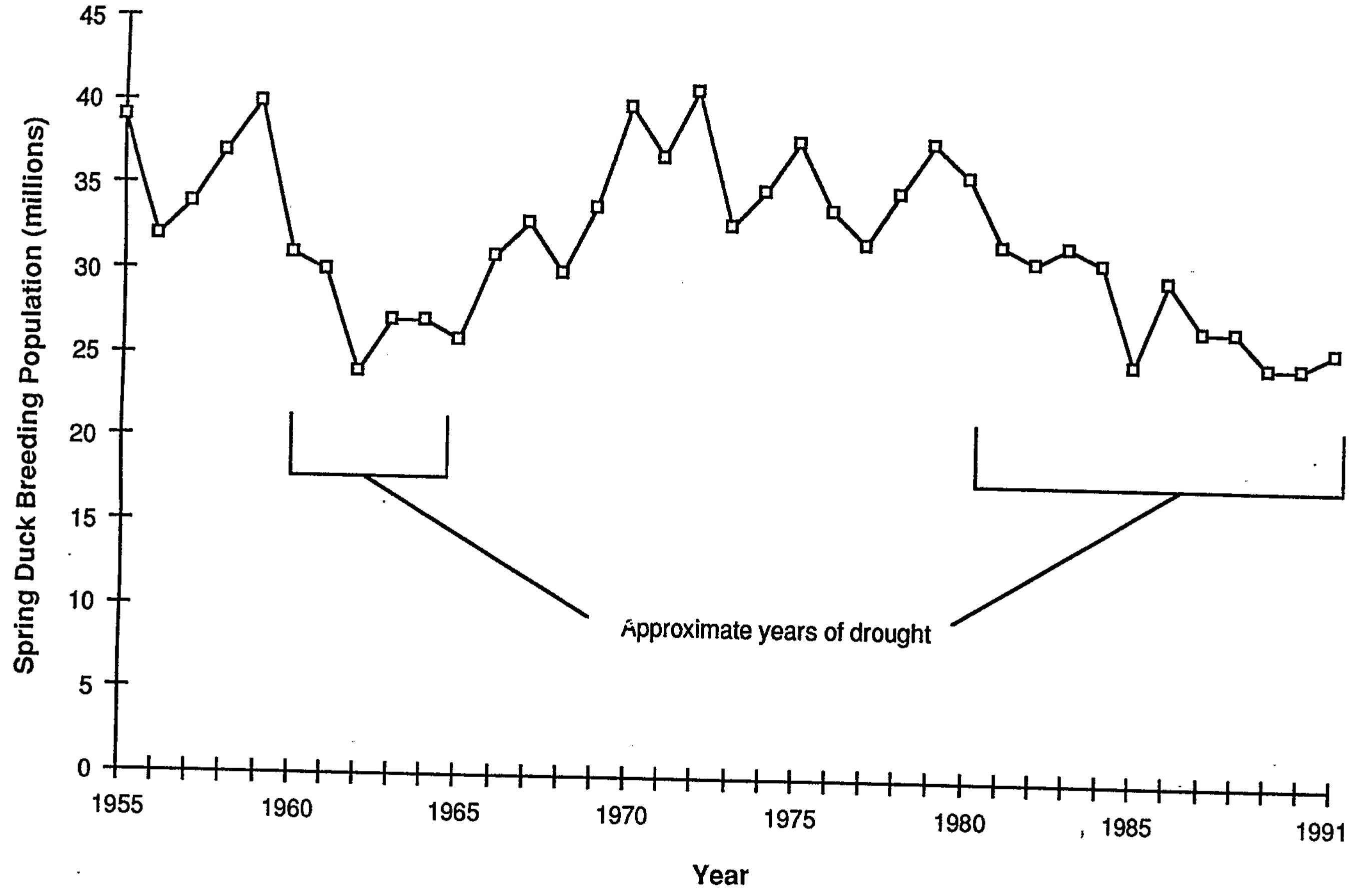
Summary. Numerous species of ducks have suffered significant declines in population levels in North America in recent years (i.e., mallard, American wigeon, blue-winged teal, northern pintail, and redhead), and several other species appear to be declining also (e.g., canvasback, northern shoveler, green-winged teal). In the last 15 years, the overall breeding population of ducks has dropped by 24 percent. Investigators believe that the declines are due primarily to drought and human activities that have severely reduced the abundance of wetland habitats required by waterfowl for both breeding and overwintering. Crowding of birds into the remaining areas may contribute to outbreaks of disease and increased mortality. Degradation of the remaining wetlands by acid rain and/or agricultural runoff may be reducing the reproductive success of ducks in the remaining habitats. Uncovered oil pits contributed significantly to the mortality of migratory waterfowl until recently, but uncovered cyanide ponds used by the gold mining industry remain a threat.

2.3.1. Description

Background. About one half of North American duck populations breed in the western prairie pothole regions of south-central Canada and the north-central United States (Smith et al., 1964). In general, ducks prefer well-vegetated areas in close proximity to open water for nesting sites (Bellrose, 1976). The aquatic invertebrates of the potholes and other wetlands provide food for females during egg production and for ducklings until fledging (Palmer, 1962).

Trends. The most recent US Fish and Wildlife Service (FWS) May Breeding Waterfowl and Habitat Survey indicates that the 1991 spring breeding population for ducks was 19 percent below the long-term average from 1955-1990 (Exhibits 2.3.1 and 2.3.2). In the last 15 years, the number of breeding ducks and geese overall in North America has dropped from 34 million to 26 million, a drop of 24 percent. Between 1985 and 1990 alone, many waterfowl populations declined to their lowest levels in three decades (data in US FWS, 1991).

Exhibit 2.3.1. Changes in breeding population estimates for 18 duck species included in US FWS census.



The 1991 spring duck breeding population was 19 percent below the long-term average from 1955 to 1990. US FWS experts conclude that the marked decreases in abundance in the early 1960's and at present are due to drought-induced decreases in wetland habitats that ducks require for breeding. The area surveyed encompasses the prairie pothole region of the United States and Canada. Sea ducks, such as eiders, that nest in northern arctic areas are not included in the survey.

Source: US FWS, 1991.

Exhibit 2.3.2. Changes in breeding population estimates for ten species of ducks in 1991 compared with 1955 to 1990.

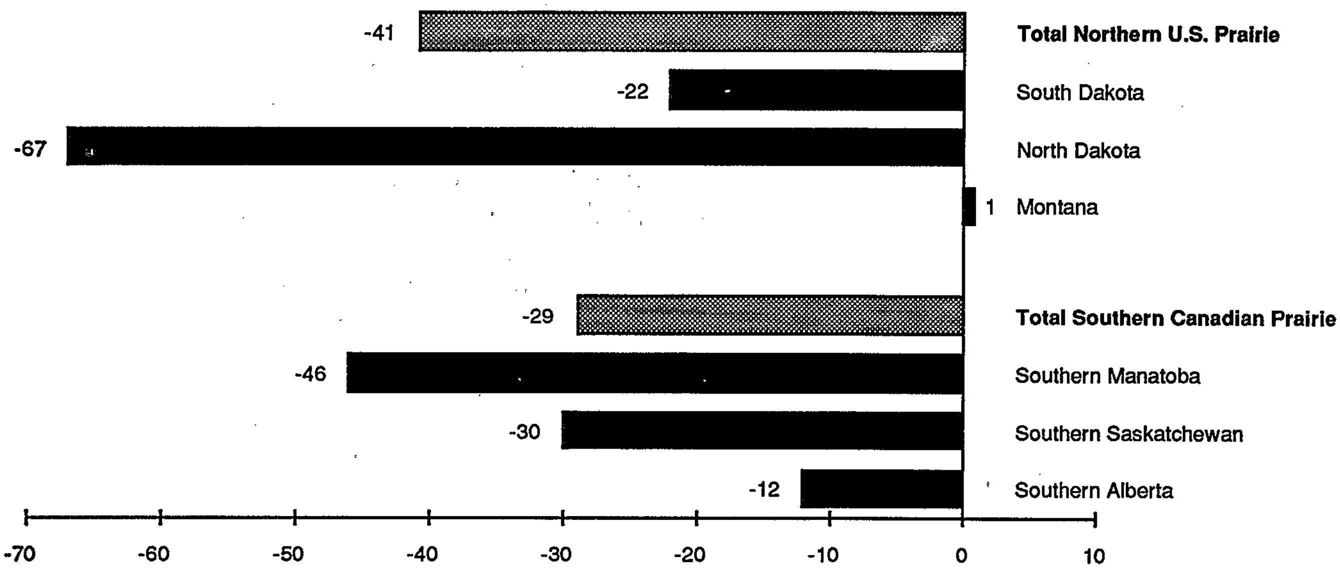
Species	Between 1990 and 1991		Between 1991 and the 1955-90 Average	
	Percent Change	*P*	Percent Change	*P*
Mallard	+1	0.430	-27	<0.001
Gadwall	-3	0.382	+22	0.001
American wigeon	+11	0.183	-14	0.004
Green-winged teal	-9	0.188	-4	0.250
Blue-winged teal	+34	<0.001	-10	0.042
Northern shoveler	-3	0.333	-8	0.051
Northern pintail	-20	0.015	-62	<0.001
Redhead	-6	0.277	-26	<0.001
Canvasback	-9	0.268	-16	0.070
Scaup	+25	0.004	-7	0.121
Total Dabblers & Divers**	+6	0.028	-19	<0.001

** Excludes scoters, eiders, oldsquaws and mergansers in strata 1-50.

Although there has been a slight increase in several duck populations in the last year (1990 to 1991, first two columns), overall, there has been a significant 19 percent decline in total dabbler (e.g., mallard) and diving duck (e.g., scaup) breeding population levels as of 1991 compared with the previous 35 years (last two columns).

Source: Reproduced from US FWS (1991) with permission of the Director, US FWS.

Exhibit 2.3.4. Summary of the number of May ponds (adjusted for visibility) in portions of Prairie Canada and the northcentral United States, 1990 and 1991.



Percent Change from the Long-term Average in the Number of Ponds Counted in May, 1990 and May, 1991

Long-term trend for Canadian prairie is measured from 1961 to 1990
Long-term trend for U.S. prairie is measured from 1974 to 1990

Canada, which provides the majority of wetlands used by breeding waterfowl in North America, has suffered a 29 percent loss of wetlands compared with the past 30 years. The United States, with a smaller portion of the waterfowl breeding habitat, has suffered a 41 percent loss, compared with the past 16 years.

Source: Reproduced from US FWS (1991) with permission of the Director, US FWS.

contributed to a loss of wetland habitat, particularly over the last decade. Each of these is discussed briefly below.

Land development. Wetland breeding habitats have been severely impacted by human activities; filling and development of wetland areas and diversions of water for agriculture, industry, and domestic uses have contributed to loss of wetlands. Agriculture alone accounted for 87 percent of the wetland conversions between 1954 and 1974 (US FWS, 1990). The US FWS estimates that 53 percent of the wetlands existing in the conterminous United States as of the 1780's were lost by 1980 (Dahl, 1990). Terborgh (1989) estimated that waterfowl breeding habitat has declined by 80% to 90% from presettlement times. Much of the wetland losses have occurred recently. For example, about 50% of the coastal wetlands on the Atlantic Flyway have been destroyed since 1953 (Jerry Serie of the US FWS as reported by Steinhart, 1989*P). Intensive agricultural practices also have reduced nesting cover throughout the prairies (Reynolds et al., 1990), which leads to increased nest predation and reduced reproductive success (Sheehan et al., 1987). Wintering habitat also has been severely impacted. Half of the waterfowl that migrate via the Pacific flyway overwinter in California's Central Valley. The Valley originally contained 4,000,000 acres of wetlands, but owing to agricultural and urban development, today only 280,000 acres remain, of which only 100,000 are protected in State and Federal wildlife refuges (Steinhart, 1989*P).

Drought. Reduced rainfall in North America during the 1980's caused the reduction of natural water sources and led to the diversion and use of the remaining water for agriculture. Steinhart (1989*P) reported that 40 percent of the prairie potholes disappeared between 1980 and 1988 primarily because of drought. Drought also contributes to the destruction of essential nesting cover (Reynolds et al., 1990). The US FWS identified drought as a principal factor accounting for the sharp decline of duck populations in early 1960's and again in the 1980's (Exhibit 2.3.1).

Acid deposition. There are two primary processes by which acid deposition adversely affects waterfowl: (1) mobilization of metals that can bioaccumulate to toxic levels in aquatic food chains[5] and (2) changes in species composition in the food web. Acid conditions tend to increase the solubility and mobility of metals which bioaccumulate (e.g., cadmium) and other toxic metals (e.g., aluminum, lead) which can lead to the disappearance of susceptible fish and invertebrate species (e.g., aquatic insects, snails) on which the waterfowl depend for food (Diamond, 1989; Mitchell, 1989; Schindler, 1988). Some studies have documented a reduction in egg-shell thickness

[5]Biomagnification occurs when a substance is found in higher concentrations at each higher level of the food chain. The top predators accumulate the substance from their food, which consists of animals that have accumulated the substance in their food.

associated with acidic conditions (Diamond, 1989; Ormerod et al., 1988 as cited in Mitchell, 1989). Data are not available to quantify the contribution of acid deposition relative to other factors that contribute to declining waterfowl populations, however.

Agricultural runoff. Pesticides and other toxic substances, excessive nutrients, and soil runoff from agricultural areas contaminate and alter many of the remaining wetland waterfowl breeding grounds in North America. For example, severe reproductive impacts occurred in ducks (e.g., mallard, northern pintail, cinnamon teal) nesting on selenium-contaminated irrigation drainwater ponds in the Kesterson Refuge and around the Kesterson reservoir in California in the mid 1980s (Ohlendorf et al., 1986, 1987). Synthetic pyrethroid pesticide runoff into the prairie potholes of Canada is eliminating the aquatic arthropod (i.e., insects and crustacea) prey of the waterfowl nesting in the potholes, resulting in reduced reproductive success in those areas (Sheehan et al., 1987). Again, data are not available to quantify the contribution of agricultural runoff to declining duck populations.

Disease. Bellrose (1976) and Stout and Cornwell (1976) have suggested that most non-hunting mortality of ducks in recent years is the result of disease (e.g., avian cholera, botulism). Dramatic outbreaks of avian botulism (*Clostridium botulinum* type C) in western North America have killed tens of thousands of waterfowl, shorebirds, and other aquatic birds in a few months (Enright, 1971; Hunter, 1970; Malcolm, 1982; National Wildlife Health Center (NWHC) unpublished data as cited by Brand et al., 1988; Parrish and Hunter, 1969) and have occurred at intervals since before the turn of the century (Kalmbach and Gunderson, 1934). Outbreaks of avian botulism in the coastal region of New York and New Jersey have been reported since 1950, with losses of several hundred birds (Reilly and Boroff, 1967; Figley and Van Druff, 1982; as cited in Brand et al., 1988). In the western states, the extreme crowding of waterfowl in remaining wetland areas during the drought of the 1980's contributed to an increase in the incidence of disease epidemics, notably avian cholera and botulism (Parrish and Hunter, 1969; Smith and Higgins, 1990). For example, 20,000 birds died of botulism at the Stillwater Refuge in Nevada in 1989 apparently as a consequence of overcrowding caused by low water conditions (as reported by Moser, 1989*P). Smith and Higgins (1990) found an inverse relationship between the density of remaining semipermanent wetland basins in Nebraska and the frequency of avian cholera epidemics. This problem may be considered secondary to the loss of breeding and wintering habitat, however.

Waste pits. In 1989, Federal wildlife officials estimated that pits and ponds used for storing oily industrial wastes were responsible for killing 500,000 migratory waterfowl, including some 100,000 ducks, in parts of New Mexico, Texas, Oklahoma, Kansas and Colorado in 1989 alone (Kelly, 1990*P; Bryce, 1991*P). Flying birds apparently are attracted to uncovered oil pits, mistaking the reflections as a sign of fresh water. This problem has been greatly reduced in recent years, however. In 1989, New Mexico passed a law requiring that open oil pits and tanks be covered with netting. Texas passed a similar law in 1991 (Bryce, 1991*P). Also in 1989, the US FWS escalated enforcement of the Federal Migratory Bird Treaty Act (MBTA) and has been prosecuting companies that have not covered their pits. Cyanide leaching ponds, common in gold and other mineral mining areas of the mid west, also kill waterfowl. The total number of birds killed is unknonw, but a single pond was found to have killed 1,450 birds (including ducks) over one eight month period (Bryce, 1991*P). The US FWS is continuing to investigate this problem, but has limited law enforcement staff to cover the large areas of concern.

2.3.3. Continued Monitoring

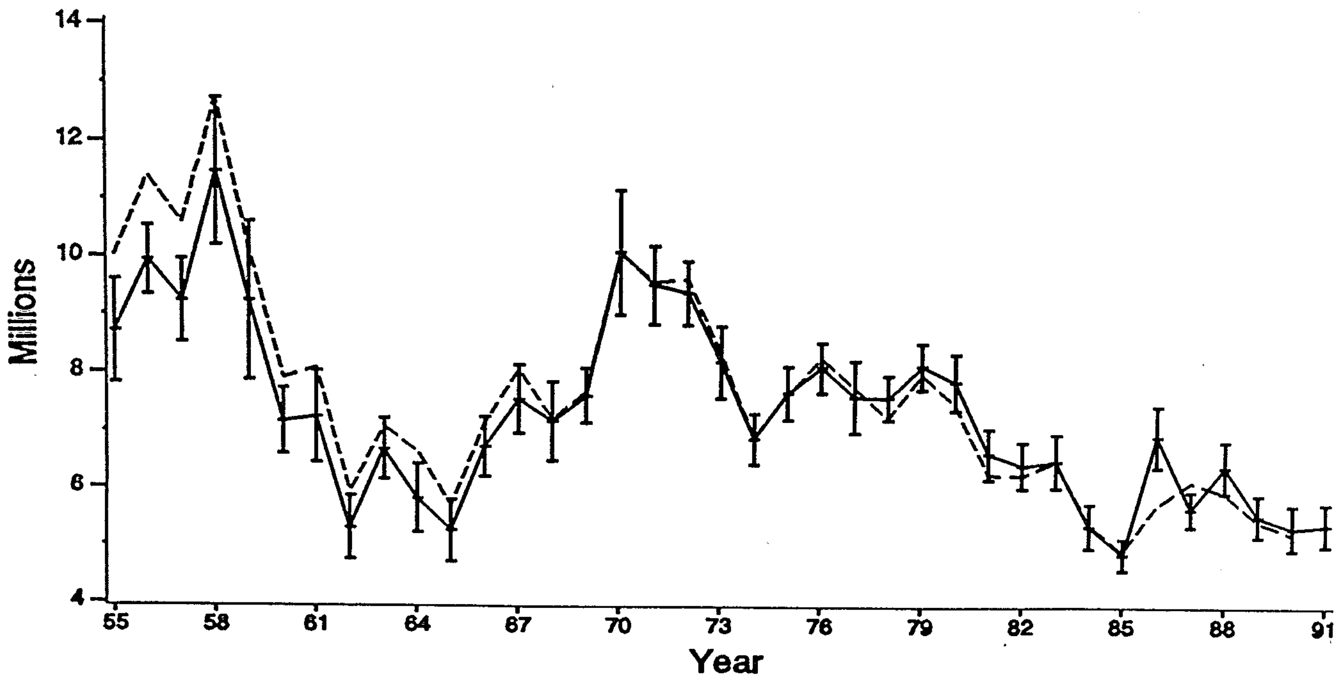
Each year since 1955, the US FWS has conducted a survey to estimate the number and species of potential breeding ducks in the pertinent nesting areas of North America. The survey, which begins in early May and continues until mid June, is conducted via air, ground, and water by Federal, State, and Provincial (Canada) personnel (Reynolds et al., 1990). The survey covers over 90 percent of the principal waterfowl breeding areas in both the United States and Canada. The results of this survey are reported annually.

There are other surveys that include data related to waterfowl population trends. The US FWS conducts a duck production survey in July of each year, and provides an index to the number, age, and size of broods produced and the number of adult birds still on nesting territories. The US FWS Patuxent National Wildlife Research Center keeps banding records that are used to estimate annual mortality rates of waterfowl populations. For mallards, the annual production rate index, along with breeding population and breeding season survival information, is used to predict a fall flight index for this species (Reynolds et al., 1990).

The Canadian Wildlife Service also conducts surveys of waterfowl populations and coordinates some of these with the US FWS.

