The Decline of North American Freshwater Fishes

Stephen J. Walsh, Howard L. Jelks and Noel M. Burkhead
U.S. Geological Survey
Gainesville, Florida

(This article originally appeared in *Action Bioscience*)

The fishes of North America's inland waters, the most diverse of any temperate region, currently face an unprecedented conservation crisis.

- About 40% are imperiled or presumed extinct and the portion of imperiled fishes is increasing.
- Threats to this fauna include habitat destruction, introduced species, altered hydrology, pollution, sedimentation, disease, parasitism, over-exploitation, and other factors.
- Extinctions and imperilment of fishes occur among diverse taxonomic groups, across regions, and in a variety of habitats.
- The southeastern and central U.S., mid-Pacific region, and coastal and interior basins of south-central Mexico have the greatest numbers of threatened fishes.

North America has a broad array of freshwater ecosystems as a result of the continent's complex geography and geological history. Within a multitude of habitats that include streams, large rivers, natural lakes, springs, and wetlands reside rich assemblages of fishes that represent diverse taxonomic groups and with unique ecological requirements. In the last few decades, the inland fishes of North America have been declining at an alarming rate. Although extinctions have occurred and many species and populations are in critical trouble, the fish biota of the continent as a whole remains diverse and there are societal actions that can stem further precipitous declines.

Fish biodiversity

Globally, fishes outnumber all other vertebrates combined and have the highest rate of discovery of new species. Fishes exhibit a remarkable diversity of morphological attributes and biological adaptations, and occur in most aquatic habitats on Earth. Even in North America, where scientific knowledge of the fauna is advanced, new species are described every year. These discoveries are the combined result of applied technologies such as gene sequencing, which increases recognition of biodiversity at all scales, and the physical documentation of new, morphologically distinct forms and populations. Biological taxonomy is the discipline of classifying and naming organisms using an internationally accepted system or code. Because of the dynamic nature of fish taxonomy and the presence of vast, unexplored areas of the planet with potentially many undescribed species, statements or conclusions about numbers and percentages of species occurring in particular habitats or geographical regions are but rough approximations. Nevertheless, overall trends are evident.

- Fresh water constitutes only about 1% of the Earth's surface area and less than 0.01% of its water by volume.
- A conservative estimate is that as many as 32,500 extant (living) fish species may exist in the world.[1] However, this number may eventually prove greater, with approximately 30,000 currently recognized as valid and over 300 new species described each year.[2]
- About 12,000 species, or approximately 43% of all currently named fishes, occur exclusively in fresh waters. A small number are diadromous, regularly living part of their lives in rivers, streams, or lakes and part in the oceans.
- North America has the greatest taxonomic richness of freshwater fishes among temperate regions of the world, although greatly surpassed in number of species by less documented areas of the tropics, especially the biological hotspots of South America, Africa, and southeast Asia.[3,4] Currently, there are approximately 1,200 recognized fish species that occur in inland waters of the continental United States, Canada, and Mexico.
- Collectively, the fish fauna (ichthyofauna) of North America's freshwater ecosystems is in serious decline as more species and distinct populations have become increasingly imperiled over time.
- Worldwide, historical and emerging trends in the conservation of fishes and fishery stocks portray gloomy conditions, yet there are reasons for optimism and potential for recovery and protection of these declining resources given societal resolve.[5]

Environmental threats

Media coverage of conservation issues about the world's animals is often greatest for species that are particularly endearing to humans, such as mammals and birds, whereas perils to aquatic faunas, including fishes, are often much less publicized. This disparity is due, in part, to taxonomic bias in research and funding in the field of conservation biology. Based on published scientific literature, fishes, amphib-

Fig. 1.
Habitat loss, landscape modification, and degradation of aquatic ecosystems are the leading causes of imperilment for North American freshwater fishes. Consequences of coal strip-mining (as shown here, tributary of Pound River, Virginia) can eliminate all but the most tolerant of aquatic life in streams. Photograph by R.E. Jenkins, courtesy of Virginia Division of Game and Inland Fishes.

ians, reptiles, and invertebrates are underrepresented in conservation studies relative to the proportion of species of each group known worldwide,[6] and organisms in the freshwater and marine realms receive much less coverage than those in terrestrial environments.[7] Among invertebrates, however, it is notable that mollusks and crustaceans, of which many species are aquatic, are generally better studied than the vast diversity of arthropods—especially insects, with the exception of butterflies and moths.

