Conservation Biology of Fishes

FRED W. ALLENDORF

Department of Zoology
University of Montana
Missoula, MT 59812, U.S.A.

"I love any discourse of rivers, and fish, and fishing."
Izaak Walton
The Compleat Angler

The following three papers were presented at a symposium on the conservation biology of fishes at the Society for Conservation Biology meeting in June of last year. The first paper presents problems special to species living in rivers; the second paper discusses desert fishes; and the final paper considers one of the most popular sport fishes of North America, the cutthroat trout. A fourth paper on the genetics of exploitation in rockfishes was presented at the symposium by Keith Nelson but is not included in this issue.

Three or four papers are obviously not sufficient to provide a comprehensive overview of the conservation of a taxon with over 20,000 species that last shared a common evolutionary ancestor some 400 million years ago (Mayr 1969). Those interested in broader aspects of fish conservation may consult the following recent publications (FAO/UNEP 1981; Fetterolf 1981; Meffe 1987; Ono, Williams, & Wagner 1983; Ryman 1981). The three papers in this issue are concerned primarily with freshwater fishes native to North America. Nevertheless, all three papers stress general principles that are relevant to all fish species.

Some 70% of all the world's fishes listed as endangered or threatened are native to North America (Ono, Williams, & Wagner 1983, page 218). In addition, only one out of 83 species from throughout the world listed as threatened or endangered by the U.S. Fish and Wildlife Service (Federal Register 1987) is a marine species. It is unclear how much the predominance of freshwater fishes from North America on such lists is due to the fishes *per se* and how much is due to the geographical distribution of ichthyologists. Nevertheless, the topics of these three papers reflect current conservation efforts with fishes.

Fishes present some unusual challenges to conservation biologists because they are different from other vertebrates in a variety of ways. Their tremendous taxonomic diversity is the first challenge. Almost exactly one-half of all vertebrate species are fishes (Mayr 1969). Fish species occur in virtually every aquatic environment on the water-planet: lakes, streams, rivers, vernal pools, desert springs, estuaries, the open ocean, deep oceanic trenches, and underneath the polar icecaps.

Fish also show much more intraspecific phenotypic variation than most other taxa (Allendorf, Ryman, & Utter 1987). Individuals within a single species of fish sometimes show enormous differences in size. For example, females from ten populations of Arctic char (*Salvelinus alpinus*) range in mean weight at first sexual maturity from 23 g to nearly 1,000 g (Johnson 1980). However, the larger phenotypic variation within fish species is apparently not associated with greater genetic variability. Heritability is the proportion of the total phenotypic variation that is due to genetic differences between individuals. Heritabilities for such traits as body length and weight are generally much lower within fish populations than within populations of other vertebrates (Allendorf, Ryman, & Utter 1987).

These comparisons suggest that the genotypic-phenotypic relationship in fishes may be somewhat different from what it is in other vertebrates. The high phenotypic variation, coupled with lower heritabilities, indicates greater susceptibility to environmental factors. This difference is not surprising in view of the indeterminate growth capacity of most fishes and the greater metabolic sensitivity to temperature of fishes in comparison to birds and mammals.

The cichlid fishes of the New World and Africa probably best demonstrate the challenges to conservation biologists resulting from the great taxonomic diversity in fish species and their unusual genotypic-phenotypic relationships. Some African rift lakes have "species flocks" consisting of over 300 described endemic species (references in Echelle & Kornfield 1984). However, two morphologically distinct sympatric 'species' of cichlids endemic to Cuatro Ciénegas, Mexico, have been shown to belong to a single reproductive population (Kornfield et al. 1982). In addition, laboratory experiments with cichlids have shown that changing their diet can result in large differences in morphology (Meyer 1987).

Fishes also show the greatest variety of reproductive systems among the vertebrates. Modes of reproduction in fishes include oviparity, viviparity, ovoviviparity, and ovi-ovoviviparity (Moyle & Cech 1982). Sexuality in fishes also runs the gamut of possibilities: simultaneous hermaphroditism, consecutive hermaphroditism, unisexuality, and bisexuality (Price 1986). Modes of sex determination in fish species includes male heterogamety, female heterogamety, multiple sex chromosomes, polygenic determination, single gene determination, and environmental determination (Price 1986).

The genetic systems of fishes show similar diversity. Most fish species show normal diploid Mendelian inheritance. However, alternative genetic systems in fish species include triploidy, tetraploidy, gynogenesis, and hybridogenesis (Turner 1984). Some of these alternative genetic systems also occur in amphibians and reptiles but they are more restricted in those taxa. For example, all of the described polyploid amphibian and reptilian species have closely related diploid counterparts, and no higher polyploid taxa have been found (Bogart 1980). Tetraploidy among fish taxa is much more widespread (Schultz 1980). Two of the more successful families of fishes apparently are descended from their own tetraploid ancestor: catostomids (suckers: 12 genera, 58 species; Nelson 1976) and salmonids (salmon, trout, char, whitefish, and grayling: 9 genera, 68 species; Nelson 1976).

