AFS Policy Statement #29:
Biodiversity
(Full Text)

By Brian D. Winter and Robert M. Hughes

This position statement is the outcome of several years of preparation and review within the American Fisheries Society (AFS). In 1991, the AFS Executive Committee (Excom) directed the Environmental Concerns Committee [ECC; later to become the Resource Policy Committee (RPC)] to initiate development of an AFS position statement on biodiversity. ECC Chair Hal Tyus assigned this task to Co-chair Brian Winter, who developed a draft statement. The draft was reviewed by the RPC and members of the AFS Endangered Species Committee. At this point, Robert Hughes was added as co-author because of his expertise. The comments received were incorporated in a new draft, which was then reviewed by a second RPC. The draft statement was again modified and returned to the RPC, which then forwarded it to the Excom for review. The Excom approved the draft statement at the 1994 AFS annual meeting for publishing in Fisheries for membership comment; it was included in the April 1995 (Vol. 20, No. 4) issue. Eight AFS member comment letters were received within a 90-day period, and the statement was revised accordingly. The Governing Board approved the revised statement on 27 August 1996. All AFS position statements are intended to reflect the diversity and geographical scope of the AFS membership. Every effort is made to ensure that each position statement is acceptable to most AFS members.

Editor's Note: This revised position statement incorporates minor changes made by the Governing Board at the 1996 AFS annual meeting and approved by members at the 1996 business meeting. The statement was published in the January Fisheries without those changes. We are sorry for any inconvenience.

Issue Definition

The Environmental Protection Agency's (EPA) Science Advisory Board has listed loss of biodiversity as one of the four greatest risks to natural ecology and human well-being (USEPA 1990). Current loss rates in global species diversity approximate those that define boundaries between geological eras when massive alterations in the Earth's biota occurred. Biological diversity, or biodiversity, can be defined as "the variety of life and its processes" (USDOI and USDA 1992) and is generally recognized at four levels in a biological hierarchy (Norse et al. 1986; OTA 1987; Cairns and Lackey 1992): (1) genetic diversity is the amount of genetic information among and within individuals of a population, species, assemblage, or community; (2) species diversity is the number and frequency of species in a biological assemblage or community; (3) ecosystem diversity is the collection of assemblages, communities, and habitats within an area; and (4) landscape diversity is the spatial variation of the various ecosystems within a larger area ranging in size from 100 km2 to 10,000 km2. Other organizational levels of biodiversity include stocks, races, guilds, ecotones, ecoregions, and biomes. Biodiversity should not be likened to an often transitory increase in the variety or numbers of species through the introduction of nonnative plants and animals (Scott et al. 1991). Examples of reduced biodiversity in aquatic systems consistent with the above hierarchy can be found in Hughes and Noss (1992).

Because some degree of biodiversity is inherent in all biological systems and some of our least-disturbed systems have little biodiversity, resource managers tend to be more concerned with the loss of biodiversity than with biodiversity itself. For these reasons, many aquatic scientists have focused on biological integrity. Biological integrity is defined as the capacity to support and maintain an integrated, adaptive community with a biological composition and functional organization comparable to those of natural waters of the region (Frey 1977; Karr and Dudley 1981). Implicit in this definition is the comparison of existing biological systems against some natural expectation or standard. Natural conditions can be estimated from sediment cores, other historical information, or minimally disturbed waters (Hughes 1995). The degree of naturalness is evaluated by the amount the waterbody would be altered by the removal of humans, the quantity of societal energy needed to create or support the waterbody, and the present biota relative to that existing before Euro-American settlement (Anderson 1991). Integrated waters reflect the region's natural climate, geology, soil, and vegetation. A waterbody that supports biota adapted to the region can usually adjust to natural disturbances without human intervention or major disruption in species composition or biological processes. This concept of biointegrity is also incorporated with our discussion of biodiversity, although integrity is a much more normative term.

A common argument for maintaining biodiversity is the value of saving the vast storehouse of genetic material of plants and animals for future, often unknown, benefits (Cairns and Lackey 1992). Humanity has already obtained tremendous benefits from the diversity of life forms, including medicines, foods, and industrial products, even though the "genetic library" has barely been tapped (Ehrlich and Wilson 1991). Biodiversity also is important to preserving ecosystems that provide, among other things, food, timber, maintenance of the gaseous composition of the atmosphere, regulation of global and local climates, and the production and maintenance of soils (McNeely et al. 1990; Ehrlich and Wilson 1991). It has also been argued, however, that biodiversity must be sustained simply because humans have a moral obligation to ensure the natural, evolutionary existence of species and ecosystems whose values do not depend on their human usefulness (Ehrenfeld 1978; Taylor 1986).