Major deficits in funding for faunal surveys, monitoring, and basic research, and the general lack of public awareness about the conservation status of fishes across taxonomic groups and ecosystems is a significant problem. Given the myriad of threats to aquatic habitats throughout the world, the degree to which degradation of these habitats is accelerating, and the overall proportion of biodiversity represented, extraordinary resources are in unprecedented danger of being significantly diminished or lost. In particular, freshwater habitats are some of the most threatened in the world.[8,9,10] Moreover, aquatic systems are inextricably linked to terrestrial habitats, and pollutants and sediments from perturbed landscapes flow downhill into lakes, streams, and rivers. Threats to freshwater ecosystems are so pervasive that many endemic species, those naturally restricted to a single drainage or ecoregion, are greatly imperiled simply because restricted geographic distribution makes them more vulnerable to human modification of landscapes. Among the most important threats to fishes in freshwater habitats are:

- *Destruction or modification of habitat resulting in reduced range size and/or loss of populations.* Examples include dam construction, channelization, mining, clearing of natural forests for agriculture, urban development, and other intensive land-use practices.
- *Water depletion.* Some desert fishes have become extinct as a result of human exploitation of limited groundwater resources.
- *Pollution from identified point and non-point source contaminants.* Runoff from urban areas, and the compound effects of multiple pollutants, often reduces water quality to the point that only the most tolerant species remain in receiving water bodies.
- *Erosion and sedimentation.* Fine sediments can smother bottom substrates, to the detriment of many bottom-dwelling (benthic) species, whose prey and reproductive success are dependent on clean substrates and good water quality.