Note about the 1991 US FWS Survey. The 1991 US FWS breeding duck population estimates differ from previous years due to several improvements. Most importantly, the information used to estimate the Visibility Correction Factor (VCF), which is necessary when too few ducks are seen in an area to make a population estimate, has been changed from the average of prairie VCFs from 1961-73 to include only the current and prior years' data. This has resulted in a reduction of many of the historical population estimates upon recalculation, because prairie averages were not appropriate for all habitats and visibility has changed in recent years due to drought and intensive agricultural practices. Exhibit 2.3.5 shows how historical mallard population estimates have changed as a result of the new VCF estimation method. Also this year's Survey has been expanded to include additional transects in traditional survey areas, and there are plans to initiate activities in areas not currently included in the May Breeding Waterfowl Survey (US FWS, 1991).

Exhibit 2.3.5. US FWS May Breeding Waterfowl Survey estimates for mallards from 1955 to 1991 using old and new estimation methods.



Solid line represents estimates based on new analytical procedures with 95% statistical confidence intervals. Dashed line represents estimates based on the old estimation procedures.

Source: Reproduced from US FWS (1991) with permission of the Director, US FWS.

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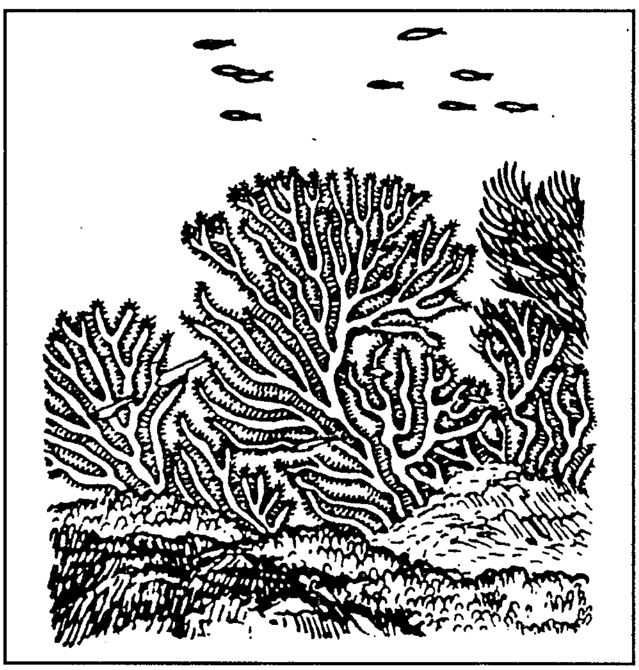
2.4. Coral Reef Communities Worldwide

Summary. For years, coral reef communities[6] have been suffering from adverse effects of human activities, including physical destruction (e.g., boat anchors, coral mining), nutrient runoff and sedimentation, and coastal pollution from agriculture, industries, and sewage. In addition, during the 1980's, four coral reef community bleaching events occurred on an unprecedented geographic scale. While corals often survive bleaching, they can be weakened and become more susceptible to other causes of mortality. In some areas, the Galapagos for example, the reefs died almost a decade ago, and have not yet recolonized.

Some scientists believe that these large-scale bleaching events occurred in response to elevated water temperatures that might be associated with a global warming trend added to other sources of coral reef community damages. Participants in a recent National Science Foundation (NSF)-sponsored meeting (June, 1991), however, concluded that there is no proof as yet of a global warming trend. Instead, the participants concluded that wide-spread coral bleaching may represent the cumulative effect of local perturbations that result from population growth, land use, and resource exploitation (D'Elia et al., 1991). All scientists agree, however, that coral reef communities are deteriorating at an unprecedented rate and scale. John Ogden, director of the Florida Institute of Oceanography, has concluded that "virtually every reef system in the world is suffering" (NYT, 1990*P), and Williams and Bunkley-Williams (1990a) are concerned that the coral bleaching cycles will continue, possibly with more intensity, until "coral dominated reefs no longer exist."



The coral reef bleaching events are only one manifestation of major tropical marine disturbances that appear to be increasing in frequency. In 1990 (Williams, 1991) and again in March and April of 1991 (Booth, 1991*P), a massive die-off of black sea urchins occurred in the Caribbean Sea and the Florida Keys. This is the third massive die-off of this group in this area since 1984; diademid urchin populations first crashed in the Caribbean Sea and western North Atlantic

[6]Drawing of coral reef in the box is reproduced with permission of the artist, Jo Moore.

in 1983 and 1984, when 95 to 99 percent of the urchins in all locations declined (Carpenter, 1990; Williams and Bunkley-Williams, 1990a). A massive die-off of diademid urchins occurred in Hawaii in 1981. Other marine disturbances that may be related to those of coral reef communities have included giant clam die-offs, turtle tumor outbreaks, and recurring herring mortalities (Alder and Braley, 1989; Williams and Bunkley-Williams, 1990b). In the remainder of this section, however, we focus on the coral reefs and stony coral organisms which are responsible for building and maintaining the physical structure of the reef.

2.4.1. Description

Background. Stony corals are coelenterates that produce a calcium carbonate skeleton. Reef-building species of stony coral need relatively shallow water because of the light requirements of the symbiotic zooxanthellae (dinoflagellate algae) that live in their tissues (Barnes, 1968). These algae utilize wastes from the corals, supply up to 63 percent of the corals' nutrients, and facilitate calcification (Glynn, 1991). Without these services, the stony corals cannot build their skeletons. The coral skeletons provide a substrate for many other species. Tropical reefs are associations of usually several thousand species of different animals, including fish, sea urchins, clams, crustacea, and many other groups of organisms. Other reef community members, including fire corals, sea anemones, sponges, gorgonians, sea fans, soft corals, and giant clams, also use photosynthetic symbionts.

Coral bleaching occurs when the corals lose or expel a majority of their zooxanthellae, when the concentration of pigments in the zooxanthellae declines markedly, or when some combination of these events occurs (Glynn, 1991). As a result, the coral host becomes pale or "bleached" in appearance due to the loss of plant pigments and the increased visibility of the coral's calcareous skeleton (Glynn, 1991). Bleaching also can occur in the other photosymbiotic species (e.g., sea fans, soft corals). Bleached corals may survive for some time without the nutrition supplied by the zooxanthellae by consuming their own tissues, which can leave them unable to reproduce (Szmant and Gassman, 1990). The extent of bleaching and tissue damage that can be tolerated is unknown (Glynn, 1991).

The effects of bleaching events range from slight, with full recovery possible, to severe, with most of the coral dying, and the skeletal remains eroding before new recruitment from other areas is possible (Hayes and Bush, 1990; Holthus et al., 1989; Glynn, 1991). In one study, continued bleaching was documented for more than a year after the initial event (Bunkely-Williams et al., 1991). Recovering corals grow more slowly than unbleached corals (Goreau and MacFarlane, 1990) and may not reproduce (Szmant and Gassman, 1990). More than two to four years is required for a reef to fully recover from an extensive bleaching event (Glynn and D'Croz, 1990; Suharsono, 1988).

Trends. Coral reefs around the world have been declining and suffering damage over the past 10 to 20 years (Williams and Bunkley-Williams, 1990a; D'Elia et al., 1991). Coral reefs are deteriorating in the Pacific (Gomez, 1988) and the Atlantic (Rogers, 1985; Lang as reported in Hollings, 1987*P) due to physical destruction (e.g., boat anchors, coral harvesting), nutrient runoff and sedimentation, industrial or agricultural chemicals, and sewage pollution. The affected areas include the coasts of Australia, China, Japan, Panama, Thailand, Malaysia, the Philippines, India, Indonesia, Kenya, the Red Sea, Colombia, the Caribbean, and the United States (NYT, 1990*P). In the Florida Keys, corals are dying at a faster rate than 5 years ago, and some scientists predict that the Florida reef may be dead by the year 2000 (J. Porter as reported by Keating, 1991).

Until recently, isolated instances of coral bleaching have occurred in response to heavy rains, pollutants, decreased salinity, or other local stresses (Roberts, 1987, 1988). Worldwide coral bleaching events, or "complexes,"[7] occurred in 1979/80, 1982/83, 1986/88, and 1989/90 (Glynn, 1991; Williams and Bunkley-Williams, 1990a). In 1980, three widely separated areas in the Pacific suffered extensive bleaching: Australia (Oliver, 1985), Easter Island (Cea-Egana and DiSalvo, 1982), and Okinawa (Yamazato, 1981). Bleaching also occurred in Florida in 1980 and in Bonaire in 1979 (Williams and Bunkley-Williams, 1990a). In 1983, some coral species appear to have been eliminated from the eastern Pacific (Glynn, 1984; Glynn and Weerdt, 1991), and 97 percent of the corals on some reefs in the Galapagos Islands and other corals in the eastern Pacific were killed (Glynn, 1991). The Great Barrier Reef of Australia bleached extensively in 1982, one year before the 1983 reports of bleaching in other areas (Williams and Bunkley-Williams, 1990a). In the 1986/88 event, the areas most severely affected were Florida, the Bahamas, and the Greater Antilles, while reefs off Bermuda, Curacao, Lesser Antilles, Panama, Venezuela, and Tobago suffered less (Williams and Bunkley-Williams, 1990a). The eastern Pacific bleached less in 1986/88 than in 1982/83; however, overall, more bleaching occurred in more areas in 1986/87 than in 1982/83. For example, the area bleached in Australia's Great Barrier Reef in 1987 was two to four times the size of areas bleached there in 1982/83 (Williams and Bunkley-Williams, 1990a).

Williams and Bunkley-Williams (1990b) received numerous reports of coral bleaching events in mid-to-late 1989 from many areas of the Caribbean and predicted that a larger scale bleaching event would occur in 1990. The most severe and extensive coral reef bleaching event ever reported occurred in the tropical western Atlantic in 1990 (Williams, 1991). Mass mortalities of fire coral and some stony corals occurred in the beginning of the event. The most severe bleaching seemed to occur in the Northern Caribbean, Bahamas, Florida, Texas, and Bermuda, but some severe-to-moderate bleaching appears also to have occurred throughout much of the Caribbean and in Hawaii, Australia, and Fiji. Bleaching in French Polynesia was reported in June, 1991

[7]Groups of time-related bleaching events.

(Williams and Grizzle, 1991). Exhibits 2.4.1 to 2.4.4 show the worldwide distribution of these bleaching events.

Some corals have recovered from the bleaching events described above whereas others have not. Coral cover on an Indonesian reef attained 50 percent of its former level after five years (Brown and Suharsono, 1990; as cited in Glynn, 1991). On the other hand, on eastern Pacific coral reefs that suffered high coral mortality in 1982/83, bioerosion now exceeds net carbonate production, which threatens to reduce the reef skeleton to sediment (Glynn, 1988). In the Galapagos Islands, no recruitment of reef building organisms has been observed after seven years (Glynn, 1988). Similarly, some reefs along the Pacific coast of Costa Rica exhibited 100% mortality in 1982/83 and recruitment has been minimal since, prompting experiments in restoration by transplanting living coral fragments from elsewhere onto the dead reef framework (Guzman, 1991).

2.4.2. Hypotheses

Many of the physical causes of coral reef community deterioration are incontrovertible (e.g., physical destruction, nutrient runoff and sedimentation, point source pollution) and also may contribute to the observed incidence of disease. There are natural causes (e.g., hurricanes) that physically stress the reefs as well. The general scientific consensus is that bleaching (i.e., expulsion of zooxanthellae) is stress-induced. Elevated water temperature has been accepted by many as the primary cause of the large-scale bleaching events (D'Elia et al., 1991; Goreau et al., 1991; Williams and Bunkley-Williams, 1990a). Coral stress induced by pollution, sedimentation, and physical destruction may prevent corals from withstanding temperature changes that normally would have little effect (Bunkley-Williams and Williams, 1990). Each of these hypotheses is discussed below.

Physical destruction. On certain coral reefs, the number of visitors and boats has increased dramatically in the last 30 years, and direct coral harvesting and damage from boats appears to be increasing (Ward, 1990*P). Years ago, Davis (1977) found that 20 percent of the staghorn corals in Fort Jefferson National Monument, Dry Tortugas, Florida, showed severe damage from anchors. Dustan and Halas (1987) found continued degradation of a Florida coral reef from 1975 to 1983 due to physical disturbances in the shallow areas. Some investigators have argued that predation on scleractinian corals of the western Pacific by the crown-of-thorns starfish (*Acanthaster planci*) which physically removes large sections of reef, is attributable to human disturbances of natural predators on the starfish, although there is some debate over this hypothesis (Walbran et al., 1989).

Nutrient runoff and sedimentation. Freshwater runoff, with associated sediment loads, can have adverse effects on coral communities. Runoff usually is loaded with both sediments and nutrients. Dustan and Halas (1987) and Acevedo and Goenaga (1986) have documented examples of deterioration of reefs off Florida and Puerto Rico due to

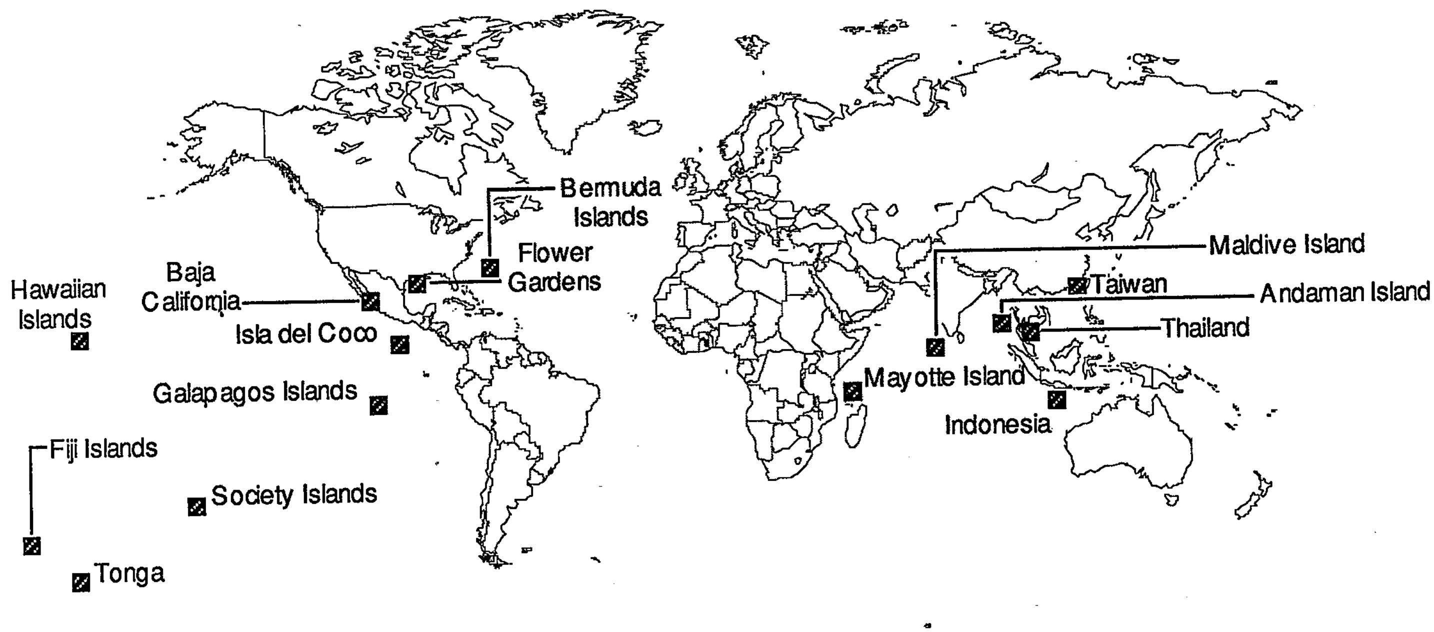
Exhibit 2.4.1. Location of coral reef bleaching sites reported during 1979 to 1980.

Source: Figure adapted from Glynn (1991), Williams and Bunkley-Williams (1990) and E.H. Williams, Jr. and L. Bunkley-Williams, pers. comm. to Glynn.

Exhibit 2.4.2. Location of coral reef bleaching sites reported during 1982 and 1983.

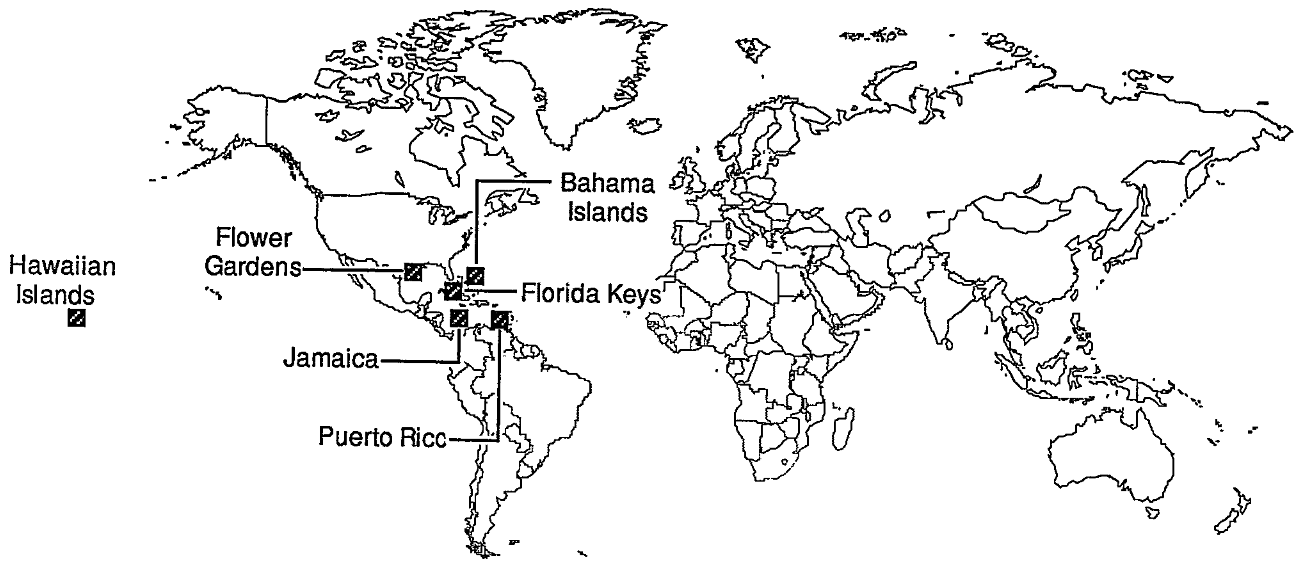
Source: Figure adapted from Glynn (1991), Williams and Bunkley-Williams (1990) and E.H. Williams, Jr. and L. Bunkley-Williams, pers. comm. to Glynn.

Exhibit 2.4.3. Location of coral reef bleaching sites reported during 1986 and 1987.



Source: Figure adapted from Glynn (1991), Williams and Bunkley-Williams (1990) and E.H. Williams, Jr. and L. Bunkley-Williams, pers. comm. to Glynn.

Exhibit 2.4.4. Location of coral reef bleaching sites reported during 1989 and 1990.



Source: Figure adapted from Glynn (1991). The 1990 record for the Sultanate of Oman was reported by R. Salm (IUCN Bull. (1990) 21:9).

deposition of nutrient-laden sediments. Prime coral reef habitat is a low-nutrient environment. The nutrients may allow algae to grow quickly and to smother the corals, blocking light and trapping sediment (Pastorok and Bilyard, 1985). Off the Florida Keys, the most important threat to the reefs appears to be excessive nutrient loading from agricultural fertilizers and septic tanks, which has caused increased algal growth on the corals (Keating, 1991*P; Lauter, 1991*P). Lapointe (1989*P) believes that algal reefs will replace coral reefs in the Caribbean as a direct result of nutrification. Sediments in runoff also can smother reefs, reducing the number of species present and the percent cover, as shown in Exhibit 2.4.5 (Pastorok and Bilyard, 1985). Excess sedimentation results from land clearing, road building, and river and stream channelization. In some areas, increased runoff of nutrients and sediments as a consequence of rainforest destruction has caused deterioration of coral reefs (Glynn, 1991).

Point source pollution. Coastal sewage discharges and oil spills have contributed to local declines of coral reefs. The three components of sewage pollution that are most detrimental to corals are nutrients and sediments, as discussed above, and toxic substances (e.g., PCBs, metals, chlorine, pesticides, and petroleum hydrocarbons). Sewage is threatening the coral reef communities of the Red Sea, Caribbean, Hawaii, and the Caroline Islands (Pastorok and Bilyard, 1985). Oil spills also are damaging coral reef communities. In 1986, more than eight million liters of crude oil spilled into the sea on the Caribbean coast of Panama. Among other adverse effects on the reefs, there was extensive mortality of shallow subtidal corals; at depths less than three meters, the abundance of the most common scleractinian coral decreased by 51 percent to 96 percent, and total coral cover decreased by 75 percent (Jackson et al., 1989). Algae invaded the reef, and formed dense mats. Three years after the spill, oil continued to ooze out of the mangrove sediments onshore and the corals had not fully recovered (Booth, 1989*P).