Background Information

The loss of biodiversity is associated, in most instances, with human population pressure and the overconsumption of resources. The human population totals 5.2 billion and is increasing at the rate of 1.8% per year (Lubchenco et al. 1991). The net U.S. annual growth rate, including immigration, is 1.01% (USDOI and USDA 1992). If growth continues at a similar rate, the world human population will double by 2035 (Becker 1992), while that of the U.S. will double by 2056. Population growth erodes biodiversity through the immediate needs of people for food, shelter, goods and services. The high rate of material and energy consumption makes the U.S. population growth rate an even

greater concern because U.S. citizens, on average, consume goods and energy at the rate of 20-30 persons from less-materialistic countries (Ehrlich and Ehrlich 1977).
Other social considerations fostering losses in biodiversity include rapid cultural transitions, anthropocentrism or inadequate environmental ethics, primary focus on economics, outdated political institutions, short-sighted policy implementation, and lack of a coherent natural resource policy (Soulé 1991; Maser 1992). These human activities have a profound impact on the aquatic environment through exploitation of renewable and nonrenewable resources; the alteration of habitats; the diversion and depletion of surface and groundwater supplies (including the loss of pervious surfaces by urban development, devegetation, and soil compaction); and the addition of toxic substances, wastes, and pollutants to lakes, streams, and oceans, thereby modifying the biodiversity of freshwater and marine ecosystems (Lubchenco et al. 1991; Allan and Flecker 1993). Aquatic physical and chemical habitat and biological communities have been altered by: (1) in-channel modifications (i.e., filling, channelization, gravel removal, dredging, etc.); (2) construction and operation of dams and reservoirs; (3) riparian and wetland alteration; (4) water diversion and withdrawal; (5) point-source and nonpoint-source pollution, including siltation and nutrient loading; (6) introduction of nonnative species and stocks; (7) hatcheries; (8) overharvest; (9) acid precipitation; (10) global atmospheric change; (11) increased ultraviolet radiation; and (12) interaction among two or more of these stressors (Williams et al. 1989; Nehlsen et al. 1991; Cairns and Lackey 1992).

Such environmental impacts have resulted in an alarming increase in the rate of loss of biodiversity at the genetic, stock, species, assemblage, ecosystem, and landscape levels.

Genetic

Reisenbichler et al. (1992) found that levels of genetic variation among steelhead populations in coastal Washington, Oregon, and northern California were substantially lower than those in British Columbia, probably due to higher levels of fishing, habitat modification, or hatchery production (and distribution of very few hatchery populations across a large number of wild populations) in the United States. Overfishing, habitat degradation, and poorly designed hatchery programs can cause loss of genetic variation within populations through inbreeding or random genetic drift (Nelson and Soulé 1987; Ryman and Laikre 1991). Habitat destruction can eliminate or reduce certain genetic components of a population (e.g., life-history types dependent on the lost habitat), thereby reducing genetic variation within a population. Such reductions in genetic variation often reduce the fitness or productivity of populations. For example, Allendorf and Leary (1986) concluded that heterozygosity (one measure of genetic variation) was positively correlated with phenotypic traits that affect fitness in populations across a wide range of species. Of greater significance in the long term is that loss of genetic variation threatens the ability of a population or species to adapt and persist in the face of rapidly changing environmental conditions (Schonewald-Cox et al. 1983).

Stock

Nehlsen et al. (1991) classified 214 native, naturally spawning Pacific salmon, steelhead, and sea-run cutthroat stocks from California, Oregon, Idaho, and Washington as facing a high or moderate risk of extinction, or of special concern. The plight of Pacific salmonids could have been predicted by the recent history of salmonids in the Great Lakes. There, river and estuary spawning stocks were reduced to remnants by the early 1900s (Smith 1972), greatly reducing the genetic complexity available to respond to subsequent stressors.