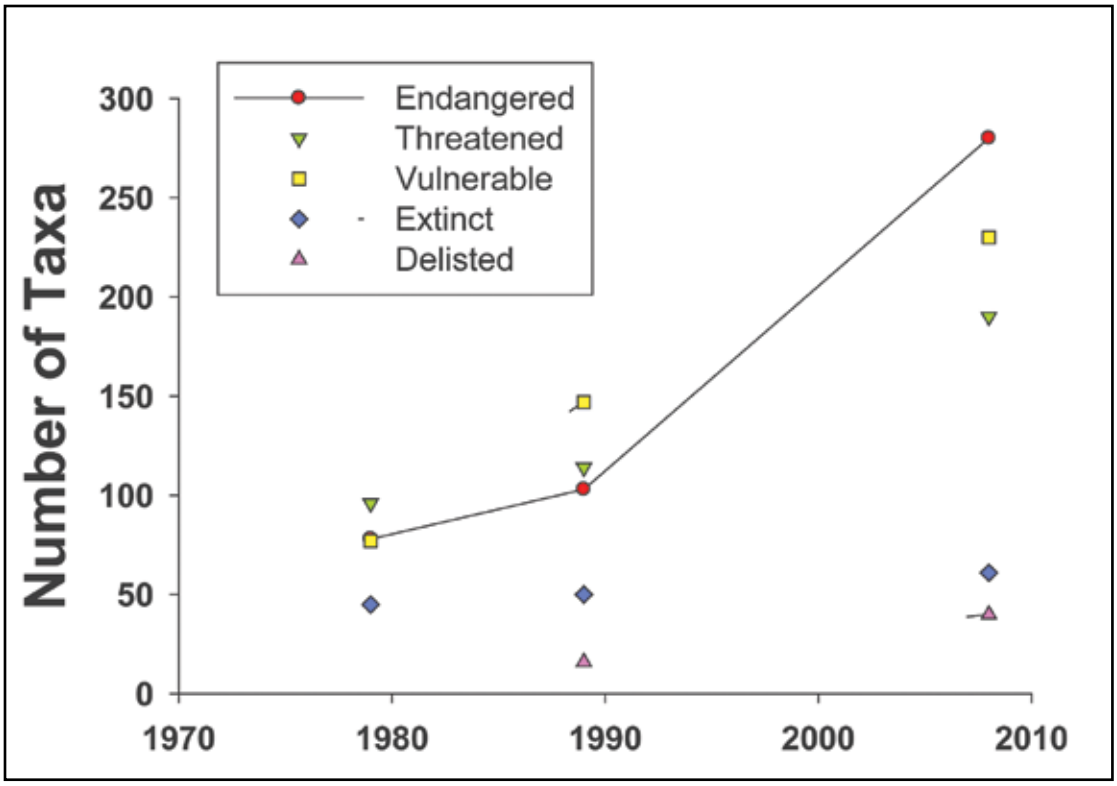

Fig. 2.
Chronological increase in the number of fish taxa imperiled in North America freshwater ecosystems, as assessed by the American Fisheries Society Endangered Species Committee. Assessments were conducted in 1979, 1989, and 2008. Delisted taxa are those that appeared on a previous list but were removed for various reasons, such as evidence of taxonomic invalidity.

- *Over-exploitation for commercial, recreational, scientific, or educational purposes.* Examples of fishes that have been over-harvested include salmons, whitefishes, trouts, Striped Bass, and sturgeons.
- *Disease or parasitism.* For instance, whirling disease, a microscopic parasite introduced from Europe, has ravaged many wild and hatchery populations of trouts and salmon in the U.S. and Canada.
- *Other anthropogenic factors including introduction of non-native species, which may result in hybridization, competition, and predation.* Numerous introductions of fishes, both from outside of North America and intra-continental transplants, have had severe negative impacts on native species[11] including some that have caused extinction.
- *Climate change.* Regional variation in rainfall patterns, storm events, and droughts can affect habitats and potentially have negative consequences for rare species.

Conservation status of North American freshwater and diadromous fishes

The Endangered Species Committee of the American Fisheries Society (AFS-ESC) has tracked the plight of imperiled fishes in North America for over 30 years, with the explicit aim of providing objective and unbiased status assessments independent of the influence of policy or regulatory considerations. Recently the AFS-ESC, represented by 16 scientists from the United States, Canada, and Mexico, with the assistance of numerous colleagues, evaluated the conservation status of the entire continental fish fauna[12]. In the latest assessment, approximately 40% of described North American freshwater and diadromous fish species were documented as imperiled or extinct, representing a substantial increase over previous assessments. A taxon (taxa, plural) is a unit used in biological classification and is defined on the basis of a natural relationship, formally recognized as one or more lineages (=clades) of descendants sharing a common ancestry. Past conservation assessments by the AFS were limited to determining status of distinct species and subspecies. Undescribed forms, or those not named in the scientific literature using classic Linnaean binomial nomenclature, were included where sufficient data