Disease. Increased incidence of disease (e.g., black band disease, white band disease) has been associated with increased physical damage, pollution, and sedimentation of corals (Bunkley-Williams and Williams, 1990; Dustan and Halas, 1987), but firm evidence for cause and effect is lacking. Dustan and Halas (1987) point out that the observed diseases occur naturally, but poor water quality may contribute to their spread and severity.

Natural phenomena. Hurricanes can fragment coral reefs, and thereby weaken them (Bunkley-Williams and Williams, 1990; Dustan and Halas, 1987; Woodley et al. 1981). Extreme low tides associated with El Niños - Southern Oscillations (ENSO) events[8] have been known to leave coral reefs exposed, which can contribute to coral bleaching and death (Bunkley-Williams and Williams, 1990; Yamaguchi, 1975; Glynn,

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[8]ENSOs are periodic worldwide meteorological shifts associated with changes in ocean currents and atmospheric circulation lasting several months to two years.

a global warming trend, the corals may have only recently been exposed to temperatures that exceed their tolerance levels (Exhibit 2.4.6a). Second, cumulative effects from human perturbations (e.g., physical destruction, nutrient runoff and sedimentation, and other pollution) may be weakening the corals, reducing their tolerance of high temperatures (Exhibit 2.4.6b). Finally, both processes could be occurring.

Obtaining accurate data on global ocean temperatures is difficult (Bunkley-Williams and Williams, 1990; Glynn, 1991). The extreme temperatures of the last decade have most likely caused temperatures that the corals could not tolerate (D'Elia et al., 1991; Goreau et al., 1991; Williams and Bunkley-Williams, 1990a), but the hypothesis that this reflects widespread ocean warming as a consequence of global warming has not been substantiated (Glynn, 1991; D'Elia et al., 1991). The consensus of a National Science Foundation (NSF)-sponsored meeting on the issue in June, 1991, was that there is no proof that global warming is already happening, and therefore, it is not possible to claim that coral bleaching is an early indicator of the phenomenon (D'Elia et al., 1991). The group agreed, however, that reef deterioration world-wide is a serious problem.

2.4.3. Continued Monitoring

The Marine Ecological Disturbance Information Center (MEDIC), maintained at the Department of Marine Sciences at the University of Puerto Rico (P.O. Box 908, Lajas, PR 00667), is serving as a communication hub for information concerning not only coral reef bleaching events, but other major marine disturbances including sea urchin mass mortalities, fish kills, and turtle tumor outbreaks. Dr. Ernest Williams serves as the Caribbean Coordinator at the University of Puerto Rico and Dr. John Grizzle serves as the Auburn University Coordinator. MEDIC publishes a newsletter at regular intervals summarizing recent reports of marine disturbances and efforts are underway or planned to further study the phenomena and their implications.

The participants in the NSF-sponsored meeting in June, 1991, unanimously recommended an international program of intensive, long-term monitoring of coral reef communities throughout the world to collect data on the physical and biological factors that can affect reef health. Their recommendations will go to NSF, the National Oceanographic and Atmospheric Administration (NOAA), and EPA (D'Elia et al., 1991).

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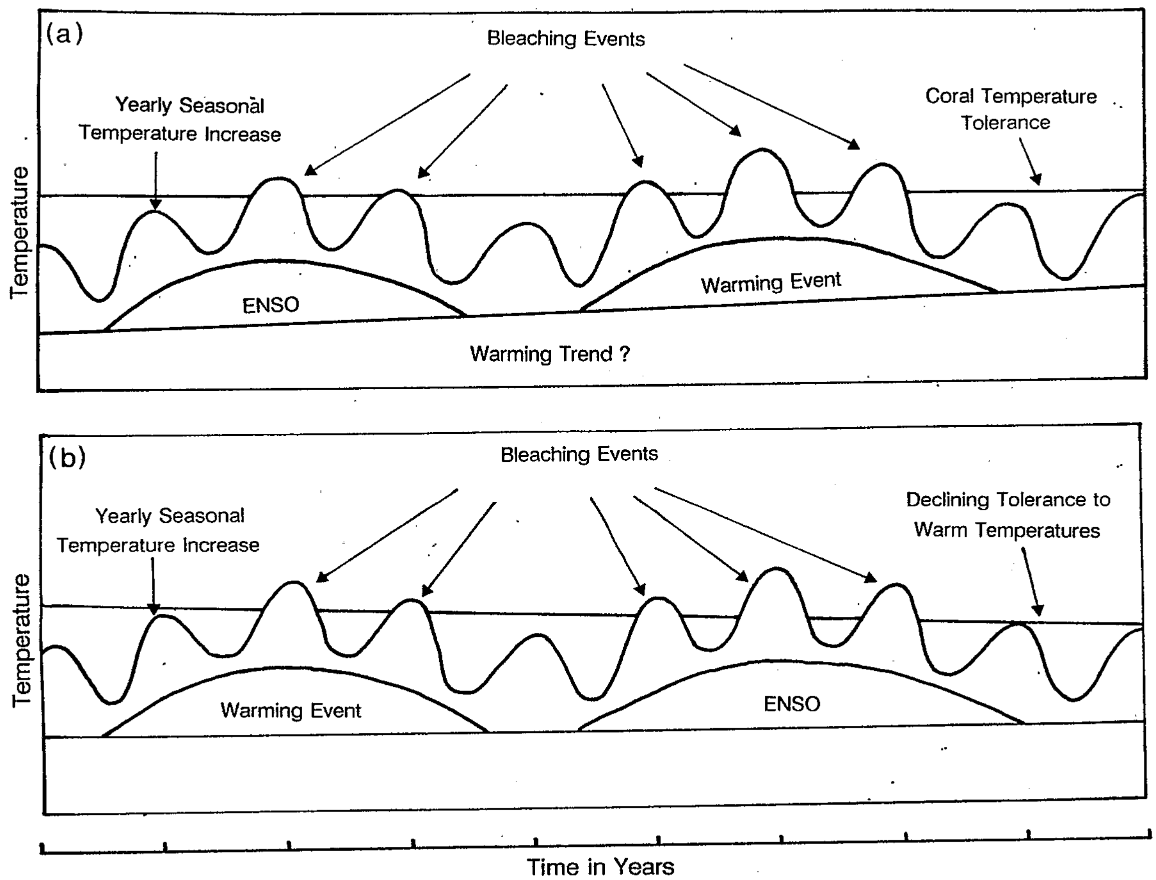
Exhibit 2.4.6. Model of causes of worldwide coral reef bleaching.



The model of causes of worldwide coral reef bleaching consists of several components. Elevated temperatures occur each year during the summer. During an ENSO or other temporary warming event, high temperatures sufficient to bleach hosts can occur. Up to three seasonal peaks of temperature can be superimposed on a single ENSO or other warming event. The middle event (i.e., main event) produces the more severe bleaching and mortalities because it occurs at the height of the temporary ENSO or other warming event. The preceding and following events are less severe because they are on the 'shoulders' of the temporary warming event.

(a) If a general warming trend were occurring in the oceans, the frequency and severity of the bleaching events would be expected to increase over time.

(b) If coral reefs were being stressed by other factors (e.g., nutrification, sedimentation, physical damage), their tolerance of high temperatures might be reduced, again resulting in an increasing frequency and severity of the bleaching events over time.

Source: Adapted from Williams and Bunkley-Williams, 1990a.

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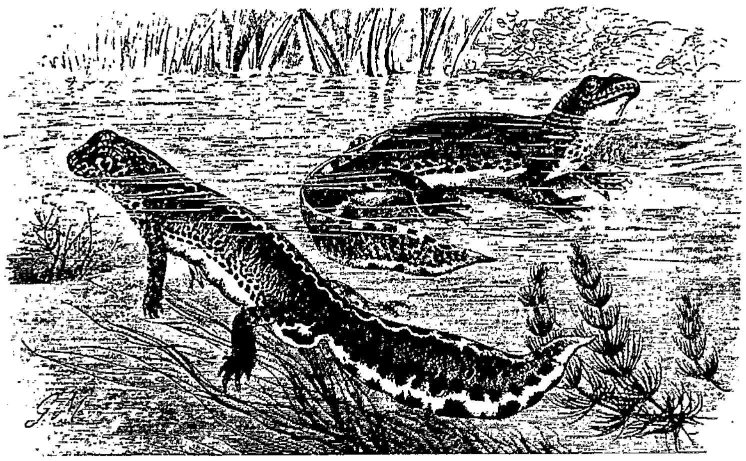
- young terrestrial salamanders eat mites and insects that consume detritus; and

- adult salamanders prey on numerous organisms (e.g., worms, slugs, larval and adult insects, and other salamanders).

Trends. Recently, the National Research Council (NRC) sponsored a workshop to examine whether the numerous reported local extinctions and declines of amphibian populations represent a worldwide phenomenon (NRC, 1990). The declines for some populations, particularly of frogs, are as high as 50 to 90 percent and are occurring even in relatively pristine habitats such as national parks and biological preserves (Blaustein and Wake, 1990). Examples of declining amphibian populations in North America and elsewhere are provided in Exhibits 2.5.1 and 2.5.2, respectively.



Although formal analyses are not yet available, the number of investigators reporting similar trends leads credence to the hypothesis that amphibians in general are suffering population declines worldwide. Many of the declines can be attributed to obvious habitat destruction or modification. However, the decline of populations in protected areas indicates that other, more global, factors also may be involved.

Not all species are declining, however. For example, there is no indication that frog populations in the vicinity of the Savannah River Laboratory have declined over the past 11 years (Pechmann and Scott, 1990), nor have frog populations in monitored Borneo streams declined (Robert Inger as reported by Blaustein and Wake, 1990). Declines are being noted primarily in temperate or higher latitudes and in higher elevations. There is little evidence for declines of amphibians within 10° latitude north or south of the equator or low-altitude regions, aside from the dramatic losses resulting from complete habitat destruction associated with deforestation, urban development, and destructive agricultural practices (Blaustein and Wake, 1990).

Exhibit 2.5.1. Examples of declining amphibian populations in North America.

- The western spotted frog is now absent from over one third of its 1970's range in Oregon (Andrew Blaustein as reported by Blaustein and Wake, 1990).

- The red-legged frog, once abundant in western states (Jennings, 1988), is now extinct in Oregon (Blaustein and Wake, 1990) and southern California (Marc Hayes as reported in Blaustein and Wake, 1990) and is declining elsewhere in California (Jennings, 1988).

- The Cascade frog is declining in Oregon (Blaustein and Wake, 1990).

- The mountain and foothill yellow-legged frog and the Yosemite toad are declining not only in the mountain and foothills of California, but also in the lakes in Kings Canyon and Sequoia National Parks in California (David Bradford as reported by Blaustein and Wake, 1990; Jennings, 1988; Jennings as reported by Cowen, 1990).

- The boreal toad (Bury and Corn as reported by Cowen, 1990), Wyoming toad (Baxter and Meyer, 1982), chorus frog, leopard frog (Corn and Fogleman, 1984), woodfrog, and tiger salamander have declined markedly in the Rocky Mountains of Colorado (Vaughan Shoemaker as reported by Blaustein and Wake, 1990; Corn and Fogleman, 1984; Harte and Hoffman, 1989). For example:

  - The leopard frog (*Rana pipiens*) inhabits only 4 of 33 sites where it was once abundant, and

  - The boreal toad is seen in just 10 of 59 areas that it had frequented previously (Bury and Corn as reported by Cowen, 1990).

- On the Huyck Preserve and Biological Research Station in the Helderberg Plateau in New York, four species of amphibians that were recorded on the Preserve in 1938 no longer occur there (Wyman, 1988b).

- Although population-level effects are not yet documented, the western toad recently has suffered severely reduced reproductive success in Lost Lake of the Oregon Cascade Mountains. Egg mortality rates in 1989, 1990, and 1991 were 50%, 100%, and 50%, respectively, whereas egg mortality rates never had exceeded 5% in the previous 11 years the lake was monitored (Blaustein and Olson, 1991).

Exhibit 2.5.2. Examples of declining amphibian populations in other areas.

- At the University of Sao Paolo's field station at Boracea, Brazil, 6 of 30 frog species have disappeared since 1982 and 7 have declining populations (Heyer et al., 1988).

- The gastric brooding frog, discovered in large numbers (i.e., many hundreds) in 1974 by Michael Tyler of the University of Adelaide, Australia, completely disappeared from its range (the Conondale Ridges area) by 1981 (Blaustein and Wake, 1990).

- The range of the natterjack toad (*Bufo calamita*) in Britain has shrunk by fifty percent in recent years (Beebee et al., 1990).

- The golden toad in Monteverde Cloud Forest Preserve, Costa Rica, has declined from around 1,000 breeding individuals in the early 1980's to a few by the mid to late 1980's (about a dozen according to Marc Hayes as reported by Blaustein and Wake, 1990; one frog only according to Martha Crump as reported by Barinaga, 1990).

- Salamanders near Oaxaca, Mexico, appear to be declining (Barinaga, 1990).

- In the Venezuelan Andes, "drastically diminished" populations of five species of *Atelopus* toads recently have been reported (La Marca and Reinthaler, 1991).

2.5.2. Hypotheses

Several explanations of a possible worldwide decline in amphibian populations are being considered in the scientific community:

- destruction of natural habitats;
- acid deposition (i.e., deposition of nitrates, sulfates, ammonia, and hydrogen);
- introduced species (i.e., competition and predation by bullfrogs, and predation by introduced fish species);
- unusual climatic variations (i.e., unusually cold winters and dry summers);
- exploitation by humans (e.g., food, research, pet trade);
- widespread use of pesticides and toxic substances;
- pathogens;
- increased ultraviolet radiation;
- synergistic interactions among the above factors; and
- natural cyclic fluctuations in populations.

In general, distinguishing human-induced trends from natural variation in amphibian populations is difficult (Pough as reported by Blaustein and Wake, 1990; Pechman et al., 1991; Wake, 1991). Moreover, there are few quantitative baseline data by which to judge recent changes (Barinaga, 1990; Blaustein and Wake, 1990; Vitt et al., 1990). To date, much of the evidence of declining population comes from the anecdotal personal experiences of herpetologists and other biologists, rather than experimental design (Young, 1990). We discuss the hypotheses listed above in the following paragraphs.

Destruction of natural habitats. An indisputable contribution to the decline of many amphibian species is habitat destruction. Beyond outright destruction of habitats, remaining surface waters and wetlands can be so modified as to be no longer suitable habitat for native species. Changes that increase temperature, eliminate suitable oviposition (i.e., egg-laying) sites, refuges, and hibernating areas are particularly important to amphibians. On a global scale, a large proportion of the habitat used by amphibian species is being lost due to tropical deforestation (Wyman, 1991; Blaustein and Wake, 1990). Habitat alteration also has been suggested as a major factor contributing to the decline of frog species in western North America (Moyle, 1973; Bantu and Morafka, 1966, as cited in Hayes and Jennings, 1986). For example:

- Dam and reservoir building and mining result in removal of riparian (i.e., along the edge of rivers and streams) vegetation and decreases in stream flow, which in turn result in increased water temperature beyond the optima or tolerance range of many species (Bury and Corn, 1988a,b; Corn and Bury, 1989; Hayes and Jennings, 1986; Jennings, 1988);

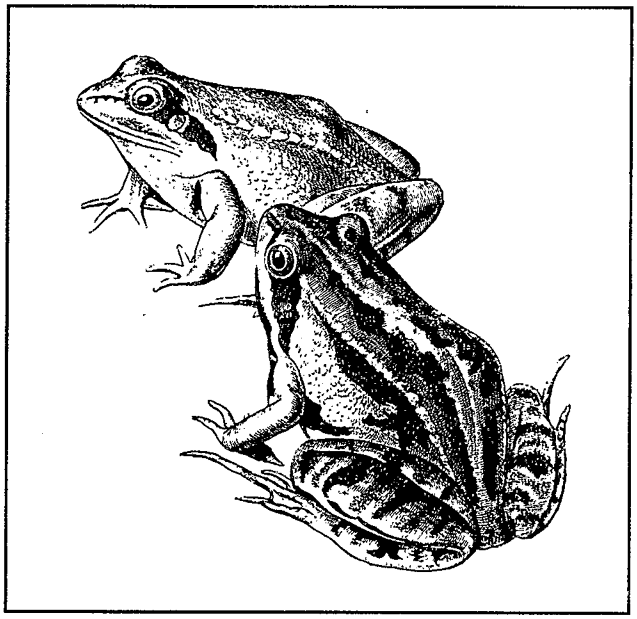
- Livestock grazing can produce similar results, i.e., removing vegetative cover, increasing ambient water temperatures, and eliminating desirable undercut banks (Jennings, 1988);

- Logged forests increase sedimentation in streams, reducing habitat for larval salamanders and frogs (Bury and Corn, 1988a; Corn and Bury, 1989). [Corn and Bury (1989) found species richness to be highest in streams in uncut forests and density and biomass of individual species to be significantly reduced in streams in logged forests (Exhibit 2.5.3.];

- Logging, clear-cutting, and roads cause obvious fragmentation of habitat suitable for amphibians. Patches of high soil acidity also may preclude movements of amphibians from one stream or pond to the next (Wyman, 1991); and

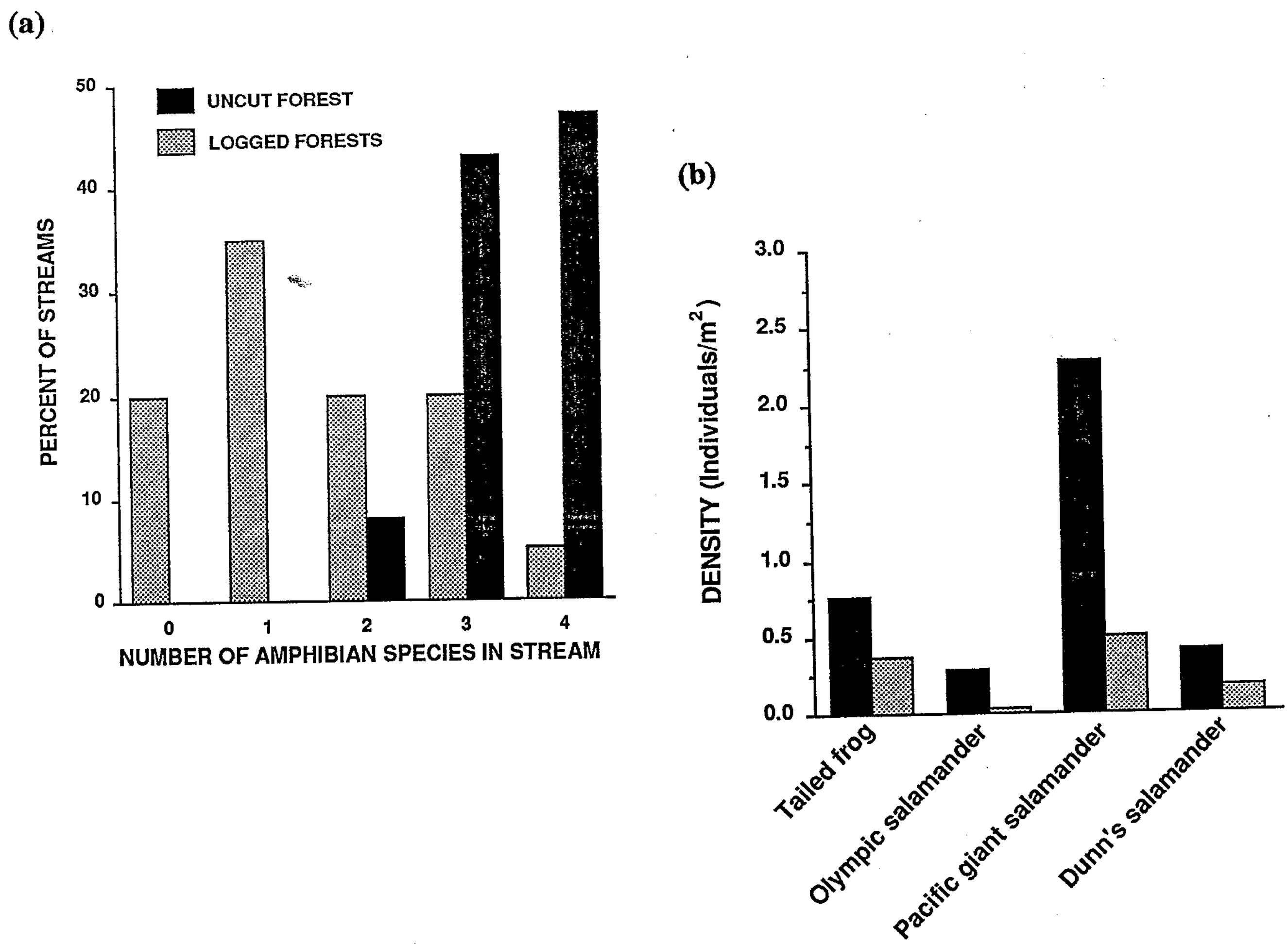
- Habitat fragmentation also may increase the probability of local population extinctions as a result of natural or other extremes in temperature or precipitation (Wyman, 1991; Jennings, 1988).