Species

As a result of tropical deforestation, plants and animals are becoming extinct at a rate of 150 species per day, a rate perhaps 100 to 1,000 times that in unperturbed environments (Reid and Miller 1989). In the United States, more than 680 threatened or endangered plants and animals are currently listed (USDOI and USDA 1992). During the past 100 years, physical and chemical alterations to habitat, introduced species, hybridization, and overharvesting have contributed to the loss of 3 genera, 27 species, and 13 subspecies of fishes from North America (Miller et al. 1989). Williams et al. (1989) classified an additional 103 fish taxa in North America as endangered, 114 as threatened, and 147 as of special concern. As much as 81% of the native fish fauna in Arizona is classified or proposed as threatened or endangered by government agencies (Rolston 1991). Almost half (42%) of the native fishes in New Mexico are "in trouble," while most of the large-river fishes native to the Colorado River basin are in "grave danger" (Rolston 1991). Although the increasing loss of fish species is evident, the endangerment of major invertebrate taxa such as mussels and crayfishes is even more dramatic. Master (1990) found that 65% and 73% of crayfishes and unionid mussels, respectively, are now extinct or at risk. Other invertebrate groups also may be endangered, but they are less studied so their status is unknown. In addition, a reduction in the diversity of marine species is occurring but is more difficult to measure (Upton 1992) because remote marine habitats are difficult to monitor (Cairns and Lackey 1992). Nevertheless, of the 236 commercially harvested marine fish stocks assessed by the National Marine Fisheries Service, 67 (28%) of them were determined to be overutilized (NMFS 1992). In addition to the overexploitation of target species, several billion pounds of nontarget species are taken as bycatch. Bycatch is defined as "the catch of any species, regardless of sex or size, which is unintentionally harvested and which is subsequently retained or discarded because of relatively low market value or legal requirements" (Upton 1992). Fish discarded as bycatch are often dead. Overfishing and high bycatch levels can result in vast changes in marine community structure.

Assemblage

When studied at the assemblage level, fishes appear to be in even more serious trouble. The Ohio Environmental Protection Agency (1988) estimated that 64%-80% of the sites sampled had impaired biological integrity; only 5% were considered exceptional. In the Great Lakes, the commercial catch of native salmonids went from 82% of total catch to 0.2% between 1900 and 1966 (Smith 1968). Judy et al. (1984) estimated that 81% of fish assemblages in the conterminous United States are harmed by limiting factors, particularly agriculture.

Ecosystem

Only 2% of streams in the conterminous United States are worthy of scenic river status (Benke 1990), indicating only 2% near-pristine ecosystem condition, while only 25%-46% of riparian plant communities remain in near-natural condition (Swift 1984). In a northeast U.S. pilot study, Larsen et al. (1994) estimated that 9%-33% of lakes between 1 ha and 2,000 ha were eutrophic; 24%-82% of the lakes were eutrophic in ecoregions most heavily settled by humans. Macauley et al. (1994) reported that 27%±10% of estuarine areas along the Gulf of Mexico coast had impaired biological integrity; 90% ±22% of large tidal river areas in the region were degraded.

Landscape

Perhaps the most telling example of landscape-level losses in biodiversity and integrity is the estimate of Vitousek et al. (1986) that humans co-opt 25% of potential global net primary production and 40% of potential terrestrial net primary production. A similar estimate is derived from land use: Houghton (1994) estimates that 32% of the Earth's land surface is devoted to cropland, and half these croplands were added this century, despite 10,000 years of settled agriculture. Old-growth forests and native prairies occur only in remnant plots in the conterminous United States, but regions with extensive and intensive agriculture, silviculture, urbanization, industrialization, mining, and water projects can be detected from space. Like the microbes that transformed the planet's original atmosphere, we may be changing our soils, climate, and stratosphere on a global scale as a result of those activities.

Fisheries management agencies have contributed to the loss of biodiversity. Conventional natural resources management tends to reduce diversity through simplification, fragmentation, and selective destruction (Sheldon 1988; Norse et al. 1986). Often, management strives for the immediate benefit of a few desirable species [e.g., rainbow trout (Oncorhynchus mykiss) or bass (Micropterus spp.)], thereby contributing to a loss of biodiversity (Cairns and Lackey 1992). The eradication of some fishes, such as gars (Lepisosteus spp.) bowfins (Amia calva), white sucker (Catastomus commersoni), and northern squawfish (Ptychocheilus oregonensis) has been pursued to increase game-fish catches or improve survival of selected species to the potential detriment of ecosystem resiliency and function (Scarnecchia 1992). Rather than limiting catches and restoring natural production, many fishery agencies subsidize overharvested sport fisheries with genetically damaging hatchery species and stocks, including nonnative transplants (Nehlsen et al. 1991; Evans and Wilcox 1991).

As much as 25%-50% of the freshwater fishes caught by anglers in the continental United States are from populations established through introductions (Moyle et al. 1986). Introduced species and stocks are major threats to native fishes (Miller et al. 1989; Nehlsen et al. 1991) by way of predation, competition, introduction of diseases and parasites for which native species lack resistance, environmental modification, inhibition of reproduction, hybridization (Moyle et al. 1986), and stimulating exploitation (Evans and Wilcox 1991). Miller et al. (1989) reported that introduced species contributed to the extinction of 68% of the North American fish species lost in the past century. Native brook trout (Salvelinius fontinalis) have been replaced by introduced rainbow trout in many Appalachian streams and by brown trout (Salmo trutto) in northeastern and midwestern streams (Kelly et al. 1980; Fausch and White 1981; Waters 1983). Unintentional nonnative introductions also threaten native fauna. More than 100 aquatic species have been introduced in the Great Lakes basin, most of them accidentally, drastically altering the functioning of the aquatic system (Radonski and Loftus 1993). Biological invasions also have disrupted estuarine and marine ecosystems. John Chapman (pers. comm., Oregon State University, Newport, Oregon) recently found that 50% of the benthic taxa are exotic in an Oregon estuary used as a harbor. Two introduced species of ascidians (sea squirts) are profoundly changing the composition of fouling communities (e.g., attached organisms such as barnacles, anenomes, mollusks, and algae) along the New England coast (Carlton 1989).