This diversity in reproduction and genetics is of more than academic interest. The paper in this issue by Allendorf & Leary (1988) discusses several unusual problems associated with the conservation of cutthroat trout. Many of the conservation problems with this salmonid species apparently result from its polyploid ancestry (e.g., fertile hybrids between taxa with large amounts of genetic divergence).

Fishes are unique in that no other major food source of man is captured from wild populations. Nelson & Soulé (1987) have considered this attribute of fishes in a philosophical context. The commercial harvesting of fish also has a variety of important biological implications. Harvested fish populations are subjected to selection on a variety of characteristics that affect an individual's vulnerability to harvesting. Nelson and Soulé (1987) have reviewed the evidence that differential harvesting has caused genetic changes in fish stocks.

The paper presented at the meeting by Nelson examined this problem in detail in rockfish of the genus *Sebastes.* This genus contains at least 100 species of marine fish (Eschmeyer, Herald, & Hamman 1983); many of these species support important fisheries on the west coast of the United States. He concluded that our understanding of the effects of exploitation cannot be gained by ordinary genetic methods. He recommended detailed analysis of the empirical effects of exploitation on the age schedule of growth and on changes in the size schedule of fecundity.

The commercial and recreational value of fish populations has also led to widespread culture of fishes in hatcheries for release into the wild to supplement natural populations. There is no parallel among other taxa to the massive and continuous release of artificially cultured individuals over large areas such as became possible through the development of hatchery programs in the last century (Allendorf, Ryman, & Utter 1987). For example, a single hatchery on Yellowstone Lake collected and shipped over 818 million Yellowstone cutthroat trout (*Salmo clarki bouvieri*) eggs between 1899 and 1957 (Varley 1979)!

A discussion of the need to protect fishes on their spawning grounds from an article on "pisciculture" by G. Brown Goode of the U.S. National Museum in the 1898 edition of the Encyclopedia Britannica presents the view of early fish biologists:

> How much must they be protected? Here the fish-culturist comes in with the proposition that "it is cheaper to make fish so plentiful by artificial means that every fisherman may take all he can catch than to enforce a code of protection laws."
>
> The salmon rivers of the Pacific slope of the United States, the shad rivers of the east, and the whitefish fisheries of the lakes are now so thoroughly under control by the fish-culturist that it is doubtful if anyone will venture to contradict his assertion. The question is whether he can extend his domain to other species.

It is interesting to note that two whitefish species from the Great Lakes are extinct, and three additional species are threatened or endangered (Ono et al. 1983). The paper by Allendorf & Leary (1988) discusses problems in conservation related to artificial culture and release of salmonids throughout the western United States.

Fish are generally restricted to water. This obvious characteristic has some perhaps not so obvious effects on their conservation. For example, fishes are not as easy for humans to observe and appreciate as are birds and mammals. It has therefore been more difficult to attract public support for their conservation. Moreover, it also appears that fishes have been somewhat ignored by conservation biologists. For example, the most recent list of endangered and threatened species by the U.S. Department of the Interior (Federal Register 1987) includes over 300 species of mammals, over 200 species of birds, and only 83 species of fish, even though there are many more species of fish than mammal and bird species combined (Mayr 1969).

The dependence of fish on water has also brought many species into conflict with humans over increasingly valuable water resources. An analysis of the source of threats to the fishes of the United States is revealing. Ono, Williams, & Wagner (1983) listed five categories of threats to 151 fish species that they considered to be endangered or threatened: habitat alteration, overutilization for commercial purposes, disease, introduction of exotic or non-native fishes, and restricted natural range. Individual species were threatened by any combination of these five factors. A surprising *98%* of all species were threatened by habitat alteration. The next most common threat was introduced fishes, which threatened 37% of the species. The final major threat was restricted natural range (24%). Less than 5% of the species were threatened by either commercial harvesting or disease.

The paper in this issue by Meffe & Vrijenhoek (1988) considers genetic aspects of conservation and recovery programs of fishes in the deserts of western North America, where the conflict for water resources has been most acute. Over 75% of the U.S. federally listed endangered species occur in the Southwest (Sheldon 1988). Meffe & Vrijenhoek compare two models of genetic population structure in desert fishes based upon geographic isolation and gene flow. They emphasize "the need to incorporate experimental studies of population genetics and fitness into management of endangered fishes."

Sheldon's paper in this issue describes conservation problems intrinsic to species living in flowing water because of the geometry of river systems. He emphasizes the importance of recognizing the threats of fragmentation of drainage networks by impoundments and the homogenization of faunas by interbasin connections and introductions. His analysis of these problems makes the important conclusion that biogeographic considerations are essential in any plan for the conservation of North American fishes.