Nonetheless, the most disconcerting aspect of the apparent global decline in amphibian species is that declines have been observed in populations that are not subject to overt habitat destruction. The following sections review hypotheses to explain this phenomenon. Given the recent recognition of the problem, none of the following hypotheses has been extensively developed or investigated.



Acid deposition. Acid deposition, including dry deposition and deposition from snow melt, can have various adverse effects on amphibians. Many salamanders, toads, and frogs breed in temporary pools formed in the early

Exhibit 2.5.3. Effect of logging on amphibian species number and density in western Oregon.



(a) *The number of amphibian species per stream is higher in forested than in logged areas (i.e., three or four species of amphibian were present at more than 90 percent of streams in uncut forests; whereas over 50 percent of streams in logged forests had no amphibians or only one species present).*

(b) *The density of each of the four species of amphibians is higher in the forested than in the logged areas.*

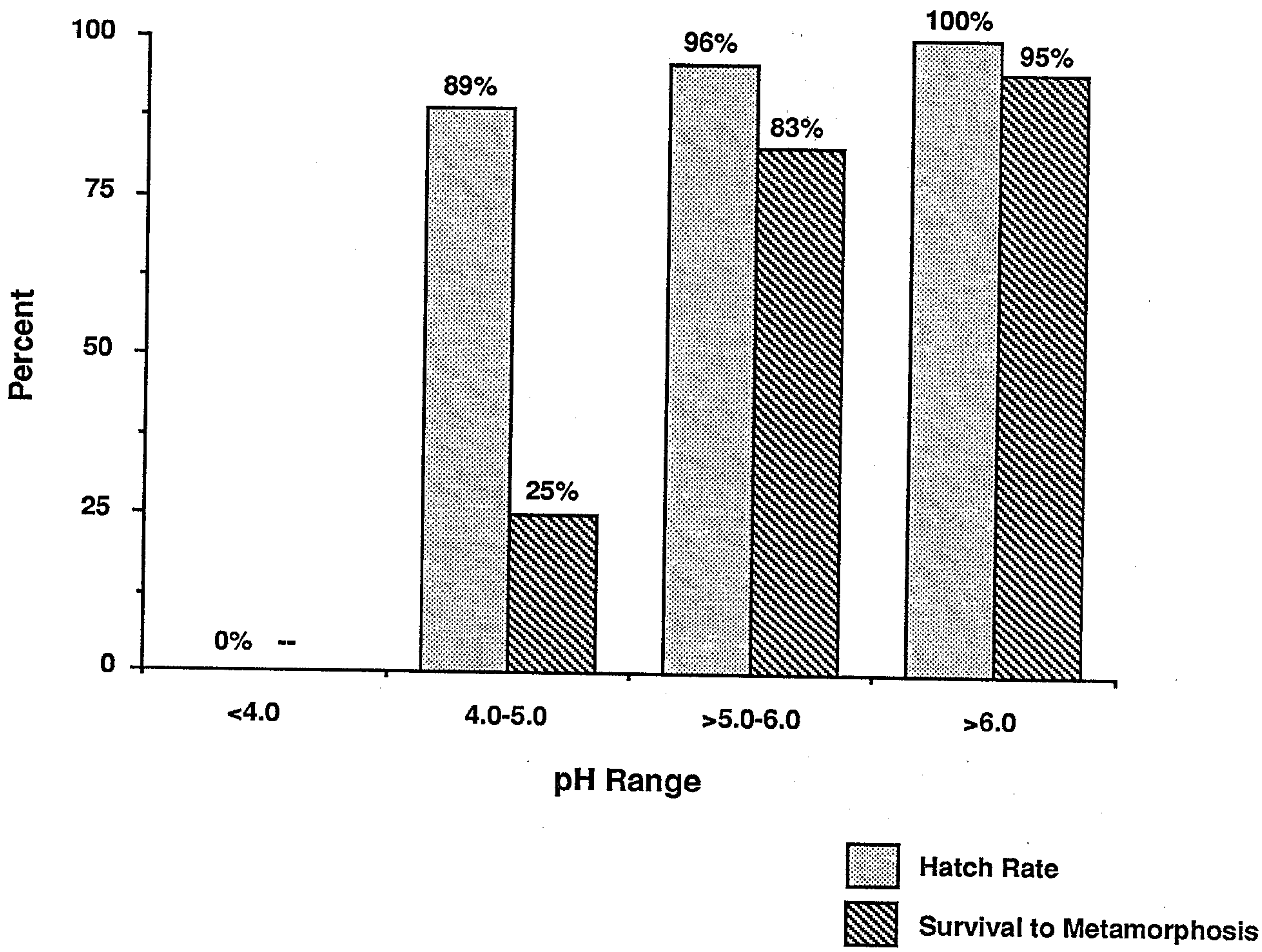
Source: Corn and Bury, 1989.

spring by melting snow and rain (Freda, 1986; Freda et al., 1991; Pough, 1976). These breeding ponds are generally small, low in acid buffering capacity, and darkly stained by humic substances. These factors increase the potential for acidification and make it difficult to distinguish the contribution of acid from anthropogenic factors (e.g., atmospheric deposition) from that of natural sources (e.g., sphagnum and organic acids) (Freda, 1986; Pough, 1976). Acidified soils also can stress terrestrial forms (e.g., toads, salamanders) and life stages (e.g., efts), particularly in areas with low soil buffering capacity (Wyman, 1991). Acidic soils apparently contribute to the loss of sodium and water from amphibians, resulting in a sodium and water deficit (Frisbie and Wyman, 1991). When conditions dry during droughts, soils become more acidic and amphibians lose water both as a consequence of the dry conditions and the loss of sodium, which is followed by more water loss (by osmosis) (Frisbie and Wyman, 1991). The synergistic effects of low soil moisture, low pH, and high temperatures may produce lethal water stress on terrestrial amphibians (Wyman, 1991).

Investigators have documented several ways in which acid deposition can have adverse effects on amphibians. Acid influx during spring snow melts can acidify breeding ponds to levels that cause death in embryos (Harte and Hoffman, 1989; Pough, 1976; Pough and Wilson, 1977) and larvae (Saber and Dunson, 1978). Harte and Hoffman (1989) suggested that acid spring snow melts were responsible for the 65 percent decline of a Rocky Mountain population of the tiger salamander (*Ambystoma tigrinum*); however, this finding recently has been disputed (Scott Wissinger, unpubl. data, Wyman, pers. comm.). Chronic acid surface water conditions can inhibit sperm mobility and cause developmental abnormalities in embryos (Gosner and Black, 1957; Pough and Wilson, 1977; Cook, 1983; Pierce, 1985; Schlichter, 1981). Acidic conditions also can slow or inhibit development of eggs (Harte and Hoffman, 1989; Pough, 1976), and tadpoles (Beebee et al., 1990; Freda and Dunson, 1986; Pierce and Montgomery, 1989) (Exhibit 2.5.4). Slower developmental rates increase the chances of predation and failure to metamorphose from tadpole to frog before the pond dries out. Freda and Dunson (1985) found that sodium loss is increased and total body sodium reduced in amphibian larvae exposed to acidic water. The larvae die when about half of the body's sodium content has been lost. The same problem may affect terrestrial salamanders (Frisbie and Wyman, 1991; Wyman, 1991). Interactions between pH and other chemical and physical variables (e.g., temperature, concentrations of aluminum, calcium, and organic acids) may cause variability in amphibian mortality at specified pH levels (Freda, 1986; Freda and Dunson, 1986).

Amphibian species show a range of sensitivities to acidic conditions. Those species that breed in naturally more acidic conditions appear to be more resistant to acid (Pierce, 1985). Acid-sensitive species tend to be absent from acidic ponds (Freda and Dunson, 1986) and salamanders have been shown to avoid areas of low pH soils (Wyman and Hawksley-Lescault, 1987). Adults of at least 10 species of amphibians show distributions and densities that are positively correlated with soil pH (Wyman, 1988a;

Exhibit 2.5.4. Acid tolerance of natterjack toad development.



Low pH reduces hatch rate and survival to metamorphosis in natterjack toads. Growth rate also is reduced at low pH.

Source: Adapted from Beebee et al., 1990.

Wyman and Hawksley-Lescault, 1987; Wyman, 1991). Wyman (1988a) also found a strong negative correlation between the number and density of species of amphibians in a forested habitat and the acidity of the soil. Available evidence links the loss of the natterjack toad from lowland heaths that formerly supported about half of the British population to recent acidification of this habitat (Beebee et al., 1990).

In summary, acidified surface waters have been shown to have adverse effects on developing embryos and larvae, and acid deposition has been implicated in the decline or reduced range of some terrestrial as well as aquatic species and life stages. The extent to which acid deposition and concurrent changes in water and soil chemistry may be responsible for other species declines is not known.

Introduced species. Several investigators have suggested that bullfrogs and introduced carnivorous fish may be contributing to declines of amphibian populations in the United States, particularly in the western states. Bullfrogs were first introduced to western North America in California in 1896 (Heard, 1904*P, as cited in Hayes and Jennings, 1986). Over 60 species of fishes have been introduced to western North America over the past 120 years, and of these, 59 percent are predatory (Hayes and Jennings, 1986; Jennings, 1988). We discuss the evidence for concerning bullfrogs and fish separately below.

Bullfrogs. Changing land-use patterns in the United States have resulted in favorable habitat for bullfrogs and increased competition of native frog populations with bullfrogs (Corn and Fogleman, 1984; Hammerson, 1982; Hayes and Jennings, 1986). Some investigators (e.g., Dumas, 1966; Hammerson, 1982; Moyle, 1973) claim that several frog species' populations are declining in the west at least in part because of bullfrogs. The most frequently cited of these, Moyle (1973), reported that the two frog species that used to be the most common in the San Joaquin Valley of California are now absent or rare, while the bullfrog has become the dominant frog on the valley floor and has spread to the surrounding foothills. The native species are found only in areas where the bullfrog is absent. The evidence implicating bullfrogs as the cause of declining populations of frogs in the western United States cited by Moyle (1973) includes:

- The sizes of frog and bullfrog populations tend to be inversely correlated;
- Bullfrogs are the most frequently encountered Ranid (i.e., true frog) species in many areas;
- Bullfrogs occupy areas once inhabited by declining species of frogs; and
- Bullfrogs are known to eat juvenile frogs of other species when both are in captivity.

The bullfrog hypothesis is not universally accepted, however, because predation has not been observed in the field (Hayes and Jennings, 1986), and because the appropriate competition and predation experiments have not yet been conducted to test the hypothesis critically (Jennings, 1988).

Fish. In California and other western states, frogs originally evolved with little pressure from fish predation and may not have any natural defense mechanisms against fish predators. About 8 of 50 introduced fish species that have become most extensively naturalized in the west are carnivorous, and some are known to prey on frogs (Hayes and Jennings, 1986). Two types of evidence support the role of introduced fish species in the decline of western frogs: (1) an inverse relationship between the abundance of introduced fishes and the abundance of endemic frogs (i.e., frog species found only in that area); and (2) the fact that many of the introduced fish are specialized to feed on aquatic life (e.g., amphibian eggs and larvae) (Jennings, 1988). Hayes and Jennings (1986) believe that in the absence of adequate data, available information suggests that the introduction of alien fish species may be more important than the introduction of bullfrogs in contributing to the decline of frog species in western North America.

Unusual climatic variations. Unusually cold winters or dry summers may have contributed to local declines and extinctions of amphibian populations. For example, unusually heavy frosts in recent years may account for the widespread extent of declines in southeast Brazil (Heyer et al., 1988). The severe drought of the mid-1970's caused large areas of amphibian breeding habitat to dry up, resulting in reproductive failure of the northern leopard frog in Colorado (Corn and Fogleman, 1984; Hayes and Jennings, 1986). Whether these events represent natural extremes in weather patterns or have resulted from the effects of human activities on regional and global climate is unknown.

Wyman (1991) recently suggested that global climate change may be contributing to the general amphibian decline. He surveyed 25 herpetologists active in the northeastern United States for their opinions on the causes of declining species in this region. Although the survey results represent largely subjective impressions, the herpetologists cited "problems at the edge of the range" as a major cause for the declines of 12 of the 19 species identified as declining over part or all of their ranges. Wyman pointed out that the first areas in which one would expect to see population declines as a result of global climate changes would be at the edge of species' ranges. These also are the areas where natural, cyclic fluctuations would be most pronounced.

Exploitation by humans. Frogs have periodically been exploited for food by several cultures in many areas. Alain Dubois of the Natural Museum of History in Paris points out that the French consumption of frogs legs has been linked to a marked decline of native frogs in Europe, India, and Bangladesh (as cited by Blaustein and Wake, 1990). The red-legged frog was heavily exploited in the western United States in the late 1800's, which contributed to its initial decline, although exploitation does not explain the continued loss (Jennings, 1988). This hypothesis does not apply to most of the declining populations of amphibians, however.

Widespread use of pesticides and other toxic substances. Species with "amphibious" life histories, i.e., whose life cycle require both terrestrial and aquatic habitats, can be particularly vulnerable to environmental pollutants (NRC, 1990; Norse, 1990). The eggs of many amphibians are laid in water and have little physical protection from water-borne contaminants. Many species' larval stages are also aquatic. Adult amphibians are carnivorous and therefore vulnerable to toxic substances that tend to biomagnify in food chains (e.g., mercury, PCBs).[11] In addition, amphibians' skin is permeable to airborne gases as well as many soil- and water-borne contaminants.

Amphibians are sensitive to the usual variety of toxic substances (Power et al., 1989). To date, however, the evidence that pesticides and toxic substances are contributing to a large-scale decline in amphibian populations is limited. Baxter and Meyer (1982) have stated that aerial application of pesticides caused some of the declines of leopard frog in Wyoming (Corn and Fogleman, 1984). Although it is known that larval stages of some species are particularly sensitive to toxic substances (Hayes and Jennings, 1986), definitive studies linking environmental contamination with reduced populations of larval stages are lacking at this time.

Pathogens. Although epizootics (e.g., diseases) are of concern in declining populations of several groups of organisms, (e.g., cholera and botulism in waterfowl, distemper in seals), wild frog population responses to pathogens and parasites are essentially unstudied (Hayes and Jennings, 1986). Lucke tumor herpesvirus (LTHV), which causes renal carcinomas (malignant) in frogs, was prevalent a decade ago when leopard frog population densities were high. Leopard frog populations subsequently declined, but tumor incidence is increasing again after an absence for 10 years despite low population densities (Hunter et al., 1989). Recent data from Pennsylvania suggests a synergistic effect of low pH stress and bacterial infections in declining frog species in this state (Simon, as described by Wyman, pers. comm.). Possible contributions of other pathogens to amphibian population declines have not been studied, nor has the potential for interaction of pathogens and other stresses been evaluated.

Increased ultraviolet radiation. The exposed skin of amphibians could render them more sensitive to increased ultraviolet radiation than other vertebrate groups. However, higher UV levels have not been measured in association with declining amphibian populations as yet (Barinaga, 1990).

Synergistic effects among factors. Synergistic effects may result from more than one of these stresses. As soils dry, they become more acidic, increasing the water stress on

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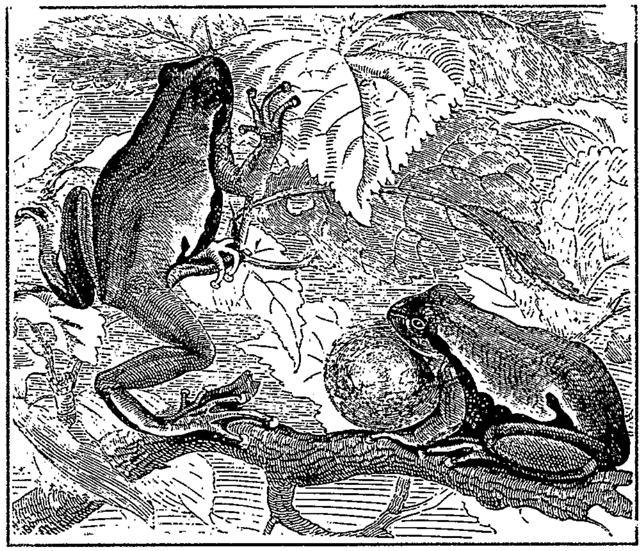
[11]See footnote number 5, page 49.

amphibians (see *Acid deposition* above) (Wyman, 1991). Amphibians also are more sensitive to heat stress in the absence of water. Drought, heat, and acidity represent potentially significant stressors when occurring together (Wyman, 1991).



Natural, cyclic fluctuations. Animal populations fluctuate in size due to natural changes in food supply, predation, competition, pathogens, and abiotic conditions such as weather. Some fluctuations after unusual events such as prolonged drought or early frosts may seem catastrophic. For example, census data from 1979 to 1990 for three salamander species and one frog species at a breeding pond in South Carolina showed extreme fluctuations in population size from year to year, but no overall trend over the 11 years (except for one population which increased slightly; Pechmann et al., 1991). Thus, at any given time, one would expect a number of populations worldwide to be in decline, others to be stationary, and still others to be increasing. Anthropogenic stresses may exacerbate naturally-initiated declines in populations, but distinguishing which fluctuations may be outside the range of natural variation is difficult because of the large number of factors and interactions involved.

2.5.3. Continued Monitoring

The International Union for the Conservation of Nature (IUCN) recently set up a "Declining Amphibian Populations Task Force" at the Environmental Research Laboratory in Corvallis, Oregon. The Task Force is trying to set up a worldwide communication network and to establish a database for all scientists involved in amphibian research (Vial, 1992). The Task Force also is to organize a global monitoring program for (1) determining the status of amphibian populations, (2) assessing the implications of any declines, (3) studying potential causative factors, and (4) making appropriate policy recommendations based on these findings.

Several meetings focused on the declining amphibian population issue have been held in the past year. In August, 1991, a symposium was held at the annual meeting of the Society for the Study of Amphibians and Reptiles to discuss "Amphibian Declines and Habitat Acidification." Resulting papers will be published in the Journal of Herpetology. A workshop on "Declines in Canadian amphibian populations; designing a national monitoring strategy" was held in Canada in October 1991. Regional Working Groups of the Task Force also have been holding meetings.

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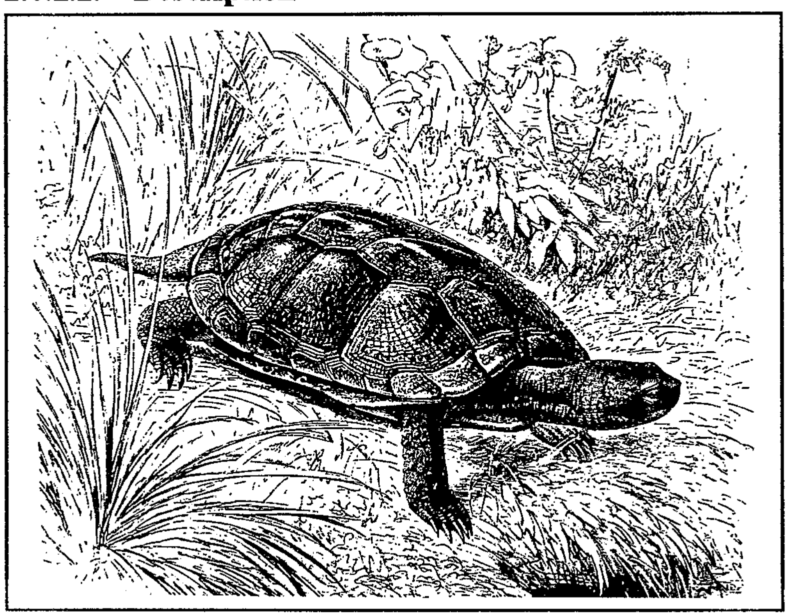
2.6. Turtles Worldwide

Summary. Approximately one third of the world's species of land turtles (terrestrial and freshwater semi-aquatic) are now considered to require conservation attention. All of the world's sea turtle species are considered threatened or endangered. For the land turtles, habitat destruction and fragmentation appear to be the primary causes. Juvenile and adult sea turtles suffer primarily from capture by shrimp trawlers, but other factors also cause excess mortality. Various human activities on nesting beaches have reduced the survivorship of sea turtle eggs and hatchlings.