Losses of biodiversity in aquatic ecosystems may be abetted by a public bias against cold-blooded animals resulting from the terrestrial orientation of humans (Hughes and Noss 1992). This bias may be the principal factor responsible for the lack of scientific and public awareness of the importance of biodiversity of small, cold-blooded, and largely unobserved aquatic organisms as compared with the large, warm-blooded animals that live on land with humans (McClanahan 1990). Consequently, much of the public and traditional fishery managers view fishes as a recreational or commercial commodity, or as organisms without intrinsic value.

Some species (e.g., some sharks) are lawfully hunted to near-extinction because they pose a perceived threat to human life (Hughes and Noss 1992). The removal of “the big things that run the world” can have unknown and far-reaching impacts on entire ecosystems (Terborgh 1988; McClanahan 1990). For example, the extinction of sea otters in local areas resulted in increased sea urchin populations, reductions in kelp forests, and alterations in nearshore communities (Estes et al. 1989).

If there is a public bias against cold-blooded vertebrate animals such as fish, there is certainly a general lack of awareness of the importance of invertebrate life forms and their interactions in biodiversity. Although fish are the best-known species of aquatic organisms, microorganisms, small algae and invertebrates account for the greatest number of aquatic organisms (Cairns and Lackey 1992). The United States is home for an estimated 500,000 species of plants and animals, of which small organisms such as arthropods and microbes make up the vast majority (Knutson 1989). These small organisms are as important to the maintenance of ecosystems as the more visible large animals (Wilson 1987). Microcrustaceans (zooplankton) and insects are food for most species of fishes and birds and some species of mammals (Janzen 1987; Wilson 1987). Many of these organisms are as vulnerable to extinction as larger plants and animals (Dourojeanni 1990).

The alteration of a food web at the primary or secondary level can have devastating impacts to the ecosystem. For example, the introduction of a freshwater shrimp in the Flathead Lake-River ecosystem (Montana), for the purpose of enhancing the rainbow trout (Oncorhynchus mykiss) population, resulted in the dramatic decline of zooplankton, the collapse of the kokanee salmon (O. nerka) population (itself introduced), and the displacement of birds and mammals that fed on the spawning kokanee (Spencer et al. 1991). In another example, at least 22 species of birds and mammals feed on salmon carcasses on the Olympic Peninsula, Washington (Cederholm et al. 1989). Bilby et al. (1996) determined that salmon carcasses are major sources of carbon and nitrogen for aquatic and terrestrial organisms in systems with healthy salmon runs. Willson and Halupka (1995) found that Pacific salmon in all life history stages are keystone species in southeast Alaska vertebrate assemblages. Thus, the removal or diminution of salmon cascades throughout the terrestrial and aquatic ecosystems, making the concept of "excess production" meaningless.

The United Nations Convention on Biological Diversity was negotiated in 1992 because of international recognition of the global impact of declining biodiversity. Although no U.S. policy to conserve biodiversity exists as of this writing, concerns for biodiversity are inherent in at least 29 federal laws (OTA 1987). However, the federal "effort" to preserve biodiversity is piecemeal at best. The National Environmental Policy Act requires an impact assessment of proposed federal actions, but it is procedural in nature and does not result in redirection of those actions; the Endangered Species Act does not protect species until they are at extreme risk, which may be too late; the Marine Mammal Protection Act regulates the take of marine mammals but does not broadly protect habitat or the prey base; and the Clean Water Act is directed toward water quality which is only one of many habitat concerns (Blockstein 1992). Contrary to the United States, both Canada and Mexico have directly faced the threats of declining biodiversity.

In response to the United Nations Convention, Canada developed a Canadian Biodiversity Strategy to (1) conserve biodiversity and to use biological resources in a sustainable manner, (2) improve understanding of ecosystems and increase resource management capabilities, (3) promote understanding of the need to conserve biodiversity and sustainable rates of bioresource use, (4) maintain or develop incentives for the above, and (5) work with other countries to conserve biodiversity, to use bioresources in a sustainable manner, and to equitably share the benefits of using genetic resources. Initial implementation steps include reporting on policies, plans, and activities for implementing the strategy; coordinating strategy implementation; encouraging nongovernmental participation; and reporting on biodiversity status.