These three papers provide different perspectives on the challenges to conservation biology provided by fishes. The most striking common theme of these papers is the issue of the objectives of fish conservation biology. What should we be trying to "conserve"? Each paper struggles with this question, and each concludes with a different answer.

Acknowledgments

I thank Pete Brussard for inviting me to organize the symposium, the Society for Conservation Biology for providing financial assistance for travel to the speakers, Dave Ehrenfeld for his help and patience, the reviewers of these papers for their time and helpful comments, and Nils Ryman for his suggestions on this paper. I was supported by grant BSR-86000108 from the National Science Foundation while this paper was prepared.

Literature Cited

Allendorf, F. W., and R. F. Leary. 1988. Conservation and distribution of genetic variation in a polytypic species, the cutthroat trout. Conservation Biology 2:170–184.

Allendorf, F. W., N. Ryman, and F. M. Utter. 1987. Genetics and fishery management. Past, present, and future. Pages 1–19 *in* N. Ryman and F. Utter, editors. Population Genetics and Fishery Management. University of Washington Press, Seattle.

Bogart, J. P. 1980. Evolutionary implications of polyploidy in amphibians and reptiles. Pages 341–378 *in* W. H. Lewis, editor. Polyploidy: Biological Relevance. Plenum Press, New York.

Echelle, A. A., and I. Kornfield, editors. 1984. Evolution of fish species flocks. University of Maine Press, Orono.

Eschmeyer, W. N., E. S. Herald, and H. Hamman. 1983. A Field Guide to Pacific Coast Fishes of North America. Houghton Mifflin, Boston.

FAO/UNEP. 1981. Conservation of the genetic resources of fish: Problems and recommendations. FAO Fisheries Technical Paper Number 217. 43 pp. Rome, Italy.

Federal Register. 1987. Endangered and threatened wildlife and plants. 50 CFR 17.11 & 17.12. U.S. Department of the Interior.

Fetterolf, C. M., Jr. 1981. Foreword to the Stock Concept Symposium. Canadian Journal of Fisheries and Aquatic Sciences 38:iv–v.

Goode, G. B. 1898. Pisciculture. Pages 126–129 in the Encyclopedia Britannica. Werner Company, New York.

Johnson, L. 1980. The Arctic charr, *Salvelinus alpinus.* Pages 15–98 *in* E. K. Balon, editor. Charrs, Salmonid Fishes of the Genus *Salvelinus.* Dr. W. Junk Publishers, The Hague.

Kornfield, I., D. C. Smith, P. S. Gagnon, and J. N. Taylor. 1982. The cichlid fish of Cuatro Ciénegas, Mexico: Direct evidence of conspecificity among distinct trophic morphs. Evolution 36:658–664.

Mayr, E. 1969. Principles of Systematic Zoology. McGraw-Hill Book Company. New York.

Meffe, G. K. 1987. Conserving fish genomes: Philosophies and practices. Environmental Biology of Fishes 18:3–9.

Meffe, G. K., and R. C. Vrijenhoek. 1988. Conservation genetics in the management of desert fishes. Conservation Biology 2:157–169.

Meyer, A. 1987. Phenotypic plasticity and heterochrony in *Cichlasoma managuense* (Pisces, Cichlidae) and their implications for speciation in cichlid fishes. Evolution 41:1357–1369.

Moyle, P. B., and J. J. Cech, Jr. 1982. Fishes: An Introduction to Ichthyology. Prentice-Hall, Englewood Cliffs, New Jersey.

Nelson, J. S. 1976. Fishes of the World. John Wiley, New York.

Nelson, K., and M. Soulé. 1987. Genetical conservation of exploited fishes. Pages 345–368 *in* N. Ryman and F. Utter, editors. Population Genetics and Fishery Management. University of Washington Press, Seattle.

Ono, R. D., J. D. Williams, and A. Wagner. 1983. Vanishing Fishes of North America. Stone Wall Press, Washington, D.C.

Price, D. J. 1986. Genetics of sex determination in fishes—a review. Pages 77–89 *in* G. W. Potts and R. J. Wooten, editors. Fish Reproduction: Strategies and Tactics. Academic Press, London.

Ryman, N., editor. 1981. Fish gene pools: Preservation of genetic resources in relation to wild fish stocks. Ecological Bulletin (Stockholm), Vol. 34.

Schultz, J. 1980. Role of polyploidy in the evolution of fishes. Pages 313–340 *in* W. H. Lewis, editor. Polyploidy: Biological Relevance. Plenum Press, New York.

Sheldon, A. L. 1988. Conservation of stream fishes: Patterns of diversity, rarity, and risk. Conservation Biology 2:149–156.

Turner, B. J., editor. 1984. Evolutionary Genetics of Fish. Plenum Press, New York.

Varley, J. D. 1979. Record of egg shipments from Yellowstone fishes, 1914–1955. Information paper no. 36. Yellowstone National Park. U.S. Dept. Interior.