cont. on p. 15

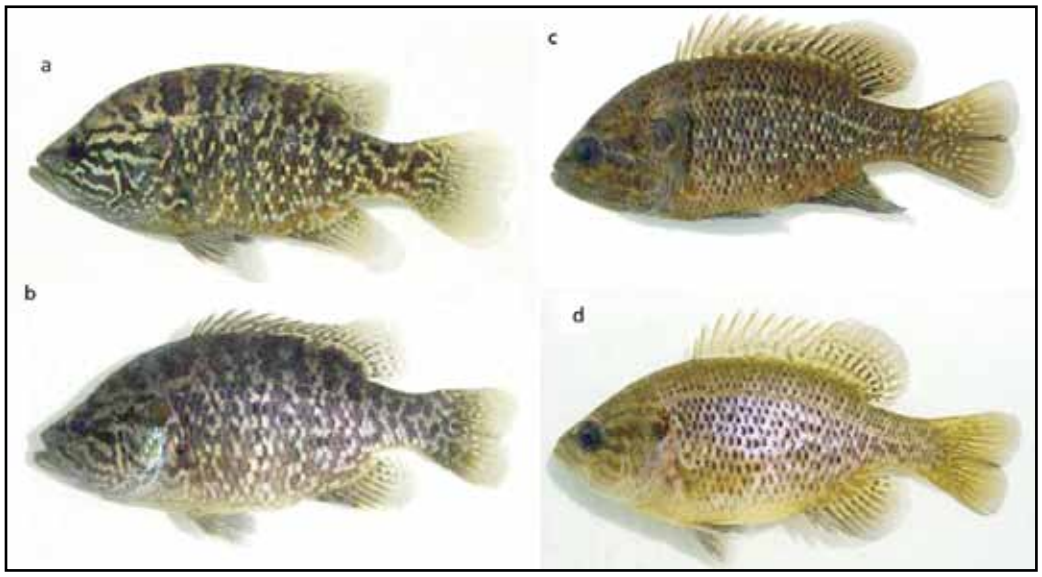

Fig. 1.
Photograph of left lateral aspect of adult Warmouth Lepomis gulosus wild caught (quarry pond Lincoln University of Missouri Campus, Cole Co., MO) a) male TL=155 mm, wt=81.1 g, b) female TL=157 mm, wt.=87.6 g and F2 tank raised (source St. James Ditch, Mississippo Co., MO) c) male TL = 150 mm, 71.1 g and d) female TL=135 mm, 54.2 g. Images are not to scale.

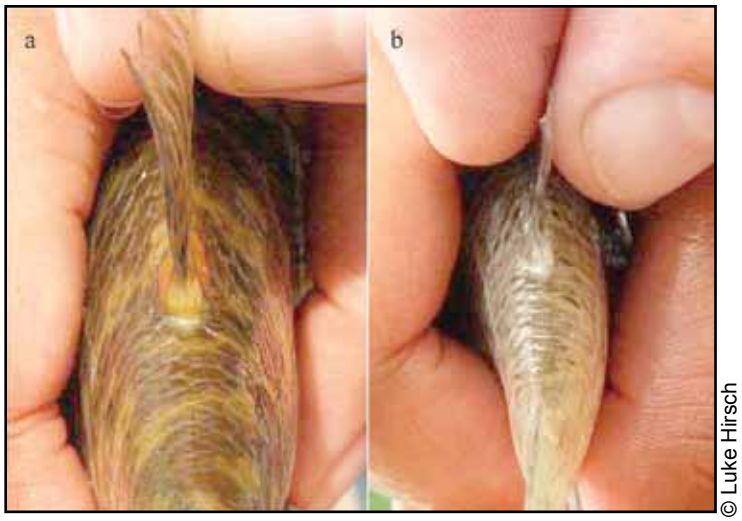

Fig. 2.
Photograph of posterior aspect of dorsal fin rays of adult Warmouth, *L. gulosus* a) male and b) female. Notice orange-red spots lateral to insertion point of dorsal rays on male. Images are not to scale.

Fig. 3.
The Boulder Darter, *Etheostoma wapiti,* a handsome inhabitant of our native waters and only found at one site near the border of Tennessee and Alabama. CFI is returning this species to a second historical site in hopes of its successful reestablishment.
Photos in Figs. 3-5 by CFI

Fig. 4.
Spotfin Chub, *Erimonax monachus*, is also called the Turquoise Shiner, but one can easily see from the subterminal mouth and its grazing behavior that the "chub" designation is appropriate. However, while observing an iridescent blue male displaying in the water column, the splendor of turquoise is quite fitting.

Fig. 5.
One of our most beautiful Topminnows, *Fundulus julisia*, is found only in a small region called the Barrens Plateau, located to the west of the Cumberland Plateau. This species is extremely threatened in its native waters by introduced mosquitofish and the lowering of the water table, as wells are being used by the many nurseries located in the area.