In 1992, the president of Mexico convened an international biodiversity meeting that resulted in the creation of CONABIO (National Commission for the Knowledge and Use of Biodiversity). CONABIO has a staff of 50 and an average annual budget of US $3 million. Almost 80% of these funds support biodiversity projects such as atlases, databases, and public awareness television programs.

Efforts to protect or restore biodiversity in the United States, while laudable, are limited in scope. One example is Bring Back the Natives, a cooperative state-federal program coordinated by the National Fish and Wildlife Foundation to restore the health of riverine systems and the associated native species on lands administered by the U.S. Forest Service and Bureau of Land Management. In another example, five state agencies and four federal land management agencies in California have agreed to make “the maintenance and enhancement of biological diversity a preeminent goal in their protection and management policies” (USDOI and USDA 1992). The forest ecosystem management plan proposed for the Pacific Northwest is an even more ambitious outgrowth of these efforts to integrate biodiversity conservation and forest ecosystem management, including socioeconomic factors (FEMAT 1993). Such efforts to protect and restore biodiversity should be expanded. When doing so, it is important to recognize that human-altered ecosystems are not inherently bad and that the cultural policies of overpopulation and overconsumption and inadequately developed ethics that ultimately cause these alterations are beyond the control of managers (Radonski and Loftus 1993). Efforts to maintain and restore biodiversity must consider the value and stability of existing ecosystems and acknowledge that both perturbed and natural ecosystems are now present. The objective should be to maintain species, ecosystems, and landscapes in as sustainable and as nearly natural states as possible. Although human-altered ecosystems are not inherently bad, we must recognize that many existing ones are not sustainable, nor are the human cultures and technologies they support. Without fundamental changes in policies and environmental ethics consistent with the above, biodiversity will continue to deteriorate. Fishery managers must begin to make that message clear.

Needed Actions

The American Fisheries Society policy concerning biodiversity includes five broad areas (general policy, education, management, monitoring, and research):

General Policy

(1) Encourage the United States, Canada, and Mexico to develop explicit, comprehensive national policies on biodiversity (see Studds 1991), adopt strategies for the maintenance and restoration of biodiversity, identify and promote international linkages that sustain biodiversity, and make the support of national and international conservation efforts national priorities wherever possible, including the maintenance and expansion of international aid, the “debt-for-nature” program, bilateral agreements that address resource conservation, and the “man and the biosphere” program. Encourage the United Nations to assist other nations in the development of similar efforts in member nations. The signing of the Convention on Biological Diversity (CBD) by more than 150 countries, including the United States, is a good beginning. The AFS should urge the United States to ratify the CBD as quickly as possible.

(2) Encourage all agencies at all levels to periodically review their programs for consistency regarding the protection and restoration of biodiversity and to modify any inconsistencies that may be found.

Education

(3) Encourage the education of policy makers, resource managers, industry, schoolchildren, and the public, particularly landowners, about the importance of maintaining biodiversity and preserving genetic diversity. Root causes such as population growth, overconsumption, institutional shortcomings, and inadequately developed environmental ethics should be linked to losses in biodiversity.

(4) Encourage and support the education of policy makers, resource managers, industry, and landowners on how to manage, protect, and restore altered ecosystems to be as productive and as nearly natural as possible.

Management

(5) Recommend that planning occur on an ecosystem, watershed, landscape, and ecoregion basis, rather than in a piecemeal recovery of individual species. The primary goal in land-use and ocean planning should be to maintain ecosystem integrity at multiple scales.

(6) Support management for ecosystem processes (e.g., nutrient cycling, energy and water flow), landscape processes (e.g., succession, natural disturbances), and native species assemblage and processes (e.g., migrations, multiple life history strategies, multiple functional guilds, evolution of species and other levels of biological diversity). Natural disturbances such as floods, fires, and drought help maintain natural communities and thus included in ecosystem management strategies.

(7) Recommend that the evaluation of the impacts to biodiversity from proposed actions be included in environmental assessments and impact statements.

(8) Encourage the establishment of sanctuaries in representative types of marine, estuarine, and freshwater habitats and greater protection and restoration of native ecosystems in those habitats. The sanctuaries should include large core areas with buffers and interconnecting corridors to protect gene pools yet facilitate genetic exchange.

(9) Encourage the proper use of agricultural, commercial, and residential lands to avoid nonpoint pollution, including increased temperature, siltation, and the loss of large woody debris. Specific actions include real estate development guidelines such as prohibitions on development in floodplains and dewatering of wetlands; the inclusion of riparian buffer strips along streams, rivers, and lakes; and the use of best management practices on all lands.