Background. The turtles represent one of the most ancient groups of animals, having survived from before the age of the dinosaurs, or over 150 to 200 million years (Behler and King, 1979). Of the land turtles, snapping turtles, musk and mud turtles, and pond turtles are primarily aquatic, inhabiting a variety of freshwater habitats. Box turtles and tortoises represent the primarily terrestrial land turtles. Sea turtles feed at sea, but lay their eggs onshore. Because the principal causes of declining populations differ for land and sea turtles, we discuss them separately in Sections 2.6.1 and 2.6.2, respectively.

2.6.1. Land Turtles

2.6.1.1. Description



Background. Both freshwater semi-aquatic and terrestrial turtles and tortoises lay their eggs in "nests" dug on dry ground. Suitable nesting sites (i.e., appropriate soil texture and conditions) may be some distance from the turtles' normal foraging habitat, and females may need to travel some distance to lay their eggs. Both aquatic and terrestrial turtles are relatively slow moving on land, making them vulnerable to mortality on roadways during dispersal movements and during travel to locate nest sites. Turtles also tend to be long-lived with a low yearly reproduction rate, characteristics that make recovery from population declines difficult.

Exploitation by humans. Turtles and tortoises are used for food by numerous cultures in developing countries (Bury, 1982; Morafka, 1982; Stevens, 1990*P), and several species are heavily utilized in the pet trade (Bury, 1982) or simply collected for pets (Luckenbach, 1982). Data to quantify these losses are not readily available, however.

2.6.2. Sea Turtles

2.6.2.1. Description

Background. Sea turtles breath air, and therefore tend to swim near the surface of the ocean. They lay their eggs on dry land to incubate, generally on a small number of suitable "laying beaches." Once the eggs hatch, the juvenile turtles must be able to reach the sea using light cues for orientation.

Trends. All of the eight sea turtle taxa of the world now require conservation attention and all of the five sea turtle species that breed in US coastal areas are Federally designated as endangered or threatened (NAS, 1990). Exhibit 2.6.2 lists population trends for several species of sea turtle for which adequate long-term data are available. For example, on the Mexican coast of the Gulf of Mexico where 40,000 Kemp's ridley turtles were observed nesting on a single day in 1947, the total population of nesting females now may be no more than 350 (NAS as reported by Abramson, 1990*P).

2.6.2.2. Hypotheses

Recently, the National Academy of Science's (NAS) Committee on Sea Turtle Conservation reviewed factors that threaten the five sea turtle species found in coastal United States' waters. These and other factors are likely to threaten sea turtles worldwide. We describe factors that cause increased mortality of eggs and hatchlings on land and factors that increase juvenile and adult mortality at sea separately in the next two subsections.

<u>Mortality of Eggs and Hatchlings</u>

Numerous human activities can cause increased levels of mortality in sea turtle eggs and hatchlings on land: beach erosion and accretion, beach armoring, artificial lighting, beach nourishment and cleaning, increased human presence, recreational beach equipment and vehicles, introduced non-native dune and beach vegetation, and direct hunting. We discuss each of these hypotheses briefly below.

Exhibit 2.6.2. Sea turtle population trends.

Species	Location	From	To	Population Change
Kemp's ridley	Mexico	1947	1988	-99%
Loggerhead	Georgia, US	1963	1989	-70%
	South Carolina, US	1973	1989	-71%
	Florida, US	1981	1989	NSC
Green turtle	Florida, US	1971	1989	+100%
	Surinam	1968	1981	NSC
	Costa Rica	1971	1987	NSC
Hawksbill	Surinam	insufficient time series		
Leatherback	Puerto Rico	insufficient time series		
	Virgin Islands	insufficient time series		

All values approximate; estimated from figures. NSC = no significant change.

Source: NAS, 1990.

Beach erosion and accretion. Coastal development has increased erosion rates and interrupted natural shoreline migration, which results in loss of suitable nesting habitat (NAS, 1990). In Florida, where 90 percent of the loggerheads in the Western Hemisphere nest, eroding beaches may present one of the greatest long-term threats to the species (R.H. Spadoni, as reported by Dean, 1992*P).

Beach armoring. Shoreline development such as sea walls, rocks revetments, riprap, sandbags, and jetties, causes loss of beach area, increased amounts of debris onbeaches, and beach erosion. These factors in turn result in loss of sea turtle nesting habitat, restricted female access to suitable nesting sites, and can cause turtles to abandon nests or construct egg cavities of improper size and shape (NAS, 1990).

Artificial lighting. Sea turtle hatchlings use light as a cue to find the sea following hatching (Daniel and Smith, 1947; Carr and Ogren, 1960 as cited by NAS, 1990). Artificial light from buildings, streetlights, dune crossovers, or vehicles can disorient hatchlings potentially resulting in death (McFarlane, 1963; Philibosian, 1976; Ehrhart, 1983; as cited in NAS, 1990; Witherington and Bjorndal, 1991). Also, adult females have been found to avoid nesting areas because of light (NAS, 1990).

Beach nourishment and cleaning. The deposition of sand (beach nourishment) to replace sand lost by erosion can result in severe compaction, inhibiting or preventing nest digging (Raymond, 1984). The composition of the deposited sand may differ from native sand, reducing hatching success (NAS, 1990). Both of these factors have been found to inhibit successful reproduction of sea turtles (NAS, 1990). Cleaning of beaches can disturb nests and hinder or trap emergent hatchlings.

Increased human presence. Human activities on the beach, particularly in the evening and at night, can disturb female sea turtles as they try to dig their nests and lay eggs (Hosier et al., 1981; NAS, 1990).

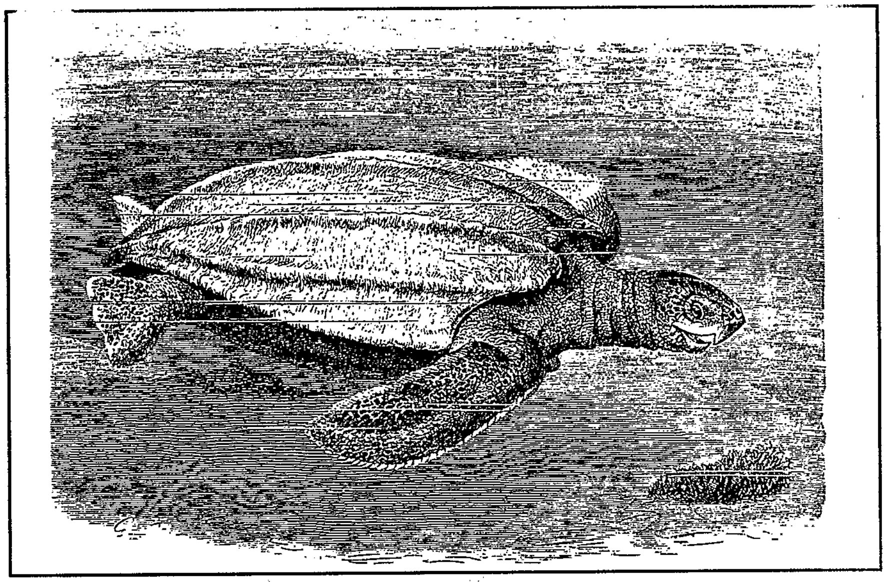
Recreational beach equipment and vehicles. Vehicles on the beach deter nesting attempts, destroy clutches, and interfere with the seaward journey of hatchlings (NAS, 1990).

Non-native dune and beach vegetation. In the United States, the introduced Australian pine has increased beach shading, which lowers sand temperatures and may alter the normal sex ratio of the hatchlings, which is temperature-dependent (NAS, 1990). Other species of introduced vegetation have disrupted sea turtle nesting success because of increased root mats and erosion (NAS, 1990).

Direct taking of eggs. Direct taking of eggs is seldom reported in the United States. In some other countries, however, eggs are taken in large numbers. For example, in Mexico in 1989 alone, an estimated 10 million sea turtle eggs were gathered illegally by poachers on government protected beaches and sold for supposed aphrodisiac properties (H. Aridjis, as reported by Branigin, 1990*P).

Mortality of Juveniles and Adults

The most important source of mortality for juvenile and adult sea turtles of the coast of the United States is shrimp trawling. Other important factors include other fisheries and entanglement in lost fishing gear and marine debris, dredging, collisions with boats, petroleum-platform removal, power plant intake pipes, direct take, pollution, ingestion of plastics, and disease (NAS, 1990). We discuss each of these factors briefly below.



Shrimp fishing. In the absence of "turtle-excluding" devises, shrimp fisheries take a large number of sea turtles incidental to their capture of shrimp, and this may represent the largest single source of adult sea turtle mortality (NAS, 1990). Although the National Marine Fishery Service originally estimated that 11,000 turtles are killed each year by shrimpers, a special panel of the National Academy of Sciences (NAS) estimated that shrimp boats working the United States' southern Atlantic coast and Gulf of Mexico may have been killing up to four times that level (NAS, 1990; Abramson, 1990*P). Murphy and Hopkins-Murphy (1989) found that 83 percent of the 78 studies they reviewed suggested that shrimp trawling is a major source of sea turtle mortality. Several investigators have documented increased incidence of dead turtles on beaches with the onset and peak of shrimp trawling activities (Hellestad, et al. 1982; other studies summarized by Caillouet et al., 1991). Loggerhead populations are declining in areas where there is active shrimp fishing (e.g., Georgia and South Carolina; Murphy and Hopkins-Murphy, 1989; NAS, 1990), but may be increasing where shrimp fishing is absent or low (e.g., southern Florida) (NAS, 1990). NAS (1990) estimated that 70 to 90 percent of the turtles washed up on shore during periods when fisheries are open in South Carolina and Texas are killed in shrimp trawls.

The NAS panel concluded that use of nets with escape doors could reduce sea turtle drownings by 97 percent (Abramson, 1990*P). Regulations requiring the use of turtle-safe nets were first issued in 1987, but the regulations were contested and not strictly enforced. The NAS findings will support Federal efforts to enforce the regulations.

Other fisheries and discarded or lost gear. Data on the association of turtle mortality with other fisheries and entanglement in gear are sporadic and thus difficult to assess. NAS (1990) cited numerous reports from different regions that sea turtles have become entangled in fin fish trawls, seines, pompanon gill nets, weirs, traps, long lines, lost fishing gear, and other debris.

Dredging. In the United States, there were at least 149 confirmed incidents in which sea turtles were entrained by hopper dredges working in two shipping channels from 1980 to 1990 (NAS, 1990). The majority of the turtles found were dead or dying.

Collisions with boats. In the United States, many sea turtle deaths (50 to 500 loggerhead and 5 to 50 Kemp's ridley turtles) and strandings have been associated with collisions with boats. Areas with high concentrations of recreational boat traffic are of most concern (NAS, 1990).

Petroleum-platform removal. The use of explosives when removing petroleum platforms has likely caused the mortality of numerous sea turtles (50 to 500 loggerhead and 5 to 50 Kemp's ridley turtles) and other large marine organisms (NAS, 1990).

Power plant intake pipes. Numerous sea turtles (about 50 per year) have been found dead in the intake pipes for cooling water at coastal power plants of the United States. One power plant where the incidence has been high (averaging 11 turtle deaths per year) is located where the continental shelf along their migratory route is narrow, forcing sea turtles to pass close to the shore (NAS, 1990).

Direct take. The extent of this problem is unknown. Some illegal take of turtles occurs in the United States, but the numbers are probably negligible (NAS, 1990). In Mexico, on the other hand, Aridjis (president of a Mexican environmental organization) has stated that 75,000 endangered sea turtles were killed by fisherman in 1989 alone, most of which are sold to Japan (Branigin, 1990*P). Recently, with pressure from the United States, Japan has agreed to end importation of hawksbill turtles (Abramson, 1991*P).

Pollution. Few studies have assessed the potential or actual impacts of pollution on sea turtles; thus, the effects of pollution cannot be estimated. Tissues and eggs have been found to be contaminated with organochlorines, heavy metals, hydrocarbons, and radionuclides, however (NAS, 1990). An increased incidence of disease, at least in one location, is suspected of being associated with marine pollution (see below).

Disease. Cutaneous fibropapillomatosis, a disease of green turtles, has been reported with increasing frequency in Florida (Witherington and Ehrhart, 1989; as cited in NAS 1990) and the Hawaiian Islands (Balazs, 1986; as cited in NAS, 1990). In addition, unconfirmed cases have been reported from Puerto Rico, Curacao, Venezuela, and Belize (E.H. Williams, pers. comm.). In Florida's Indian River, up to 52 percent of the green turtles have fibropapillomas (tumors that grow on both the inside and the outside of the turtle's skin). Research on the cause of the disease is in progress (Jacobson et al., 1989), and there is concern that ocean pollution may be at least partly responsible (Reuter, 1990*P).

Ingestion of plastic. An estimated 100,000 marine animals, including sea turtles, die each year from eating or becoming entangled in plastic debris in the ocean. Approximately 24,000 metric tons of plastic packaging is dumped into the ocean each year. National Marine Fisheries Service (NMFS) scientists estimated that one-third to one-half of all turtles have ingested plastic products or byproducts (Cottingham, 1988; as cited in NAS, 1990). Carr (1987) discussed the implications of a recent discovery that juveniles of many species of sea turtles may spend three to five years feeding and swimming near the surface of the open-ocean (i.e., pelagic stage). During this time, they depend for food on oceanic convergences (e.g., fronts, rips, and driftlines). Unfortunately, these same convergences concentrate buoyant ocean debris (e.g., plastic bags, styrofoam beads, and tar balls) which the turtles can mistake for food. The leatherback and the olive ridley appear to be mainly surface foragers after reaching maturity, and so may remain vulnerable to surface ocean debris as adults. Other species for which the surface feeding stage ends just prior to sexual maturity, no longer face this threat (i.e., the animals become benthic foragers in coastal areas). Juvenile loggerheads containing tar pellets and plastic beads have been found in great numbers washed up on the Florida east coast. Some researchers believe that the marked tendency of leatherbacks to ingest sheets and bags of plastic film results from the plastic sheets' resemblance to jellyfish (Carr, 1987).

2.6.3. Continued Monitoring

Numerous organizations monitor specific populations of turtles. These include the American Museum of Natural History, World Wildlife Fund, Center for Marine Conservation, the World Conservation Union, the Durrell Institute of Conservation and Ecology in Canterbury, England, and the newly established Marine Ecological Disturbance Information Center (MEDIC) in Puerto Rico (see Section 2.7).

United States government agencies that monitor several species of turtle include the Department of the Interior, Fish and Wildlife Service and the National Marine Fisheries Service of the National Oceanic and Atmospheric Administration.

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2.7. Marine Mammals

Recent mass mortalities of bottlenose dolphins in the United States (1987 and 1990) and striped dolphins in the Mediterranean (1991) have triggered public and scientific concern that pollution, in addition to incidental catches of dolphins by the tuna fishing industry, may threaten dolphin populations. Pathological examination of dolphins stranded in the United States in 1987 suggest a chronic immune system suppression. This could have been a consequence of sublethal exposure to a red tide and/or a consequence of unusually high concentrations of PCBs in the dolphin tissues.

In addition, recent "epidemics" of a distemper-like virus have caused mass mortalities among several populations of seals. Some suspect that coastal pollution has increased the seals' susceptibility to the virus, but the cause of the outbreaks is as yet undetermined. Unusually warm temperatures also may contribute to outbreaks of the virus.

In addition to mass mortality events, many pinniped (i.e., seals, sea lions, and walruses) populations have been declining recently. Bioaccumulation of PCBs or other toxic substances are known to reduce reproductive success in seals, and may be contributing to these population declines in some areas.

Because of their position high in the marine food chain and because they use body fat for insulation, both groups of marine mammals are particularly susceptible to chemicals that bioaccumulate in fatty tissues (e.g., PCBs). As a result, these groups might serve as sensitive monitors of marine pollution. The causes of mass mortalities and population declines in these groups therefore appears to warrant additional investigation. We review the dolphin and pinniped trends separately in Sections 2.7.1 and 2.7.2, respectively.

2.7.1. Dolphins

2.7.1.1. Description

Background. Dolphins are piscivorous (i.e., fish eating), and their position high in the food chain makes them especially susceptible to bioaccumulating higher levels of certain chemicals (e.g., PCBs, mercury) than other marine species, particularly in their fat. At times of stress, dolphins mobilize their fat reserves, which might suddenly release accumulated contaminants to their blood.

Trends. Bottlenose dolphin die-offs in the North Atlantic occurred in 1987 and 1990. During an 11-month period beginning in the summer of 1987, an estimated 3,000 bottlenose dolphins (approximately half of the Atlantic coast dolphin population) died along the Atlantic coast of the United States (Scott et al., 1988), of which over 740 were found stranded (Geraci, 1989; McKay, 1989). The stranded dolphins exhibited skin lesions and internal lesions characterized by fibrosis (indicating a chronic infection) in the lung, liver, pancreas, and heart (Geraci, 1989). Systemic bacterial infection appeared to be the ultimate cause of death (Geraci, 1989). Since January of 1990, more than 300 dead or dying bottlenose dolphins, more than twice the usually expected number for the time period, have washed ashore along the Gulf states, (Lancaster, 1990*P). The National Marine Fisheries Service is investigating the cause of the 1990 strandings.

In 1990, at least 1,000 striped dolphins washed up on the Mediterranean coastlines of Spain, Italy, and France (Jones, 1990; Simons, 1992*P), and in late 1991, hundreds of dead and dying striped dolphins were found beached on the coast of Italy, Sicily, and a Greek island (Jones, 1991b; Simons, 1992*P).

2.7.1.2. Hypotheses

Hypotheses to account for the recent dolphin die-offs include poisoning by a naturally occurring red tide, infection following immunosuppression resulting from the accumulation of toxic substances, and natural occurrences. These are discussed below.

Red tide. Geraci (1989) concluded that the most likely cause of the 1987 bottlenose die-off was poisoning by a "red tide" algal bloom. Red tide algae occur naturally and produce brevetoxin, a potent toxin of the nervous system. Eight of 17 (i.e., 47 percent) dolphins analyzed in the 1987 killing contained this neurotoxin; the other 9 did not contain detectable levels. Geraci (1989) hypothesized that the toxin made the dolphins susceptible to the numerous chronic disorders that finally killed them. The results of this report remain controversial, however (Lancaster, 1990*P; McKay, 1989). For example, brevetoxin is not known to weaken the immune system of organisms, and the kind of red tide that produces brevetoxin is common in the Gulf of Mexico, where no die-offs had been reported as of 1989 (McKay, 1989). In the Mediterranean striped dolphin deaths, red tides were ruled out because none of the dolphins examined showed signs of algal toxins (Jones, 1990).

Pollution-impaired immune system. Toxic chemicals might have weakened the immune system of the dolphins, thus increasing their susceptibility to disease (McKay 1989). Geraci (1989) reported high levels of PCBs, DDT, and chlordane in the bottlenose dolphins stranded in 1987. Levels of PCBs were, on average, an order of magnitude higher than in other cetaceans, and several dolphins had the highest PCB tissue levels on record (compared with the reports of Gaskin et al., 1971, 1983; Aguilar, 1983; Tanabe et al., 1984; Martineau et al., 1987; Muir et al. 1988; as cited in Geraci, 1989). Further analysis of PCB levels in the bottlenose dolphins collected in the 1987/88 mass mortality event and in two other species that were not affected (i.e., common and white-sided dolphins caught incidentally in fishing nets) indicated higher levels in the bottlenose dolphins (Kuehl et al., 1991). Furthermore, the bottlenose dolphins were found to be contaminated with other yet unidentified polychlorinated and polybrominated chemicals (Kuehl et al., 1991).

PCBs are known immunosuppressants (Safe, 1984; Smailowicz et al., 1989; Thomas and Hinsdill, 1978; Tryphonas et al., 1989). Greenpeace noted that PCBs are known to cause lesions such as those found on many dolphins in 1987 (McKay, 1989). Geraci (1989) did not believe that contaminants could be the major cause of the event, however, because there are vast differences in response to these compounds within and between species, and the timing of the outbreak did not coincide with any major release of contaminants. McKay (1989) observed that contaminants may have killed some animals directly or weakened them, making them susceptible to disease, infection, and other causes of mortality. The rather sudden nature of the die-off may have resulted from a "triggering" stress or lack of food that caused the dolphins to rely more heavily than usual upon their fat reserves for energy.

In the case of the European striped dolphin deaths, researchers at the University of Barcelona found PCBs in some animals at levels up to 10 to 50 times levels that are considered dangerous for humans (Simons, 1992). It is not known whether this could have increased their susceptibility to the virus that appears to have caused their deaths (Jones, 1990).