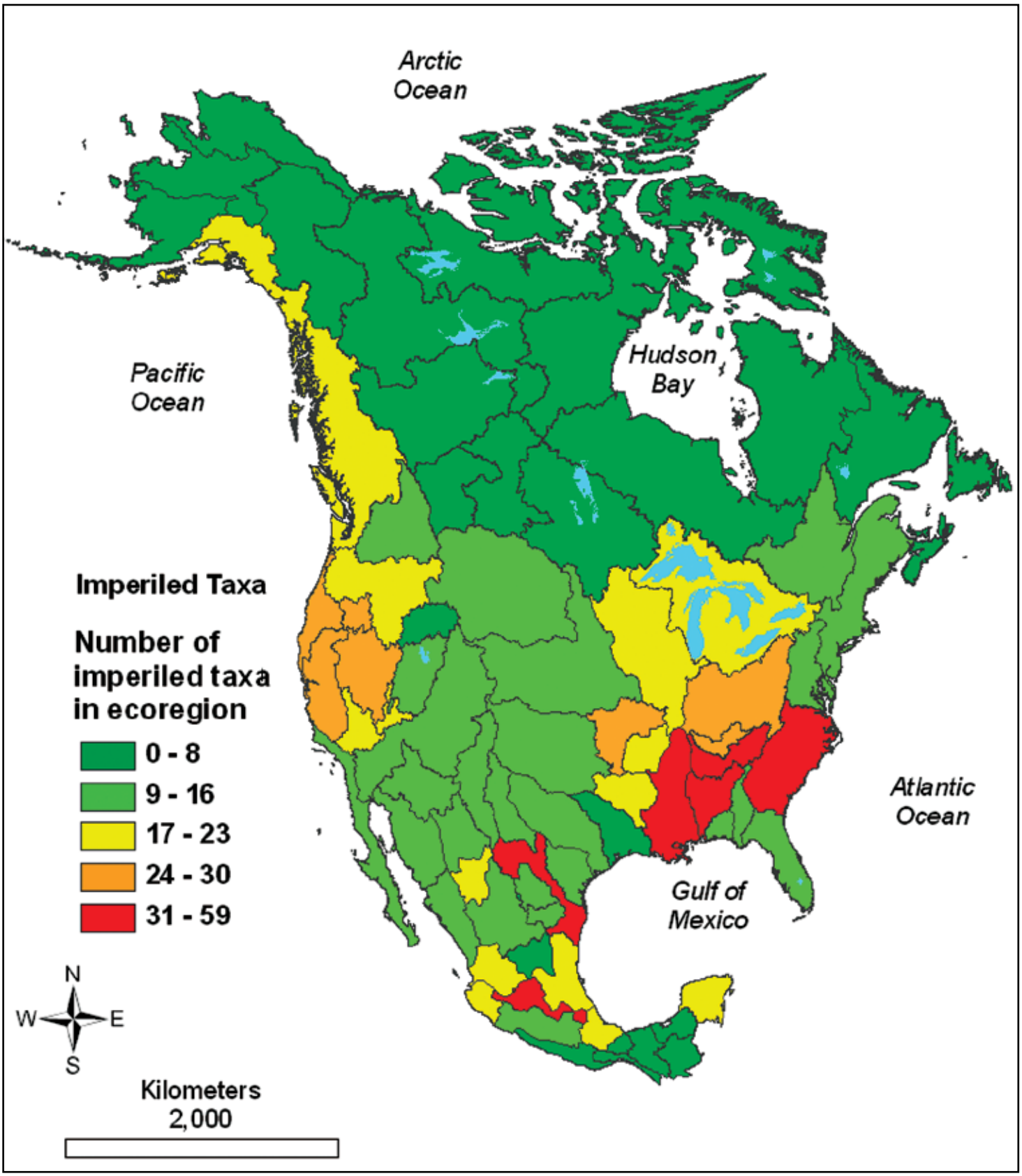

Fig. 3.
Numbers of imperiled freshwater and diadromous fishes by ecoregions within North America based on the most recent conservation assessment by the American Fisheries Society's Endangered Species Committee.[12]

Decline of N.A,. Freshwater Fishes...cont. from p. 12

were available to document taxonomic distinctiveness, as evidenced by unique morphological, genetic, or other attributes. In the most recent assessment, additional infraspecific taxa were included in the form of distinctive populations, or what are sometimes referred to in the scientific community as evolutionarily significant units (ESUs) or distinct population segments (DPSs, although this term has certain legal connotations under the Endangered Species Act within the U.S.; see http://www.fws.gov/endangered/POLICY/Pol005.html). Taxa were ranked in a hierarchical arrangement of imperilment that corresponds to equivalent categories recognized by many public agencies and conservation organizations:

- Endangered (E): in imminent (fewer than 50 years) danger of extinction, or extirpation (loss of populations) throughout most portions of a taxon's range.
- Threatened (T): in imminent danger of becoming endangered.
- Vulnerable (V): in imminent danger of becoming threatened; comparable to a designation of "Special Concern" by many agencies and conservation organizations.
- Extinct (X): a taxon that has not been observed for over 50 years. Two subcategories were included: Possibly Extinct (X_p), a taxon suspected to be extinct, as evidenced by more than 20 but less than 50 years since living representatives were observed, and Extirpated in Nature (X_n), where all populations in natural habitats are presumed eliminated but surviving individuals are maintained in captivity.