(10) Emphasize restoration of ecosystem processes and aquatic communities by addressing underlying problems. Management tools such as fish culture, fish passage facilities, and fish transfer programs could be employed in the context of addressing these underlying problems and contributing to their solution.

Monitoring

(11) Encourage and assist in the identification and monitoring of species and ecosystems that show early signs of decline or degradation and that need protection. Fieldwork identifying how the various parts interact and how human activities have affected those interactions must take place for effective protective action to occur.

(12) Support increased funding and decreased restrictions for long-term, comprehensive biological monitoring programs such as the U.S. Environmental Protection Agency's (EPA) Environmental Monitoring and Assessment Program, U.S. Geological Survey's National Water Quality Assessment, and state biological criteria programs. Encourage EPA and state support for quantitative biological criteria for all surface waters.

Research

(13) Encourage fisheries management agencies to improve sampling designs and stock assessment to prevent overharvest and to devise gear and harvest methods that minimize bycatch while increasing bycatch penalties.

(14) Support increased funding for environmental research to support biodiversity, including the National Center for Biological Diversity and Conservation Research (see Blockstein 1988, 1989) and the creation of a National Institutes for the Environment (see Howe et al. 1990). Research should address the linkages among habitat, biodiversity, and productivity as well as the importance of biological diversity in ecosystem processes. Systematics is the basis for recognizing biodiversity and should also be supported.

(15) Recommend that social science research be conducted to determine how people manage their resources, how changes in resource availability and land use affect human behavior, how people value and use their natural resources, and what types of incentives, economic or otherwise, will contribute to the conservation and ecologically sustainable use of those resources.

(16) Recommend regional-scale research and monitoring to document how varying percentages of disturbed land and extents of riparian vegetation affect the physical and chemical habitats of aquatic systems and their resident biota. This information is needed to explicitly predict the amounts of land that should be set aside to protect aquatic and riparian ecosystems and the biological benefits of doing so.

References

Allan, J. D., and A. S. Flecker. 1993. Biodiversity conservation in running waters. BioScience 43:32-43.

Allendorf, F. W., and R. F. Leary. 1986. Heterozygosity and fitness in natural populations of animals. Pages 57-76 in M. E. Soulé, ed. Conservation biology: the science of scarcity and diversity. Sinauer Associates, Sunderland, MA.

Anderson, J. E. 1991. A conceptual framework for evaluating and quantifying naturalness. Conserv. Biol. 5:347-358.

Becker, C. D. 1992. Population growth versus fisheries resources. Fisheries 17(5):4-5.
Benke, A. C. 1990. A perspective on America's vanishing streams. J. North Am. Benthol. Soc. 91:77-88.

Bilby, R. E., B. Fransen, and P. A. Bisson. 1996. Incorporation of nitrogen and carbon from spawning coho salmon into the trophic system of small streams: evidence from stable isotopes. Can. J. Fish. Aquat. Sci. 53:164-173.

Blockstein, D. E. 1988. U.S. legislative progress toward conserving biological diversity. Conserv. Biol. 2(4):311-313.

1989. Toward a federal plan for biological diversity. Issues in Science and Technology 5(4):63-67.

1992. An aquatic perspective on U.S. biodiversity policy. Fisheries 17(3):26-30.

Cairns, M. A., and R. T. Lackey. 1992. Biodiversity and management of natural resources: the issues. Fisheries 17(3):6-10.

Carlton, J. T. 1989. Man's role in changing the face of the ocean: biological invasions and implications for conservation of near-shore environments. Conserv. Biol. (3): 265-273.

Cederholm, C. J., D. B. Houston, D. L. Cole, and W. J. Scarlett. 1989. Fate of coho salmon (Oncorhynchus kisutch) carcasses in spawning streams. Can. J. Fish. Aquat. Sci. 46(8):1,347-1,355.

Dourojeanni, M. J. 1990. Entomology and biodiversity conservation in Latin America. Am. Ent. 36(2):88-93.

Ehrenfeld, D. 1978. The arrogance of humanism. Oxford University Press, New York.

Ehrlich, P. R., and A. H. Ehrlich. 1977. Ecoscience: population, resources, environment. W. H. Freeman, San Francisco.

Ehrlich, P. R., and E. O. Wilson. 1991. Biodiversity studies: science and policy. Science 253:758-762.

Estes, J. A., D. O. Duggins, and G. B. Rathbum. 1989. The ecology of extinctions in kelp forest communities. Conserv. Biol. 3(3):252-264.

Evans, D. O., and C. C. Wilcox. 1991. Loss of exploited indigenous populations of lake trout, Salvelinus namaycush, by stocking of nonnative stocks. Can. J. Fish. Aquat. Sci. (Suppl. 1) 48:134-147.