Disease. Many of the dolphins analyzed in the 1987 die-off had bacterial and viral infections which may have killed the animals. However, the "pattern of illness that could be associated with a known pathogen" does not support the hypothesis that disease was the ultimate cause of the massive mortality of dolphins (Geraci, 1989).

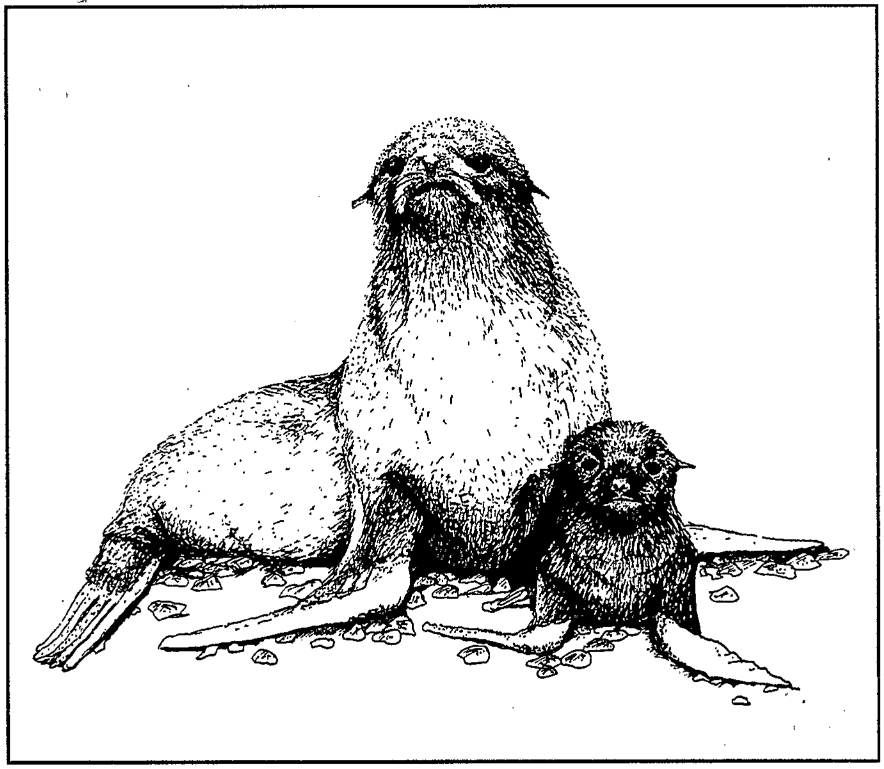
The majority of the Mediterranean striped dolphin deaths, however, were attributed to a morbillivirus (Jones, 1990). A different strain of morbillivirus was responsible for the western Mediterranean die-off in 1990 than for the eastern Mediterranean die-off in late 1991. There are no records in the literature over the past hundred years of a cluster of virulent epidemics in dolphins like the ones observed in the Mediterranean (S. Kennedy, as reported by Simons, 1992*P). The possibility that PCB's or other toxic substances may have acted as an immunosuppressant is under consideration (Jones, 1990; Simons, 1992*P).

2.7.2. Pinnipeds (Seals, Sea Lions, and Walruses)

2.7.2.1 Description

Background. Pinnipeds live mainly in the far north and extreme south, many species congregating in dense aggregations on "haul-outs" along coastal areas during the mating and pupping season. Like dolphins, the position of seals, sea lions, and walruses near the top of the marine food chain makes them especially susceptible to bioaccumulating higher levels of certain chemicals (e.g., PCBs, mercury), particularly in their blubber (Addison, 1989). These contaminants can be released relatively quickly when the animal mobilizes its reserves of fat at times of stress, such as during lactation or when it molts (Harwood and Reijnders, 1988).

Trends. In recent decades, populations of several species of pinnipeds in the United States have exhibited population declines despite substantial relief from hunting pressures afforded by the Marine Mammal Protection Act of 1972 (MMPA). In addition, mass mortalities and population declines of seals around the northern hemisphere have captivated public attention (Dickson, 1988; Dietz et al., 1989; Harwood, 1989, 1990a,b; Stirrup, 1990; Stolzenburg, 1990).



Examples of mass mortalities and continuing population declines are presented in Exhibits 2.7.1 and 2.7.2, respectively.

2.7.2.1. Hypotheses

In the early part of this century, hunting was responsible for decimating many pinniped populations in the Northern hemisphere to a few percent of their original nineteenth century numbers (e.g., Durant and Harwood, 1986; Helander and Sjoasen, 1985).[12] Since passage of the MMPA in the United States, other threats have emerged, including coastal development, habitat destruction, marine pollution, interactions with fisheries, and entanglement in marine debris and fishing nets (WRI, 1988). The mass mortalities of seals in several areas of the North Atlantic have been diagnosed as due to phocid distempervirus (PDV) and secondary pulmonary and other infections (Osterhaus and Vedder, 1989). The cause(s) of the recent outbreaks of PDV are not clear, and some investigators have suggested that pollution-impaired immune defenses may be responsible. Warmer than usual ocean temperatures also may play a role. We discuss the hypotheses to explain mass mortalities and continued population declines separately below.

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[12] Illustration of northern fur seal in the box reproduced with permission of the artist, Kimberly Hall.

Exhibit 2.7.1. Mass mortalities of pinnipeds.

- 1955: In the Antarctic, over 3,000 crabeater seals (*Lobodon carcinophagus*) died; no live pups were found, and mortality was estimated at 85% (da Dilva et al., 1957; Laws and Taylor, 1957).
- 1978: 1,200 walruses (*Odobenus rosmarus*) out of a herd of around 6,000 died in the Bering Strait, apparently from physical trauma (e.g., trampling by other walruses) (Fay and Kelly, 1980).
- 1979-1980: At least 500 harbor seals (*Phoca vitulina*) out of a population of 10 to 14 thousand died along the coast of New England from an influenza A type virus (Geraci et al., 1982).
- 1987: In the fall, several thousand Baikal seals (*Phoca sibirica*) out of a population of up to 100,000 died in the Soviet Union (Grachev et al., 1989).
- 1988: At least 17,000 to 18,000 European harbor seals died in several areas, e.g., Kattegat, Wadden Sea, Skagerrak, Limfjorden, western Baltic, Norway, and the British Isles (Dietz et al., 1989; Osterhaus et al., 1990) The die-off was preceded by a few months by increased rates of abortion (Dietz et al., 1989). In some areas, 90% of the local population of seals died in 40 to 60 days. The primary cause of death was acute and severe bacterial pneumonia.

Exhibit 2.7.2. Declining populations of pinnipeds.

- The population of Stellar's sea lion (*Eumetopias jubatus*) in the eastern Aleutian Islands and the Gulf of Alaska decreased 90% from 50,000 at the beginning of the 1960's to 5,000 by the late 1960's (Stirrup, 1990). The population continues to decrease at a rate of 5 to 7% per year (Braham et al., 1980; Merrick et al., 1987; Calkins and Goodwin, 1988; as cited in Pitcher, 1990).

- Gulf of Alaska harbor seals (*Phoca vitulina richardsi*) at Tugidak Island have declined by about 85% between 1976 and 1988 (Pitcher, 1990).

- The decline of northern fur seals (*Callorhinus ursinus*) in the Pribilof Islands at an annual rate of 7.5% in the late 1970's may have stabilized in the 1980s (Fowler, 1982, 1985; York and Kozloff, 1987; as cited in Pitcher 1990).

- Southern Dutch harbor seals (*Phoca vitulina*) in the Delta area of the Wadden Sea declined from 1,000 to 10 or 20 seals between 1955 and 1969, and are now extinct (Reijinders, 1985).

- Northern Baltic grey seals (*Halichoerus grypus*) and ringed seals (*Pusa hispida*) continued to decline in the 1970's despite reduced hunting pressure (Hook and Johnels, 1972; as cited in Addison, 1989).

Mass Mortalities

PDV (phocid distempervirus). Little doubt remains that the proximate cause of the recent mass mortalities of harbor seals (Exhibit 2.7.1) was an infectious disease outbreak with a morbillivirus (*Phocid distempervirus-PDV*) closely related to canine distemper virus (CDV) (Hofmeister et al., 1988; Osterhaus and Vedder, 1989; Osterhaus, 1989; Osterhaus et al., 1988, 1990; Kennedy et al., 1988; Mahy et al., 1988; Cosby et al., 1988; as cited in Law et al., 1989).[13] CDV is known to depress the immune system in dogs (Appel, 1987; as cited in Osterhaus and Vedder, 1989), and PDV is likely to have immunosuppressive effects in seals (Osterhaus and Vedder, 1989). The majority of deaths occurred as a result of secondary bacterial infections rather than due to PDV directly (Harwood, 1990a; Osterhaus and Vedder, 1989).

It is not clear whether the recent outbreaks of PDV are the result of anthropogenic stresses on these populations or naturally occurring phenomena. Mass mortalities of various North Atlantic seal populations showing pneumonia-like symptoms have been reported at intervals of about 50 years throughout the 1800 and 1900's (Harwood, 1990b; Dietz et al., 1989). Nonetheless, there is evidence supporting the roles of pollution and ocean warming events as contributing factors to the outbreak, as discussed below.

Pollution-impaired immune system. Moderate to high levels of various pollutants have been detected in pinnipeds, particularly several populations of European seals, since the late 1960's. These include PCBs (Anas, 1974; Duinker et al., 1979; Law et al. 1989), DDT/DDEs (Anas, 1974; Duinker et al., 1979; Law et al., 1989), chlordane compounds (Kerkhoff et al., 1981; Kerkhoff and de Boer, 1982), and mercury (Duinker et al., 1979). PCBs are known to depress immune function in rats (Safe, 1984; Smailowicz et al., 1989; Thomas and Hinsdill, 1978; Tryphonas et al., 1989) and possibly to reduce plasma concentrations of retinol (i.e., vitamin A) and thyroid hormone, which might result in increased susceptibility to microbial infections (Brouwer et al., 1989). Some investigators report that the disease outbreaks are more severe in seal populations inhabiting more polluted coastal areas (Duinker et al., 1979; Harwood, 1990a). Other evidence suggests, however, that pollution may have played only a small role. For example, the majority of the seals found dead in England contained concentrations of PCB, DDT, HCB, and HCH at the lower end to middle of the spectrum of contamination levels observed in the North and Baltic seas (Law et al., 1989). Moreover, Harwood and Reijnders (1988) observed that the greatest number of seal deaths had not occurred in the most polluted areas of the Wadden and Baltic

[13]All of Koch's postulates for cause-and-effect have been satisfied, including virus isolation and characterization and protection of seronegative seals against fatal-challenge infection by vaccination with inactivated CDV vaccines (Osterhaus and Vedder, 1989; Wickelgren, 1989).

Seas. A quantitative study of the relationship between measured environmental contaminant levels and seal mortality incidence has not yet been conducted.

Global warming or short-term temperature fluctuations. Lavigne and Schmitz (1990) have examined records of regional air temperatures and found that preceding each of five major seal die-offs, mean air temperatures were 1 °C to 3 °C higher than the preceding 10-year average.

In summary, the cause of the outbreaks of PDV in seal populations in recent years is unknown, and it is not clear whether the outbreaks reflect naturally occurring phenomena or result from one or more human-caused stresses.

Declining Populations

Pollution-impaired reproduction. In general, seals in the waters of Japan, the United States, other north Pacific countries, and in Europe have been found to be contaminated with organochlorines and metals to varying degrees, although most at apparently nontoxic levels (Himeno et al., 1989; Duinker et al., 1979). High tissue concentrations (i.e., parts per million and above) of several chemical compounds, particularly PCBs and DDT/DDEs, have been measured in seal blubber since the 1960's (Anas, 1974; Duinker et al., 1979; Law et al., 1989; Reijnders, 1980, 1985; Shaw, 1971). Several studies suggest that these high contaminant levels have caused the reduced reproductive success observed in several seal populations (Dietz et al., 1989; Hook and Johnels, 1972; Jensen et al., 1969; Koeman et al., 1972 as cited by Reijnders, 1985; Reijnders 1976, 1978, 1980, 1981b, 1986; Law et al., 1989). Analyses by Helle et al. (1976a,b) and Addison (1989) have suggested that in ringed seals, PCB blubber lipid concentrations over about 70 ppm (and/or higher DDT/DDE concentrations) are associated with reproductive defects caused by uterine occlusions. Whether the high organochlorine residues cause these effects, or whether reduced reproductive success isa parallel result of some other cause is not yet clear (Addison, 1989).

Additional evidence that contaminant-induced reproductive effects can cause population declines comes from the Dutch Wadden Sea, where the Rhine River has delivered high loads of PCBs and other pollutants over the past several decades. The local population of common seals crashed from 3,000 in 1950 to fewer than 500 in 1975 (Duinker et al., 1979). Reduced reproductive success appears to be the cause, and concentrations of PCB, DDT, copper, lead, zinc, and cadmium in tissue samples from seals found dead in the Dutch Wadden were higher than in those from a stable population in the German Wadden Sea (Duinker et al., 1979). Reijnders (1986) experimentally demonstrated that a diet of fish from the Dutch Wadden Sea could reduce reproductive success in seals. Seals fed Dutch Wadden Sea fish, containing doses of 1.5 mg PCB/day and 0.22 mg DDE/day for two years, experienced significantly reduced reproductive success compared with a "control group" fed northeastern Atlantic fish and receiving doses of 0.4 mg PCB/day and 0.13 mg DDE/day. The effect appears to occur in the post-ovulation phase, with the period around implantation being most sensitive. The effect is reversible; after changing the diet of the experimental group to fish from the northeast Atlantic, the reproductive success of the experimental group returned to control levels (Reijnders, 1986).

Some infectious agents (e.g., *Leptospira sp.*) have been found to interfere with reproduction, and this effect may be magnified if the animals are already immune-deficient as a result of poisoning with organochlorine pollutants (Risebrough et al., 1980).

Marine debris. Fowler (1982, 1987) has suggested that the recent decline in abundance of northern fur seals in the Pacific is the result of excess mortality caused by entanglement in marine debris. The abundance of debris, principally net fragments, in the areas occupied by fur seals, and the number of observed entanglements support the hypothesis. With harbor seals or Steller sea lions, however, investigators have found no evidence that entanglement is a serious problem (Stewart and Yochem, 1985; Merrick et al., 1987; as cited in Pitcher 1990).

Reduced food supply. Some investigators believe that the decline of the Stellar sea lion (Exhibit 2.7.2) may be the result of overfishing in the Shelikof Strait, which reduces the size and nutritional value of the sea lion's food supply (Stirrup, 1990). Definitive evidence is still lacking, however.

Unknown. The North Atlantic populations of harbor seals, Steller sea lions, and northern fur seals have exhibited similar patterns of decline over time, and yet a single causative agent that the three populations have in common has not yet been identified (Pitcher, 1990).

2.7.3. Continued Monitoring

Several United States organizations have been involved in investigating mass mortalities in marine mammals, including the National Marine Fisheries Service (NMFS) of the National Oceanic and Atmospheric Administration (NOAA), the Southeastern US Marine Mammal Stranding Network, Texas A&M University, and the Armed Forces Institute of Pathology. Various organizations track marine mammals in Europe and elsewhere as well.

The Marine Ecological Disturbance Information Center (MEDIC), recently established at the Department of Marine Sciences at the University of Puerto Rico (P.O. Box 908, Lajas, PR 00667), is serving as a communication hub for information concerning not only coral reef bleaching events (see Section 2.7), but other major marine disturbances and may assist tracking mass mortalities of marine mammals in the future.

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2.8. Forests Worldwide

Summary. Forests are declining and being damaged worldwide. In the tropics, clearing land for agriculture and other land uses is the most significant problem, whereas in the north temperate zone, forest dieback resulting from atmospheric pollution is an additional problem.

Clearing of tropical rainforest is proceeding at an unprecedented rate that could result in the complete loss of such forests by the year 2050. In North America, deforestation and reforestation are more balanced; however, old growth forests are at risk of being lost completely in the Pacific Northwest.

Beyond the conclusion that general atmospheric pollution is leading to forest dieback in the developed countries, researchers have not been able to identify a more specific common cause across the continents. Because multiple pollutants are generally present in the forests of concern, attribution of forest dieback to specific direct or indirect effects of acid rain, ozone, or other atmospheric sources of pollution remains somewhat controversial. Current evidence implicates a variety of natural biotic and abiotic stresses upon which are superimposed physical and chemical stresses of anthropogenic origin that may have originated long distances from the affected sites.

Tropical and temperate deforestation and temperate forest dieback are discussed in Sections 2.8.1 and 2.8.2, respectively.

2.8.1. Deforestation

2.8.1.1. Description

Background. Closed forests cover approximately 2.8 billion hectares, or 21 percent of the Earth's land surface (WRI, 1988). Of the closed forests, 43 percent are found in the tropics and 57 percent are in the temperate zone (WRI, 1988). Tropical moist forests occupy just over one billion hectares and constitute 90 percent of all tropical closed forests (the remainder being deciduous or semideciduous). Tropical rain forests account for about 66 percent of all tropical forests. Of the closed forests, 62 percent are broadleaf and 38 percent are coniferous. Developed nations contain over 90 percent of all coniferous forests and developing nations 75 percent of all broadleaf (i.e., hardwood) forests (WRI, 1988).

Trends. Tropical deforestation is proceeding at an annual rate of 40 million to 50 million acres, an area the size of the state of Washington (Shabecoff, 1990*P; AP, 1990*P). This estimate, based on 1987 remote sensing data from the National Oceanic and Atmospheric Administration and Landsat satellites, is 50 to 80 percent higher than previously thought, based on 1980 data (WRI, 1990; Houghton, 1990; Shabecoff, 1990*P). The majority of the increase in deforestation rate is occurring in tropical America rather than in tropical Africa or Asia (Houghton, 1990). Brazil is losing between 12.5 and 22.5 million acres each year; India is losing 3.7 million acres and Indonesia 2.2 million acres per year (Myers, 1989). Nine key countries alone account for more than 29 million acres of the estimated loss per year (WRI, 1990).[14] At this rate, tropical moist forests would be completely cleared in 50 to 60 years (assuming 2,700 million acres remaining; WRI, 1988).[15] North temperate forests already have been reduced dramatically by land clearing of the past. A reverse of this trend is evident in the eastern United States where many agricultural lands have been allowed to revert to forest (Exhibit 2.8.1).

Continued loss of old growth forests and north temperate rain forests is also of concern in the United States and Canada. For example, as of 1988, the Wilderness Society estimated that only 141,000 acres of continuous tracts (i.e., further than 400 feet from clearcuts or road) of old growth forest exists in the Pacific Northwest (Morrison, 1988). By 1987, the timber industry was logging an estimated 170 acres of old growth every day (WS, 1988). At this rate, all old-growth forest in the Pacific Northwest would be eliminated in 2.3 years. Recently, concern is mounting that northeastern forests in the United States may be at risk of extensive development.

The rapid loss of tropical forests and temperate latitude old growth forests are particularly alarming because of the relationship of forests to other organisms, including species also threatened by other aspects of man's activities. Slash and burn deforestation accounts for about 33 percent fo the annual emissions of carbon dioxide (a greenhouse gas that can contribute to global warming) caused by humans (WRI, 199). Forests are responsible for the habitat needed by the neotropical migrants, amphibians, fish, and other organisms. Living forests absorb carbon dioxide, thereby helping to offset the increasing levels of greenhouse gases contributing to possible global warming. Locally, forests help to moderate climate and to maintain soils and precipitation patterns; globally, forests also help to moderate weather patterns and stabilize water cycles (Sayer and Whitmore, 1991). Although many of the local and global environmental services of forests also can be provided by modified vegetation cover, loss of species' habitat and biodiversity cannot.

2.8.1.2. Hypotheses

The main cause of deforestation is direct human clearing, although the reasons differ somewhat for tropical versus temperate forests.