There are 700 fish taxa currently considered to be imperiled in North America's inland waters, representing 133 genera in 36 families. The majority of taxa are named species (63%), followed by named subspecies (13%), populations (12%), undescribed species (7%), and undescribed subspecies (5%). Of the total, 280 are endangered, 190 threatened, 230 vulnerable, and an additional 61 taxa (mostly described species or subspecies) are presumed to be extinct or extirpated in the wild. The number of imperiled fishes represents a 92% increase over a nearly 20-year period dating to 1989. Of those taxa currently listed and also recognized as imperiled in 1989, 89% have the same or a more severe conservation status, only 6% have improved, and 5% were delisted for various reasons, in most cases not associated with recovery of populations. The list of imperiled taxa encompasses fishes that span a remarkable diversity of lineages, morphologies, life-histories, and habitats. A taxonomic breakdown of the list and comparison to known, described species reveals disparities by family. Nearly one quarter of all imperiled taxa belong to the most species-rich family of North American freshwater fishes, the Cyprinidae, represented by the minnows and their allies. Another 15% is represented by the second-most diverse family, the Percidae, which includes a large number of darters—small, colorful fishes that have their greatest diversity and abundance in clear-flowing streams of the central and eastern U.S. The Salmonidae—trouts, salmons, ciscoes, and their allies—comprise nearly 12% of all imperiled taxa, but are disproportionally represented in comparison to other families by large numbers of infraspecific taxa.

The nomenclature (scientific and common names) of North American fishes is tracked by a joint committee of the AFS and American Society of Ichthyologists and Herpetologists, the Committee on Names of Fishes.[13] An analysis of imperiled, described species (i.e., excluding unnamed taxa, subspecies, and populations) revealed noteworthy levels of at-risk status for several fish families and the fauna in general. Of 1,188 described species, a staggering 40% were found to be in jeopardy or extinct. Groups with especially large numbers of imperiled species, relative to total number in each family, include: Acipenseridae, sturgeons (75% of species imperiled); Cyprinodontidae, pupfishes (81%); and Goodeidae, goodeids, a primarily Mexican group of small-bodied fishes (77%). The Ictaluridae (North American catfishes) and Catostomidae (suckers)—both families with over 50 described species—have significant levels of imperilment; 54% and 38%, respectively. The Salmonidae has 7 of 38 species imperiled, but another 16 species have populations or subspecies in trouble.

There are distinct geographic trends evident for imperiled North American fishes based on distributions within natural hydrologic units, or ecoregions (defined by a combination of physical drainage features and faunal similarity[10]). The greatest number of at-risk species are in the southeastern U.S., the mid-Pacific coast, the lower Rio Grande, and coastal and south-central inland regions of Mexico.[12] Of particular note is the distribution of imperiled fishes in North America within ecoregions; 80% of all taxa are confined (endemic) to a single ecoregion, and another 10% are limited to two ecoregions. A combination of limited range size and habitat degradation is attributed to much of the imperilment of the inland continental fish fauna. *Editor's Note: A color map showing the number of imperiled North American taxa by ecoregion can be found on page 14.*

Why be concerned about the decline of fishes in North America's inland waters?

Loss of biodiversity on planet Earth arguably ranks as the greatest impending environmental crisis currently facing humanity. The decline of North American fish species and populations, as with elements of biodiversity throughout the world, directly or indirectly impacts other faunas, is detrimental to freshwater ecosystems in general, and affects humankind in a variety of ways. Freshwater fishes are important sentinels of environmental conditions and play a crucial role in the ecology and sustainability of natural ecosystems. The natural

Fig. 4.
The Candy Darter (*Etheostoma osburni)* is a vulnerable species found in the New River system of Virginia and West Virginia. Darters are a colorful, species-rich group of small-bodied fishes limited in distribution to North America and with their greatest diversity in uplands of the central and eastern U.S. Photograph by N.M. Burkhead.