Fausch, K. D., and R. J. White. 1981. Competition between brook trout (Salvelinus fontinalis) and brown trout (Salmo trutta) for positions in a Michigan stream. Can. J. Fish. Aquat. Sci. 38:1,220-1,227.

FEMAT (Forest Ecosystem Management Assessment Team). 1993. Forest ecosystem management: an ecological, economic, and social assessment. USGPO:1993-793-071, U.S. Forest Service, Washington, DC.

Frey, D. G. 1977. Biological integrity of water—a historical approach. Pages 127-140 in R. K. Ballentine and L. J. Guarria, eds. The integrity of water. U.S. Environmental Protection Agency, Washington, DC.

Houghton, R. A. 1994. The worldwide extent of land-use change. BioScience 44:305-313.

Howe, H. F., S. P. Hubbell, and D. E. Blockstein. 1990. Rationale for the National Institutes for the Environment. The Environmental Professional 12:360-363.

Hughes, R. M. 1995. Defining acceptable biological status by comparing with reference conditions. Pages 31-47 in W. S. Davis and T. P. Simon, eds. Biological assessment and criteria: tools for water resource planning and decision making. Lewis Press, Boca Raton, FL.

Hughes, R. M., and R. F. Noss. 1992. Biological diversity and biological integrity: current concerns for lakes and streams. Fisheries 17(3):11-19.

Janzen, D. H. 1987. Insect diversity of a Costa Rican dry forest: why keep it, and how. Biol. J. Linn. Soc. 30:343-356.

Judy, R. D., P. N. Seeley, T. M. Murray, S. C. Svirsky, M. R. Whitworth, and L. S. Ischinger. 1984. 1982 National Fisheries Survey, volume 1, technical report, FWS/OBS-84/06. U.S. Fish and Wildlife Service, Fort Collins, CO.

Karr, J. R., and D. R. Dudley. 1981. Ecological perspective on water quality goals. Environ. Manage. 5:55-68.

Kelly, G. A., J. S. Griffith, and R. D. Jones. 1980. Changes in distribution of trout in Great Smoky Mountains National Park, 1900-1977. U.S. Fish and Wildl. Serv. Tech. Pap. 102, Washington, DC.

Knutson, L. 1989. On the diversity of nature and the nature of diversity. Bull. Entomol. Soc. Am. 35(4):7-11.

Larsen, D. P., K. W. Thorton, N. S. Urquhart, and S. G. Paulsen. 1994. The role of sample surveys for monitoring the condition of the nation's lakes. Environ. Mon. Assess. 32:101-134.

Lubchenco, J., and 15 other authors. 1991. The sustainable biosphere initiative: an ecological research agenda. Ecology 72(2):371-412.

Macauley, J. M., J. K. Summers, V. D. Engle, P. T. Heitmuller, G. T. Brooks, M. Babikow, and A. M. Adams. 1994. Statistical summary: EMAP-Estuaries Louisianian Province—1992. EPA/620/R-94/002. U.S. Environmental Protection Agency, Gulf Breeze, FL.

Maser, C. 1992. Global imperative: harmonizing culture and nature. Stillpoint Publishing, Walpole, NH.

Master, L. 1990. The imperiled status of North American aquatic animals. Biodiversity Network News 3(3):1-2, 5-7, 7-8.

McClanahan, T. R. 1990. Are conservationists fish bigots? Bioscience 40(1):2.

McNeely, J. A., K. R. Miller, W. V. Reid, R. A. Mittermeier, and T. B. Werner. 1990. Conserving the world's biological diversity. International Union for Conservation of Nature and Natural Resources, Gland, Switzerland.

Miller, R. R., J. D. Williams, and J. E. Williams. 1989. Extinctions of North American fishes during the past century. Fisheries 14(6):22-38.

Moyle, P. B., H. W. Li, and B. A. Barton. 1986. The Frankenstein effect: impact of introduced fishes on native fishes in North America. Pages 415-426 in R. H. Stroud, ed. Fish culture in fisheries management. American Fisheries Society, Bethesda, MD.

Nehlsen, W., J. E. Williams, and J. A. Lichatowich. 1991. Pacific salmon at the crossroads: stocks at risk from California, Oregon, Idaho, and Washington. Fisheries 16(2):4-21.

Nelson, K., and M. Soulé. 1987. Genetical conservation of exploited fishes. Pages 345-368 in N. Ryman and F. Utter, eds. Population genetics and fishery management. University of Washington Press, Seattle.

NMFS (National Marine Fisheries Service). 1992. Our living oceans: report on the status of U.S. living marine resources, 1992. NOAA Tech. Memo. NMFS-F/SPO-2, U.S. Department of Commerce, Washington, DC.