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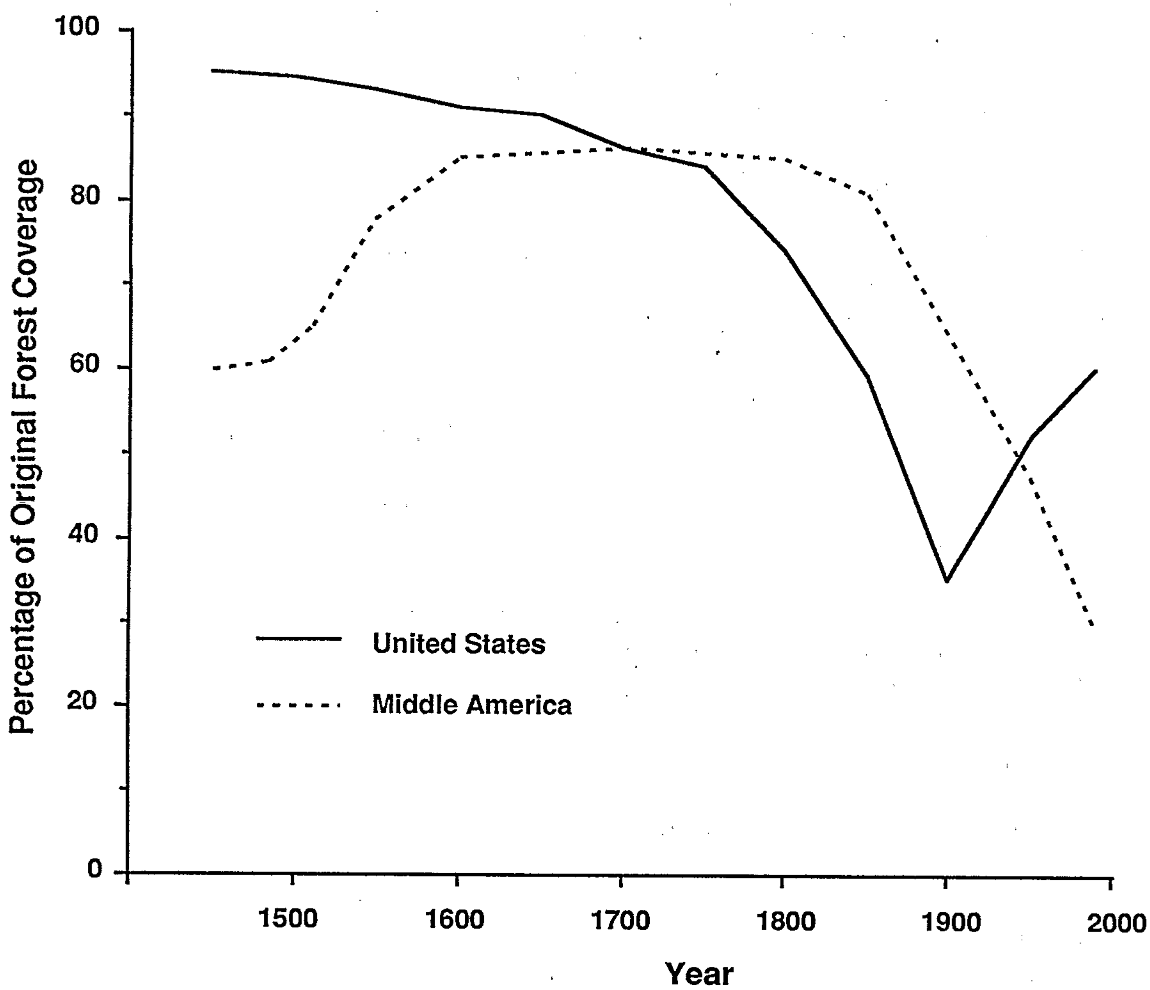
[14]There is some controversy over the exact estimates owing to varying definitions of 'deforestation' (Sayer and Whitmore, 1991).

[15] According to the New York Times, the National Space Research Institute reported that Landsat satellite images revealed that 27 percent less forest was lost in Brazil in 1990 than in 1989 (NYT, 1991).

Exhibit 2.8.1. Percent of original forest cover remaining in the United States and Middle America since 1500.



In the United States, the early deforestation of the 1700's and 1800's has been reversed in recent years, with reforestation of previously agricultural lands in the eastern states. The reverse is true in Middle America (i.e., Mexico, Central America, and the Caribbean Islands), where the recent deforestation trends continue. A picture similar to that for Middle America might result for South America.

Source: Powell and Rappole, 1986.

Tropical rainforests. Tropical closed forests are cleared primarily for three reasons: (1) for agriculture to feed growing populations, (2) for cash crops such as beef cattle to earn foreign exchange, and (3) logging of hardwoods (WRI, 1990). Agricultural conversions can reflect a government policy to expand the agricultural base (e.g., as in Indonesia) or to resettle people (e.g., as in Brazil's state of Rondonia). Agricultural conversion also occurs as a result of lack of policy or conflicting policies (WRI, 1990). Governments also have provided economic incentives for deforestation for cash crops (e.g., Brazil), despite the fact that some practices (e.g., cattle ranching) are not sustainable on the poor tropical soils. Even selective logging can result in several forest degradation. Although only some species of trees, accounting for 10 to 20 percent of the forest, are of commercial value, the techniques used to log these trees can result in destruction of another 30 to 50 percent of the forest trees (WRI, 1990). Also, the soils can be so compacted and disturbed as to impede forest regeneration (WRI, 1990). Another cause of deforestation is demand for fuelwood and fodder where the local resources cannot meet demands (WRI, 1990).

US Pacific Northwest. The coastal region of Oregon, Washington, and northern California, reaching inland to the western slopes of the Cascade Mountains, used to be covered with conifer forests characterized by very old (i.e., more than 250 years), large trees such as Douglas fir and Ponderosa pine. Nearly all of the old growth on private lands in the Pacific Northwest has already been logged (Morrison, 1988). The remaining old growth is located in 12 national forests administered by the US Forest Service (WS, 1988). In 1950, 3.5 billion board feet of timber were harvested in national forests; by 1990, the harvest had increased to 10.5 billion board feet (Lemonick, 1991*P). With respect to old growth alone, 170 acres were being cut daily by 1987 (WS, 1988).

US Northeast. There are 32 million acres of forest in New York and northern New England, where private ownership is the norm (95 percent of the forests in Maine are privately owned, 98 percent in New Hampshire, and 85 percent in Vermont). Paper companies, which own a large proportion of the forests, are finding that the value of the land for real-estate development now far exceeds the value of the land for logging (Gold, 1989*P; Daly, 1989*P). Already large tracts have been sold to developers, and without economic disincentives, this pattern is likely to continue (Daly, 1989*P).

2.8.2. Declines and Diebacks

2.8.2.1. Description

Background. Declines and "diebacks" in north temperate forests began first in Europe and then developed in the United States and Canada in the 1970's (Klein and Perkins, 1987; Siccama et al., 1982; Scott et al., 1984; McLaughlin et al., 1986). In Europe, forest decline was initially noticed only in stands of silver fir (*Abies alba*), but later spread to include other coniferous species (Norway spruce) and hardwoods such as oak, maple, and ash (Cowling, 1989; Mueller-Dombois, 1988). The most common symptoms include chlorosis and visible thinning of tree crowns, decrease in growth and root biomass, and changes in the shape and size of leaves (Schutt and Cowling, 1985; Cowling, 1989). The declines of many different forest ecosystems that have taken place recently have been called *neuartige Waldschäden* (i.e., new type of forest damage; Kandler, 1990; Tomlison et al., 1990) and *Waldsterben* (i.e., forest death) has been used to describe the consequences of the damage (Blank, 1985; Schutt and Cowling, 1985; Tomlison et al., 1990). The new forest decline is found mostly in elevated areas (Krause, 1989).

Trends. In West Germany, the percentage of Norway spruce exhibiting symptoms of decline increased from 8 to 52 percent of all West German trees between 1982 and 1987 (Raloff, 1989a). The situation for forests in eastern block countries may be substantially worse (Mazurski, 1990). As of 1987, overall 15 to 20 percent of the coniferous trees and 30 to 40 percent of the deciduous trees were affected in European countries (Krause, 1989).

In the United States, an area in which forest decline and dieback is most apparent is the Appalachian Mountains from Vermont to North Carolina, in particular in New York, New Hampshire, and Vermont (Cowling, 1989). Decreases in radial growth have been detected in low elevation red spruce in New York and several New England states (Hornbeck and Smith, 1985; as cited in Cowling, 1989) and in natural stands of loblolly, slash, and shortleaf pines in North and South Carolina, Georgia, Alabama, and Florida (Sheffield et al., 1985; as cited in Cowling 1989).

Forest decline also may be occurring in Pacific countries (Old et al., 1981; Warwick and Watt, 1983; Mueller-Dombois and McQueen, 1983; summarized by Mueller Dombois, 1988).

2.8.2.2. Hypotheses

Although there is a possibility that forest diebacks are part of a natural cycle, "the current problem is unique in that serious dieback and loss of tree vigor have occurred, with both conifers and hardwoods in different types of ecosystems, in several industrial countries in less than one decade" (Tomlinson, et al., 1990). The majority of the scientific community believes that recent forest diebacks in industrialized countries are in response to air pollution and a combination of direct and indirect effects of that pollution

(Exhibit 2.8.2) (Bucher and Bucher-Wallin, 1989; Grossman, 1988; Heliotis et al., 1988; Hinrichsen, 1986; Kander, 1990; Schulze, 1989; Schutt and Cowling, 1985; Tomlison et al., 1990; Tovar, 1989). Three direct stresses are associated with air pollution, i.e., elevated levels of ambient ozone and sulfur dioxide, acid deposition (from the combustion of fossil fuels), and nitrogen deposition (from agricultural sources). Indirect stresses include the effect of acid deposition on soil chemistry (e.g., leaching of nutrients and elevated levels of aluminum ions). Both direct and indirect stresses may have effects on tree root and foliage vigor and function. Weakened trees can become more susceptible to other natural stresses such as drought, insect pests, and temperature extremes. Global warming and biological nutrient mining also may contribute to forest dieback. We discuss each of these briefly below.

Air Pollution

Gaseous pollutant injury -- ozone and sulfur dioxide. Unlike other gaseous pollutants, concentrations of ozone in areas remote from urban and industrial sources tend to be higher at greater altitudes, a pattern which corresponds with the observed greater forest damage at higher altitudes (Frank, 1991; Krause, 1989). The adverse effects of ozone in coniferous forests have been well documented (US EPA, 1986; US EPA, 1987; Norse, 1990). Effects of ozone on herbaceous and woody vegetation include foliar injury, reduction in growth and yield, and increased susceptibility to pests and pathogens (US EPA, 1987). Ozone has been known to damage vegetation in concentrations as low as 0.1 to 0.2 ppm for periods of six hours over several days (Hinrichsen, 1986). Two large-scale studies in the United States conclusively linked ozone pollution to forest damage, one in the San Bernardino Mountains east of Los Angeles, California, and the other in Virginia (Bartuska et al., 1985, as cited by Hinrichsen, 1986). Ozone has been demonstrated to be responsible for visible injury and decreased growth in some individual eastern white pine trees (Berry and Hepting, 1963; Hayes and Skelly, 1977; Benoit et al., 1982) and in southern California forests (Parmeter et al., 1962; Ohmart and Williams, 1979). Tomlison et al. (1990) have concluded, however, that the hypothesis that elevated ozone levels are the primary cause of forest damage in Germany (Prinz et al., 1982; Prinz, 1983) is not supported by available data.

In addition to ozone effects, European forest *Waldsterben* has been attributed in some areas to direct effects of SO_2 (Ulrich, 1990). Sulfur dioxide injures trees by entering the leaves (or needles) through their stomata (pores), where it reacts with water to produce sulfuric acid. Deciduous leaves take on a "bleached" look, whereas conifer needles turn red-brown (Hinrichsen, 1986). Gradients of SO_2 concentration and vegetation damage with distance from an SO_2 source have made it relatively easy to study the effects of SO_2 on vegetation (Krause, 1989). Crop, forest, and vegetation damage have occurred in the vicinity of fossil fuel power plants and metal smelters which emit high levels of SO_2 (Hinrichsen, 1986). Although elevated SO_2 levels have been

Exhibit 2.8.2. Comparison of symptoms and possible causes of forest declines in central Europe and eastern North America.

Possible Causative Agent	Symptoms	Central Europe	Eastern North America
Foliar Leaching, Ozone, Drought	Yellowing of foliage from the lower to the upper and from the inner to the outer portion of branches—oldest tissues affected first.	Observed mainly in white fir and Norway spruce at high elevation.	Observed with white fir in the San Bernardino Mountains and recently in red spruce in New York and Vermont.
Natural Stress, Abiotic and Biotic	Dying back from the top of trees—youngest tissues affected first.	Common in oak and ash, less common in birch and beech.	Conspicuous in red spruce; maple and oak declines; ash and birch diebacks.
SO_2, Insect Pests, Drought	Increased transparency of crowns due to gradual loss of leaves but with leaves retained to the very top of the trees.	Observed in Norway spruce, white fir, Scots pine, larch, beech, birch, oak, maple, ash, and alder.	Observed only in the littleleaf disease of shortleaf pine and in the beech-bark disease.
Fertilization	Losses of fine-root biomass and mycorrhizae (beneficial symbiosis between tree roots and soil fungi).	Common in white fir, Norway spruce, and beech. Not studied in other species.	Observed mainly in red spruce decline, birch dieback, and littleleaf disease.
Chronic Ozone, Chronic SO_2	Synchronized decrease in diameter growth without other visible symptoms.	Not reported in Europe.	Observed in pitch pine and shortleaf pine.
Acute Ozone, Acute SO_2, Foliar Fertilization	Synchronized decrease in diameter growth with other visible symptoms. May result in mortality.	Studied mainly in Norway spruce, white fir, and beech. Not studied in other species.	Observed in red spruce and Fraser fir mainly at high elevation.
Ozone	Concentration of leaves and needles at tips of branches in tufts or clumps.	Common in oak and ash.	Observed in nearly all decline of broad-leaved trees and in some conifers.
Stress	Excessive production of adventitious shoots on branches.	Common in Norway spruce, white fir, and larch.	Observed recently for the first time in conifers. Common in maple and oak, ash, and birch.
Stress, N Fertilization	Excessive production of seeds and cones.	Common in spruce, fir, beech, and birch; often observed several years in a row.	Observed in many stressed trees mainly one year at a time.

Source: Adapted from Hinrichsen, 1986.

found in several areas in Europe that are experiencing severe forest declines, SO_2 levels are not elevated in other areas experiencing declines (Krause, 1989).

Acid deposition. Both wet and dry (sorbed to particulates) acid deposition occurs in north temperate forests. Wet deposition occurs through rain, snow, dew, and fog; the pH of rain water in industrialized areas typically is around 4.2 (Krause, 1989). The direct and indirect contributions of acid deposition to forest diebacks remain controversial, however. Direct effects of acid deposition may be reduced growth, premature defoliation in the autumn, and changes in sap chemistry, but long-term studies still are needed (Erb, 1987*P). Indirect effects of acid deposition include root damage from aluminum toxicity, aluminum blocking of nutrient uptake, leaching of essential nutrients from the soil, and leaching of nutrients from foliage.

Increased acidity of soils increases the mobility of metal cations such as aluminum, which can be directly toxic to roots at high concentrations (Godbold et al., 1988; Shortle and Smith, 1988) and which can competitively block root uptake of other positively charged ions that are essential nutrients (e.g., magnesium, calcium; studies summarized by Tomlison et al., 1990). Furthermore, increased soil acidity helps to leach essential nutrients such as calcium and magnesium from the soil and to create an ionic imbalance in the soil that has deleterious effects on trees' fine roots (Ulrich, 1983). The resulting moisture and nutrient stress weaken the trees, which can then succumb to pathogens, weather, and other stressors that they might have withstood in the absence of acid rain (Ulrich, 1990; Tomlison et al., 1990).

Rehfuess (1981) proposed that acid deposition also may increase the rate of leaching of calcium, potassium, and magnesium directly from foliage. A program in Munich, Germany, designed to test this hypothesis found that magnesium and/or calcium deficiency in trees exposed to ozone and acid fog results primarily from inadequate uptake of these nutrients from the soil, with the result that nutrient leaching from foliage only becomes a problem when there is an insufficient supply in the soil (Tomlison et al., 1990). Some degree of foliar leaching is considered a normal part of trees' nutrient cycling, and there appears to be no conclusive evidence that this factor is a primary cause of forest decline (Hinrichsen, 1986).

Excess nitrogen deposition. North American studies have found that 10 percent of all agriculturally applied quantities of nitrogen fertilizers evaporate into the atmosphere (Hinrichsen, 1986). In the higher elevation spruce-fir forests of the northeastern United States, atmospheric deposition of nitrogen has been estimated to be as high as 37 to 44 kg/hectare-year, with half of it coming down as wet deposition (Bartuska et al., 1985). Nitrogen oxides deposited on foliage as well as in the soil can be absorbed by trees. Nitrogen deposition on soils can stimulate nitrification and nitrate leaching, which increases soil acidity and can contribute to the stresses described in the previous paragraph (Johnson and Taylor, 1989). Excess nitrogen uptake can stimulate trees into extra growth activity, preventing them from preparing for winter (i.e., sequestering carbohydrates and other substances during the "hardening" process; Hinrichsen, 1986). Although some believe that growth stimulated by atmospheric nitrogen uptake has caused magnesium deficiencies in some European forests (Schulze, 1989), the evidence is as yet circumstantial. Evidence linking excess nitrogen oxides to forest decline in the United States also is circumstantial.

Other gaseous pollutants. A further possibility receiving attention recently is that airborne halocarbons, particularly 1,1,1-trichloroethane and tetrachloroethene, are photooxidized at the higher altitudes to the herbicide trichloroacetic acid (TCA), but additional research is needed to evaluate this possibility (Frank, 1991).

Other Stressors

Natural fluctuations. Some researchers have proposed that forest diebacks are part of natural cyclic fluctuations. Skelly (1989) suggests that pollutant deposition and naturally occurring forest stressors (e.g., pathogens, drought) occur over the same regions and elevational gradients, which make natural and anthropogenic stressors difficult to distinguish. Kandler (1990) compared old photographs of trees in several forests in West Germany with pictures of the same trees today and reviewed reports on tree condition in the early 1920s. He concluded that the *Waldsterben* complex may be part of a natural fluctuation, or at least not a new phenomenon since the turn of the century. Weather extremes, particularly drought (Krause, 1989), may have contributed to some instances of forest dieback over the past century (Tomlison et al., 1990). Long-lasting dry periods may significantly increase forests susceptibility to many kinds of disease and pest outbreaks (Krause, 1989).

Pathogens. Although some localized areas of dieback have been attributed to outbreaks of specific pathogens (e.g., fungi, insect pests), these outbreaks may occur more frequently in trees already weakened by anthropogenic pollution. In the studied examples of forest declines and diebacks, pathogens have usually been described as "accelerating" causes, and sometimes "triggering" causes, but almost never as "predisposing" causes (AIBS, 1987; Franklin et al., 1987; Manion, 1981; Houston, 1981; Warwick and Watt, 1983; as cited in Mueller-Dombois, 1988).

An important problem, however, is the loss of specific tree species to introduced pathogens. In North America, the chestnut and elm have been all but wiped out in North America by imported diseases (i.e., chestnut blight and dutch elm disease). Now, the eastern hemlock appears to be threatened with extinction in the wild by an insect apparently imported from Japan (Stevens, 1991*P). In Oregon and Washington states, past logging and fire prevention practices have resulted in the ponderosa pines being replaced by dense stands of firs and lodgepole pine. These species are more vulnerable to insect pests and large tracts have died from repeated insect pest outbreaks (Kenworthy, 1992*P).

Biological nutrient mining. Monoculturing of a single tree species (e.g., Norway spruce), cutting stands before they became senescent, and preventing natural regeneration of soil nutrients also may have contributed to the observed soil-nutrient deficiencies in Europe, particularly in spruce forests (Mueller-Dombois, 1988). Although evidence is lacking, negative consequences of repeated spruce monocultures are beginning to receive serious attention (Bourdeau, 1987). Whether the observed soil nutrient deficiencies are a result of leaching of nutrients due to soil acidification or of biological nutrient mining, experimental fertilization of German forests with the needed nutrients has succeeded in restoring tree vigor, and parts of Germany are developing plans for large-scale forest fertilization and rehabilitation (Tomlison et al., 1990).

Global warming. The scientific community has not reached a consensus on the possible contribution of global warming to north temperate forest dieback; however, it is an area of intense research. Unusual extremes in temperature or rainfall may kill trees already weakened by atmospheric pollution.

2.8.3 Continued Monitoring

Deforestation

The United Nations Food and Agriculture Organization (FAO) and the United Nations Environment Program (UNEP) sponsored the 1980 and 1990 Tropical Forest Resources Assessments. The 1990 assessment was based on remote sensing data from the National Oceanic and Atmospheric Administration and Landsat satellites. Various researchers and organizations with access to the Landsat data will continue to follow deforestation trends with these data.