balance of both aquatic and terrestrial communities is dependent on fish populations that provide critical functions such as cycling nutrients and serving as prey to a large variety of carnivores, including birds, mammals, reptiles, and other fishes. The larvae of native freshwater mussels, called glochidia, require fish hosts in order to complete their life cycles. Some migratory fishes, such as shads, smelts, chars, and salmons, serve as keystone species of entire ecosystems. For instance, a variety of predators and scavengers feed on salmon adults, eggs, fry, and decaying carcasses, and nutrients transferred from the sea and incorporated into the food chain may contribute to the health of forests adjacent to streams in which salmon spawn, thereby illustrating the linkage between terrestrial and aquatic habitats.[5,14,15] Herbivorous species provide important functions in terms of cropping algae and plants or disseminating seeds and fruits. Humans derive immeasurable recreational, commercial, and intangible benefits from fish and fishery resources, and our welfare is directly linked to their protection and sustainability. Conversely, degraded aquatic ecosystems with simplified communities and altered food webs can lead to an increase in vectors, such as mosquitoes and snails, of water-related diseases like malaria, schistosomiasis, and cholera.[16]

These are but a few examples of the global importance of freshwater fishes, their habitats, and need for the conservation of both. Overall, there are countless ecosystem services that are provided by fish species and communities in the inland streams, rivers, lakes, and wetlands of North America. Beyond the economic value of fish, fisheries, and freshwater habitats, the intrinsic value of healthy natural aquatic ecosystems profoundly affects the human spirit and well-being.

What can scientists, individuals, organizations, and governments do?

Although the status and future prospects for North American fishes may appear bleak, there are many actions that can reverse declining trends, recover populations, and provide solutions. In a survey of environmental problems associated with fishes, the following solutions collectively emerged as suggestions for effective conservation actions:[5]

- Enforce existing laws and legislate new policies that protect native assemblages and habitats.
- Create reserves and protected land areas and water bodies. Large reserves provide greatest impact for protecting multiple species and communities.
- Promote ecosystem-based management.
- Be precautionary and proactive. Act despite uncertainty and without waiting for scientific consensus. Conservation crises may become irreversible and management actions may be required before supporting scientific data are available.
- Monitor results and manage adaptively. Make adjustments to improve conservation actions and implement successful ones for the long term.
- Increase research and monitoring. The amount of funding is rarely sufficient to adequately assess resources, yet the cost in the short term to identify and conserve biotas may be far less than that required to recover species and degraded habitats.
- Emphasize sustainability. Land-use activities that protect ecosystems while at the same time providing for human needs maximize the preservation of biodiversity.

- Avoid "technoarrogance," or technological fixes that treat symptoms rather than causes.
- Educate people at all age levels, demographic groups, and professions; e.g., children, business leaders, politicians, teachers, agency managers, land-use planners.
- Include all stakeholders at all stages in conservation planning and resource management; include accountability and transparency.
- Reduce fishing pressure by better managing stocks; create incentives for recreational and commercial interests to prevent overharvest.

Fortunately, many scientists, agencies, nongovernmental organizations, and other public and private stakeholders are actively involved in conservation programs for North American fishes. Large numbers of river-keeper groups have emerged in recent years, and are engaged in protecting natural habitats and aquatic communities and seeking ways to restore systems. Many reintroductions have proven to be successful and, although relatively limited in number, some species have improved in status or had successful steps to recovery. For example, the Bonneville Cutthroat Trout (*Oncorhynchus clarkii utah*) benefited from conservation actions on public lands and is no longer considered to be endangered.

An example of a large-scale conservation endeavor to protect and recover fishes within the U.S. is the National Fish Habitat Action Plan (NFHAP). This program involves locally and regionally-driven public and private partnerships to improve fish habitats. Exemplifying actions on a smaller scale, Conservation Fisheries, a small nonprofit organization, has played an important role in the propagation of several critically endangered species and their reintroduction into native habitats where populations had previously perished or were greatly diminished in size.

Stephen J. Walsh, Ph.D., Howard L. Jelks, M.Sc., and Noel M. Burkhead, M.Sc. are research biologists with the U.S. Geological Survey in Gainesville, Florida, and serve as co-chairs of the American Fisheries Society's Endangered Species Committee. All three scientists have broad research interests in ichthyology and have conducted studies on freshwater fishes in the central and southern U.S. for over three decades. They have authored many journal articles, book chapters, and books on the biology, ecology, and conservation of fishes.