Norse, E. A., K.L. Rosenbaum, D. S. Wilcowe, B. A. Wilcox, W. H. Romme, D. W. Johnston, and M. L. Stout. 1986. Conserving biological diversity in our national forests. The Wilderness Society, Washington, DC.

Ohio Environmental Protection Agency. 1988. Biological criteria for the protection of aquatic life, volume 1. Ohio Environmental Protection Agency, Columbus.

OTA (Office of Technology Assessment). 1987. Technologies to maintain biological diversity. U.S. Government Printing Office, Washington, DC.

Radonski, G. C., and A. J. Loftus. 1993. Biodiversity and fisheries management. Fisheries 18(4):2.

Reid, W. V., and K. R. Miller. 1989. Keeping options alive: the scientific basis for conserving biodiversity. World Resources Institute, Washington, DC.

Reisenbichler, R. R., J. D. McIntyre, M. F. Solazzi, and S. W. Landino. 1992. Genetic variation in steelhead of Oregon and northern California. Trans. Am. Fish. Soc. 121:158-169.

Rolston III, H. 1991. Fishes in the desert: paradox and responsibility. Pages 93-108 in W. L. Minckley and J. E. Deacon, eds. Battle against extinction: native fish management in the American West. University of Arizona Press, Tucson.

Ryman, N., and L. Laikre. 1991. Effects of supportive breeding on the genetically effective population size. Conserv. Biol. 5(3):325-329.

Scarnecchia, D. L. 1992. A reappraisal of gars and bowfins in fishery management. Fisheries 17(5):6-12.

Schonewald-Cox, C. M., S. M. Chambers, B. MacBryde, and W. L. Thomas, eds. 1983. Genetics and conservation: a reference for managing wild animal and plant populations. Benjamin-Cummings, Menlo Park, CA.

Scott, J. M., and 10 other authors. 1991. Conservation of biological diversity: some perspectives and a look to the future for The Wildlife Society. A report to The Wildlife Society. Bethesda, MD.

Sheldon, A. L. 1988. Conservation of stream fishes: patterns of diversity, rarity, and risk. Conserv. Biol. 2(2):149-156.

Smith, S. H. 1968. Species succession and fishery exploitation in the Great Lakes. J. Fish. Res. Board Can. 25:667-693.

1972. Factors of ecologic succession in oligotrophic fish communities of the Laurentian Great Lakes. J. Fish. Res. Board Can. 29:717-730.

Soulé, M. E. 1991. Conservation: tactics for a constant crisis. Science 253:744-750.

Spencer, C. N., B. R. McClelland, and J. A. Stanford. 1991. Shrimp stocking, salmon collapse, and eagle displacement. Cascading interactions in the food web of a large aquatic ecosystem. BioScience 41(1):14-21.

Studds, G. E. 1991. Preserving biodiversity. BioScience 41(9):602.

Swift, B. L. 1984. Status of riparian ecosystems in the United States. Water Resources Bulletin 20:223-228.

Taylor, P. W. 1986. Respect for nature. Princeton University Press, Princeton NJ.

Terborgh, J. 1988. The big things that run the world, a sequel to E. O. Wilson. Conserv. Biol. 2(4):402-403.

Upton, H. F. 1992. Biodiversity and conservation of the marine environment. Fisheries 17(3):20- 25.

USDOI and USDA (U.S. Department of the Interior and U.S. Department of Agriculture). 1992. America's Biodiversity Strategy: actions to conserve species and habitats. U.S. Department of the Interior and U.S. Department of Agriculture, Washington, DC.

USEPA (U.S. Environmental Protection Agency). 1990. Reducing risk: setting priorities and strategies for environmental protection. SAB-EC-90-021. U.S. Environmental Protection Agency, Washington, DC.

Vitousek, P. M., P. R. Ehrlich, A. H. Ehrlich, and P. A. Matson. 1986. Human appropriation of the products of photosynthesis. BioScience 36:368-373.

Waters, T. F. 1983. Replacement of brook trout by brown trout over 15 years in a Minnesota stream: production and abundance. Trans. Am. Fish. Soc. 112(2A):137-147.

Williams, J. E., J. E. Johnson, D. A. Hendrickson, S. Contreras-Balderas, J. D. Williams, M. Navarro-Mendoza, D. E. McAllister, and J. E. Deacon. 1989. Fishes of North America endangered, threatened, or of special concern: 1989. Fisheries 14(6):2-20.

Willson, M. F., and K. C. Halupka. 1995. Anadromous fish as a keystone species in vertebrate communities. Conserv. Biol. 9(3):489-497.

Wilson, E. O. 1987. The little things that run the world. Conserv. Biol. 1(4):344-346.