Forest dieback

The Forest Ecosystems and Atmospheric Pollution Research Act of 1988 directed the United States Department of Agriculture (USDA) Forest Service (FS) to establish a monitoring system to track long-term trends in the health and productivity of forests and related ecosystems in the United States. The FS maintains a forest timber inventory data base and recently has been designing a Forest Health Monitoring (FHM) system in response to concerns about the potential effects of global climatic change on forests worldwide (CEQ, 1990). The FHM was implemented in the six-state New England region in 1990 with cooperative efforts of the FS and EPA. Forest conditions will be described using five 'health' indicator groups: growth, foliage symptomatology, soil chemistry, foliar chemistry, and landscape characterization (Brooks et al., 1991). Other investigators are contributing to the effort as well. For example, Tritton and Siccama (1990) recently reviewed 46 primary data sets to estimate the proportion of standing trees in the northeastern United States that are dead to serve as a baseline for future studies.

The Federal Republic of Germany established their Forest Damage Inventory in 1983 and has conducted annual surveys of their forests since. The only damage symptoms considered, however, are leaf loss and leaf discoloration. The European Forest Ecosystem Research Network (FERN) has been coordinating surveys of forests in several European countries for the past five years. Other European and Canadian vegetation condition surveys also have been conducted by various agencies and institutions over the last 20 years.

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3. CONCLUSIONS

In our literature review, we identified several biological populations as potential indicators of large-scale environmental change. In this report, we summarized hypotheses and supporting evidence for the observed trends for eight potential indicators of environmental change which have received the most attention in the recent popular press (with the exception of loss of wetlands and loss of biodiversity for which EPA has initiated other focused research efforts). The eight indicators covered in this volume are groups of animals or plants for which populations are or appear to be declining and in some cases, going extinct, more rapidly in the past few decades than in previous years. While there are examples of species that are increasing in abundance and expanding their ranges (e.g., cowbirds, fire ants, killer bees), the majority of these species represent introduced generalist species that have successfully colonized an area in which they did not evolve, and therefore have no natural controls. The expansion of populations of introduced species is often detrimental to a diversity of more specialized native species, as is the case for North American fish, neotropical migrant birds, and probably amphibians.

Available evidence indicates that human activities are contributing to many of the observed population declines described in this report. The direct destruction, degradation, and fragmentation of habitats as lands and waters are converted and altered for human use appear to be the major contributors to declines in populations of neotropical songbirds, ducks, freshwater fish, and turtles in North America. It is not yet clear whether the apparent decline in amphibian populations worldwide is real, and if so, what the cause(s) of the trend might be. Increasing environmental pollution is taking its toll on the surface water quality upon which our fish fauna depend, and may have contributed to the recent deaths and declines of dolphins and seals in the North Atlantic and Mediterranean. In addition to suffering from physical destruction, nutrient runoff, sedimentation, and other pollution, coral reef communities may be suffering directly from a global ocean warming trend or increased variability in ocean temperatures. The clearing of tropical rainforests not only threatens global biodiversity, but also the services supplied by those forests in stabilizing our global climate.

In Section 3.1, we review the eight potential indicators to identify the relative sensitivity of each of the groups of organisms to different anthropogenic stresses. We then summarize those human activities that are causing or are likely to be causing the observed declines in the eight groups (Section 3.2). Finally, in Section 3, we discuss some of the difficulties associated with trying to use any of these groups of organisms as indicators of large-scale environmental change.

3.1 Summary of Relative Sensitivity of Biological Indicators

In this section, we review some of the life-history attributes of the eight groups of organisms that help to determine their relative sensitivity to different categories of anthropogenic stress. As described below, each group is sensitive to a different suite of environmental stressors, and therefore may provide different windows by which to view environmental change and quality.

Neotropical migrant birds. Neotropical migrant birds share several life-history traits that make them particularly vulnerable to fragmentation of north temperate forests. They tend to build open nests near to the ground and to lay only a single small clutch of eggs each year. These traits have made neotropical migrant bird species vulnerable to forest edge predators and parasites. With increasing ratios of forest edge to forest interior, edge predators and parasites have access to an increasing proportion of the neotropical migrant species, which are adapted to forest interior, not forest edge, conditions. Neotropical migrant birds also are sensitive to changes in the tropical forests in which they overwinter.

North American freshwater fish. The continued existence of native North American freshwater fish species depends not only upon the chemical integrity of our surface waters, but also upon the variety of physical conditions inherent in natural springs, rivers, lakes, and estuaries which is lost when rivers are channelized and impounded. Formerly, the southwestern United States supported a high diversity of native fish species because of the numerous, yet isolated, drainage systems and surface water bodies. The relatively small and isolated populations of native fish species in these areas are particularly vulnerable to habitat destruction and the diversion of water for human agricultural, industrial, and domestic uses.

Ducks. Duck populations depend on wetland habitats for breeding, for stopovers during migration, and for overwintering. Thus, ducks are sensitive to drought and human activities that reduce the availability of wetland habitats. Waterfowl are also particularly susceptible to chemical pollution of their aquatic feeding habitats.

Coral reefs. Limited in distribution to waters warm enough for coral organisms to precipitate calcium carbonate from seawater and clear enough to permit sunlight to reach the microscopic plants that live symbiotically in their tissues, corals are vulnerable to any human activities that degrade this environment. Living in areas that represent the warmer extremes of the evolution of aquatic life on the planet, scientists are concerned that corals may be unable to adapt to ocean warming trends. Coral reef communities also require many years to recover from major destruction.

Amphibians. The life-cycle and physiology of amphibians may render them more susceptible to chemical pollution, extremes in weather, and acid deposition, than most other groups of organisms. The eggs of many amphibian species are laid in water and have little physical protection from water-borne contaminants or unusual water temperatures. Adult amphibians are carnivorous and therefore more vulnerable to bioaccumulating environmental contaminants from their food than are animals lower in the food chain (e.g., herbivores). In addition, the skin of most amphibian species is highly permeable, making them particularly susceptible to pollutants from air, water, or other environmental media. Amphibians require moist habitats to prevent excessive water loss through their highly permeable skins; they are therefore susceptible to desiccation under unusually dry or hot weather conditions. Amphibian populations are also very susceptible to physical destruction of aquatic habitats which are required for egg and larval development in many species.

Turtles. Land turtles are vulnerable to fragmentation of their habitat by roads and highways because of their relatively slow locomotion and large home ranges. Sea turtles are particularly vulnerable to several categories of anthropogenic stress, including shrimp trawling-induced mortality, pollution of the marine environment with toxic substances and physical debris, direct exploitation, and several effects incidental to human presence and developments on coastal beaches where sea turtles lay their eggs in the sand.

Dolphins and seals. Dolphins and other marine mammals are likely to be sensitive to environmental pollution because of their position high in the marine food chain and because of their relatively high body fat content, which helps minimize loss of body heat in their cold marine environments. As top carnivores, dolphins and seals feed on fish that may have accumulated toxic substances in their tissues both directly from the water and from their food. Because of their large fat reserves, dolphins and seals also can store large quantities of toxic substances that accumulate in fatty tissues (e.g., PCBs). Marine mammals are long-lived and can accumulate toxic substances from their environment over many years.

Forests. Forests provide many invaluable services: they are responsible for providing three-dimensional terrestrial habitat for a large diversity of animal species, particularly in the tropics, for moderating temperatures, for maintaining precipitation cycles, and for absorbing carbon dioxide, a greenhouse gas that can contribute to global warming. Loss of forests results in loss of these ecosystem services, which can have serious impacts many groups of organisms and the existence of many ecosystem types. Moreover, loss of forest services in one area can adversely affect forests in adjacent areas as precipitation and temperature patterns change. The health of forests depend on the physical and chemical condition of the atmosphere and of the soils on which they grow. Human activities that alter soil conditions (e.g., nutrient availability, moisture content), in particular, can have devastating effects.

3.2 Summary of Human Activities Causing Species Declines

As human populations and settlement areas continue to increase in the United States and worldwide, human activities impinge on ever increasing areas of North America and the planet. Exhibit 3 summarizes the human activities that the literature review identified as being responsible or likely to be responsible for declines in the eight groups of organisms evaluated in this review. In Exhibit 3, we group anthropogenic stresses into three multiple stress categories (i.e., habitat alteration, toxic chemicals and solid wastes, and combustion of fossil fuels) and two single stress categories (i.e., increasing introductions of non-native species and exploitation of resources, both direct and incidental). We discuss each of these stress categories below.

Habitat alteration. The ever-increasing human population continues to directly alter terrestrial and aquatic ecosystems for purposes of agriculture, industry, suburban, and urban developments. Filling of wetlands, clear-cutting or burning forests, building roadways and power transmission lines that fragment the remaining forests, and other activities associated with converting lands for human uses are major contributors to the loss and degradation of terrestrial habitats. These activities result in the loss of wetland and forest ecosystems and fragmentation of the remaining habitats. These activities also further isolate the remaining habitat islands increasing the probability of local population extinctions as a consequence of natural variation in mortality and reproductive success. These activities also can dramatically alter the condition of the remaining habitat. For example, deforestation, particularly in riparian areas (i.e., along rivers), causes increased surface water temperatures (less shade) and increased sedimentation (from runoff). For aquatic habitats, direct modification of surface water bodies (e.g., stream channelization, construction of dams, impoundments, and reservoirs) reduces physical habitat diversity and water flow, causing loss of fish species and possibly amphibians that had filled a variety of specialized niches and habitat types. Direct habitat alteration is considered to be responsible for the majority of the extinctions and reductions in populations of North American freshwater fish, neotropical migrant birds, and possibly amphibians, and is considered to contribute strongly to the declines of ducks and both land and sea turtles. Runoff of fertilizers and other nutrients (e.g., manure) from agricultural areas has resulted in eutrophication of inland surface waters and degradation of coral reef communities which evolved in low nutrient areas of the ocean. Increasing sedimentation from runoff from urban and suburban developments, logging and mining operations, and agriculture also have degraded both inland freshwater and coastal marine ecosystems.

Tropical rain forests are among the most species-rich habitats on earth. Deforestation in the tropics is seriously reducing global biological diversity. In North America, we may already be seeing consequences of tropical deforestation in the diversity of our own bird communities, as the abundance and distribution of neotropical migrant birds declines. We soon may feel other effects as we lose the precipitation and climate moderation services provided by these forests as well as their ability to serve as a sink for carbon dioxide, a gas that can contribute to global warming.

Exhibit 3. Matrix of human activities and stressors that are or may be impacting the eight groups of organisms reviewed in this report.

Human Activities	Stressors	Intermediate Effects	Neotr. Birds	NA Fish	Ducks	Coral Reefs	Amph-ibians	Turtles	Dolphins Seals	Forests
Habitat alteration:	filling wetlands	loss of wetland habitats		?	XX		X	X		
Conversion of natural environments for agriculture, mining, industry, and suburban and urban developments	clear-cutting/burning forests	loss of forest habitats	XX	X			X			XX
		increased temperature and siltation of surface waters		XX			XX			
	increased roadways and power transmission lines causing habitat fragmentation	increased ratio of edge to forest interior	XX				?			
		habitat isolation	XX				?	X		?
	alteration of surface water bodies (e.g., dams, reservoirs, channelization, impoundments)	reduced habitat diversity		XX			X			
		reduced flow, habitat loss		XX	X		?			
	nutrient runoff, sedimentation	eutrophication, smothering		XX		XX	?			
Production of toxic chemicals and solid wastes	sewage	toxics, sediments, BOD		XX		X	?			
	air toxics	toxicity, soil chemistry changes								XX
	PCBs, DDT, mercury	bioaccumulation						?	XX	
	pesticides, industrial chemicals	toxicity		XX	XX	X	?			
	physical debris, e.g., plastics,	ingestion, entanglement						X	X	

Exhibit 3.

Human Activities	Stressors	Intermediate Effects	Neotr. Birds	NA Fish	Ducks	Coral Reefs	Amph-ibians	Turtles	Dolphins Seals	Forests
Combustion of fossil fuels	increasing greenhouse gases, possible global warming	increasing extremes in temperature (a): heat		?		XX	?			
		cold	?	?			X	X		X
		increasing extremes in rainfall (a): drought	?	?	X		X			X
		floods					X			
	increasing acid deposition	lowering pH of surface waters		X			X			
		soil chemistry changes		?			?			XX
Agriculture, sport fishing, travel	introduced species	increasing exotic fish		XX			XX			
		increasing bullfrogs					XX			
		exotic water plants		XX						
Exploitation of resources	direct taking of organisms			?	?	X	X	XX		X
	incidental taking of organisms					X		XX	X	X

Production of toxic chemicals and solid wastes. The second group of multiple anthropogenic stressors listed in Exhibit 3 result from increasing and changing releases of man-made toxic substances and solid wastes into the environment as human populations expand, despite efforts to curtail releases. Sewage contributes to the degradation of aquatic ecosystems by increased sedimentation and biological oxygen demand (BOD) as well as by increasing concentrations of toxic substances in some surface waters. Emissions to the atmosphere from motor vehicles, industrial sources, and agriculture include substances that are directly toxic to vegetation and that can adversely modify soil chemistry. Air pollution is believed to be a primary cause of forest dieback in industrialized countries. Other chemical pollutants of concern include those that bioaccumulate in terrestrial and aquatic food chains to levels that have adverse effects on animals at the top of the food chain (e.g., bald eagles and osprey prior to bans on PCBs and DDT; now possibly dolphins and other marine mammals potentially due to these chemicals accumulating in the ocean). Pesticides from agricultural fields is another source of continuing environmental pollution that may be causing adverse effects on aquatic invertebrates and the ducks that feed on them. A more recent problem is increasing levels of physical debris in the environment, particularly plastics in the ocean which are ingested by or entangle sea turtles and marine mammals.

Fossil fuel combustion and global warming. The third group of multiple anthropogenic stresses listed in Exhibit 3 result from increasing combustion of fossil fuels, releasing gases responsible for the greenhouse effect. To date, the potential impacts of global warming on any of the groups of organisms identified in this report are uncertain, although warmer than usual temperatures in tropical areas have already been implicated in the increased incidence and severity of coral bleaching and death worldwide. A more near-term effect of global warming and deforestation that has not yet received much attention is the alteration of global and regional weather patterns, resulting in more extreme temperature and rainfall fluctuations than experienced in the evolutionary history of the plants and animals native to their locales. Unusually cold weather for a given season has been blamed for localized kills and population reductions of amphibians and hatchling turtles, for contributing to the dieback of north temperate forests weakened by the consequences of atmospheric pollution. Unusually high temperatures that appear to be responsible for the recent widespread coral bleaching events may reflect increased variability in weather rather than any actual current manifestation of a sustained trend towards global warming. Unusual and prolonged recent droughts have contributed to the loss of wetland and surface water habitat which are contributing to the declines of duck (and other water bird) populations, and probably contributing to declines in North American freshwater fish and amphibian populations and increased incidence of forest dieback in the western United States.

Fossil fuel combustion and acid rain. Combustion of fossil fuels, particularly coal with high sulfur content, releases gases to the atmosphere that are precursors to acid deposition. By lowering the pH of surface waters, acid deposition is contributing to the decline in North American fish and possibly amphibian populations. Acid deposition alters soil chemistry (e.g., increased mobility of toxic metals such as aluminum, increased leaching of essential nutrients from the soil) and is probably a major contributor to forest dieback in the northeast United States and in parts of Europe.

Introduced species. Human activities have greatly accelerated the introduction of species into habitats in which they did not evolve. Some introductions have been intentional, as with stocking rivers and streams with non-native sport fish and introducing agricultural plants and animals. Others are accidental, as the release of insects travelling hidden in agricultural produce or marine organisms on ship hulls or in ballast waters. Introduced species often have no natural predators or other controls in the new environment. Repeated cases have demonstrated that unchecked generalist species can often outcompete and replace several more specialized species. The scientific community considers introduced species to have caused declines in populations of North American fishes and probably amphibians. There are numerous examples of local island species extinctions as a consequence of introduced species because long-isolated island communities are particularly vulnerable to the introduction of generalist species that evolved in mainland assemblages (e.g., extinctions of native Hawaiian flora and fauna over the past 500 years). Introduced species are far more difficult to control than habitat alteration or chemical pollution because they reproduce themselves.

Direct exploitation. Humans have directly reduced animal populations by taking animals for use as food, pets, research, and exotic trade. Direct exploitation of species and groups of species has contributed to the declines of North American fish, sea turtles, and coral reefs and possibly to the declines in amphibians worldwide. Selective logging of hardwoods is degrading tropical forests. The consequences of overharvesting have been particularly devastating in the old growth forests of the Pacific Northwest of the United States and in other groups not covered by this report (e.g., Atlantic and Pacific coastal fisheries and African and other Old World tropical mammals). Direct taking of plants and animals can be a self-limiting process if humans perceive a species or population loss in time to develop sustainable harvest population management techniques. There are many examples, however, of human failure to check exploitation in time (e.g., passenger pigeon).

Incidental losses. Human harvesting techniques have sometimes involved the incidental capture of non-target organisms in large numbers. The shrimping and tuna industries have long contributed to large kills of sea turtles and dolphins, and use of dynamite in fishing near coral reefs has contributed to their decline. Kills of adults of long-lived, low-fecundity[16] animals such as sea turtles and dolphins can significantly reduce the populations' reproductive capacity and ability to recover once incidental kills are reduced or eliminated.

[16]Low number of offspring produced each year.

3.3. Monitoring Environmental Change

Although we can conclude that several different human activities have contributed to the observed declines in species and populations of several groups of organisms, the question still remains to what degree can any one or a number of these groups serve as indicators of environmental change on regional, national, hemispheric, or global scales. Each group is sensitive to a somewhat different suite of environmental conditions, and so each may provide a different window by which to view environmental conditions. One difficulty with using any of the groups as an indicator of environmental change is monitoring the group on a sufficiently large scale, with sufficient precision, and over a long enough period, to detect real trends in the first place. A second difficulty is monitoring the possible environmental stressors that may contribute to the trends on a comparable scale and level of precision. There also can be significant time lags between the occurrence of a stressor and obvious changes in various groups of organisms. Finally, given the large number of environmental variables involved and natural fluctuations in environmental conditions (e.g., weather) and population levels, establishing cause and effect can require a substantial effort with respect to geographic extent of samples, parameters monitored, and duration of the monitoring programs.

For some of the groups of organisms presented in this report, long-term large-scale monitoring programs have made it possible to detect population trends despite large year-to-year and geographic variation in population sizes (e.g., US FWS May Breeding Waterfowl Survey and Breeding Bird Survey, the Audubon Christmas Bird Counts). It therefore may be possible to use these groups as sentinels of specific types of environmental change. Populations of neotropical migrants may serve as barometers for forest loss and fragmentation in North America and, possibly, the neotropics. Ducks may serve as a barometer of the condition of some of our North American wetland ecosystems. In the cases of North American freshwater fish and coral bleaching, efforts of individual researchers compiling numerous independent studies have identified large-scale trends, but there is a need to establish a more comprehensive and standardized approach to monitoring both the populations of concern and the stressors that can be affecting them. Both North American freshwater fish and coral reef communities are likely sensitive indicators of change in their environments, integrating a variety of stressors in their responses. North American freshwater fish are more indicative of gross habitat-level changes in freshwater ecosystems, whereas coral communities are more indicative of changes in the quality (e.g., nutrient load, sediments, toxic substances, salinity, temperature) of the ocean waters.

For the remaining groups of organisms, the utility of the group as a monitor for environmental change, at least in the short term, is less clear. As yet, it is not clear whether amphibian species are showing declines worldwide. This results from a lack of long-term monitoring data for most populations, a problem which the newly established IUCN Task Force on Declining Amphibian Populations should help to solve. Similarly, there is a lack of extensive baseline data against which to evaluate trends in land turtles.

As long as sea turtle juveniles and adults are suffering high mortality rates at sea as a consequence of shrimp trawling, it will not be possible to use sea turtle populations as indicators of the quality of ocean waters and the quantity and quality of breeding beaches. However, the incidence of tumors in sea turtles may provide an indication of chemical pollution. Dolphins and seals may be sensitive indicators of the accumulation of toxic substances (e.g., PCBs) in aquatic food chains; however, scientists have not yet conclusively linked the observed mass mortalities and most declining populations to environmental contamination.

Monitoring technologies and programs are being established that will allow various agencies and organizations to follow the areal extent and condition of forests in North America and worldwide. EPA, through its Environmental Monitoring and Assessment Program (EMAP), already is cooperating with the USDA Forest Service in the Forest Health Monitoring (FHM) program in twelve states in the new England, Mid-Atlantic, and Southeastern regions of the United States. Because of the central role that forests play in carbon cycling, climate control, provision of wildlife habitat, supply of wood and other natural products of commercial value, measures of changes in forest area and condition directly affect the overall health and biological diversity of the planet.