Article References

1. Nelson, J.S. 2006. *Fishes of the world (4th edition).* John Wiley & Sons, Inc., Hoboken, New Jersey.
2. Eschmeyer, W.N. 1998. *Catalog of fishes.* California Academy of Sciences. 3 vol., 2,905 p.
3. Lundberg, J.G., M. Kottelat, G.R. Smith, M.L.J. Stiassny, and A.C. Gill. 2000. So many fishes, so little time: an overview of recent ichthyological discovery in continental waters. *Annnals of the Missouri Botanical Garden* 87(1):26-62.
4. Abell, R., M.L. Thieme, C. Revenga, M. Bryer, M. Kottelat, N. Bogutskaya, B. Coad, N. Mandrak, S. Contreras Balderas, W. Bussing, M.L.J. Stiassny, P. Skelton, G.R. Allen, P. Unmack, A. Naseka, R. Ng, N. Sindorf, J. Robertson, E. Armijo, J.V. Higgins, T.J. Heibel, E. Wikramanayake, D. Olson, H. López, R.E. Reis, J.G. Lundberg, M.H. Sabaj Pérez, and P. Petry. 2008. Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation. *BioScience* 58(5):403-414.
5. Helfman, G.S. 2007. *Fish conservation: a guide to understanding and restoring global aquatic biodiversity and fishery resources*. Island Press, Washington, D.C. 584 p.
6. Clark, J.A. and R.M. May. 2002. Taxonomic bias in conservation research. *Science* 297:191-192.
7. Irish, K.E. and E.A. Norse. 1996. Scant emphasis on marine biodiversity. *Conservation Biology* 10(2):680.
8. Master, L.L., S.R. Flack, and B.A. Stein (eds.). 1998. Rivers of life: critical watersheds for protecting freshwater biodiversity. The Nature Conservancy, 71 p. http://www.natureserve.org/library/riversoflife.pdf (accessed February 10, 2009).
9. Abell, R.A., D.M. Olson, E. Dinerstein, P.T. Hurley, J.T. Diggs, W. Eichbaum, S. Walters, W. Wettengel, T. Allnutt, C.J. Loucks, and P. Hedao. 2000. *Freshwater ecoregions of North America: a conservation assessment.* Island Press, Washington, D.C. 319 p.
10. Abell, R.A. and 26 co-authors. 2008. Freshwater ecoregions of the world: a new map of biogeographic units for freshwater biodiversity conservation. *BioScience* 43(1):406-414.
11. Fuller, P.L., L.G. Nico, and J.D. Williams. 1999. *Nonindigenous fishes introduced into inland waters of the United States.* American Fisheries Society Special Publication 27.
12. Jelks, H.J., S.J. Walsh, N.M. Burkhead, S. Contreras-Balderas, E. Díaz-Pardo, D.A. Hendrickson, J. Lyons, N.E. Mandrak, F. McCormick, J.S. Nelson, S.P. Platania, B.A. Porter, C.B. Renaud, J.J. Schmitter-Soto, E.B. Taylor, and M.L. Warren, Jr. 2008. Conservation status of imperiled North American freshwater and diadromous fishes. *Fisheries* 33(8):372-407.
13. Nelson, J.S., E.J. Crossman, H. Espinosa-Pérez, L.T. Findley, C.R. Gilbert, R.N. Lea, and J.D. Williams. 2004. *Common and scientific names of fishes from the United States, Canada, and Mexico.* American Fisheries Society Special Publication 29.
14. Helfield, J.M. and R.J. Naiman. 2001. Effects of salmon-derived nitrogen on riparian forest growth and implications for stream productivity. *Ecology* 82:2403-2409.
15. Willson, M.F.,, S.M. Gende, and B.H. Marston. 1998. Fishes and the forest. *BioScience* 48:455-462.
16. Millenium Ecosystem Assessment. 2005. Ecosystems and human well-being: wetlands and water synthesis. World Resources Institute, Washington D.C. http://www.millenniumassessment.org/documents/document.358.aspx.pdf (accessed February 10, 2009).

Fish and Fisheries, 12, 256â€“274. Burkhead, N. M. (2012). Extinction rates in North American freshwater fishes, 1900â€“2010. Bioscience, 62, 798â€“808. Cambray, J. A. (2003).Â The destruction of an endemic species flock â€“ quantitative data on the decline of the Haplochromine cichlids of Lake Victoria. Environmental Biology of Fishes, 34, 1â€“28. Zavaleta, E. S., Hobbs, R. J. & Mooney, H. A. (2001).