Changing Themes in the Study of Diadromous Fishes

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Abstract.—In the two decades since the first symposium devoted to anadromous and catadromous fishes, the study of these fishes and their life history patterns has benefited from numerous advances in perspectives and techniques. Molecular ecology, fisheries oceanography, conservation biology, climate change, nutrient cycling, and landscape ecology are some of the many fields that have blossomed during this period, providing a wealth of insights for those studying migratory fishes. The purpose of this paper is to bridge the gap between the 1986 and 2007 symposia, noting some of the scientific advances, but also the fact that many populations of diadromous fishes have declined. These problems are reflected in the focus of the present symposium on conservation and socioeconomic aspects, as well as life history, diversity, and migration patterns. The enormity of the changes in the environment, both natural and anthropogenic, poses tremendous challenges for diadromous fishes and further emphasizes the need for linkage between research and conservation, using all the tools at the disposal of modern science and the development of new ones.

The conservation and management of migratory animals presents special challenges relative to more sedentary animals because they move between distinct habitats. Each species requires more than one critical habitat and safe passage between them. As pointed out in both scientific and popular literature, many migratory animals and indeed the phenomenon of their migrations are in jeopardy (Wilcove 2008). Whether they travel by air, land, or sea, migrants are vulnerable as well as fascinating. Fisheries traditionally take advantage of migration patterns to facilitate exploitation, and habitat degradation or passage barriers pose serious problems for migratory species. The regular migrations of diadromous fishes between freshwater and saltwater allow them to take full advantage of the differences in growing conditions and breeding habitats (Northcote 1978; Gross et al. 1988) in the two environments. However, diadromy is comparatively rare among fishes, being found in fewer than 1% of the species (McDowall 1988), perhaps because of the physiological challenges associated with life in both saltwater and freshwater, the demands of upstream migration, and the difficulties in adapting to such distinctly different ecological conditions.

In 1986, a symposium in Boston was held to consider “common strategies” of these fishes, and its goal “was to identify key similarities or differences in life history patterns and to examine these to assist our understanding of diadromy” (Dadswell 1987). In the two decades since that symposium (Dadswell et al. 1987), tremendous synergies between technical advances and conceptual breakthroughs in diverse fields, including molecular biology (Carvalho et al. 1994), biotelemetry (Lacroix et al. 2004; Welch et al. 2004), analysis of stable isotopes and microchemistry (Ingram and Weber 1999; MacAvoy et al. 2000; Finney et al. 2002; Kennedy et al. 2002; Milton and Chenery 2003; Gillanders 2005; Harrod et al. 2005; Schindler et al. 2005), and ecotoxicology (Ewald et al. 1998), have greatly expanded our understanding of the life history and ecology of many diadromous fishes.

With respect to molecular biology, for example, the pivotal paper using mitochondrial DNA to show that rainbow trout *Oncorhynchus mykiss*, formerly *Salmo gairdneri*, were closely related to Pacific salmon *Oncorhynchus* spp. was published in 1986 by Thomas et al. Genetic techniques are now so fast and powerful that they can provide in-season management advice, as well as revealing patterns of rela-
tionships among populations (Habicht et al. 2007). It is also possible to take DNA from scales collected decades ago for analysis of long-term genetic changes (Nielsen et al. 1997) and parentage analysis to determine the lifetime reproductive success of individual fish (Seamons et al. 2007). Such applications were scarcely conceivable to most fisheries scientists in the mid-1980s, and no papers in the 1987 publication relied on genetics. A key journal, *Molecular Ecology*, did not publish its first issue until 1992. Another topic emphasized in the 2007 symposium, linkages with ecosystem energetics, reflects both the shift from single species to ecosystem perspectives and also the ways in which stable isotopes of elements (notably nitrogen and carbon) allow us to track “marine-derived nutrients” brought from the ocean to freshwater in the bodies of anadromous fishes. The existence of these isotopes was known, of course, but key papers applying this approach to salmon came after the 1986 meeting (Kline et al. 1990, 1993).

Beyond the importance of developing and emerging techniques in changing the face of research since the 1980s, there is the enormous increase in computing ability that we now enjoy. Indeed, many of us were getting our first personal computers in the mid-1980s, and their capacity was very limited. Now, we can run complex models, download huge amounts of data on climate and hydrology from Web sites, access maps and photographs from our offices, send large files electronically, and in so many ways expand our capacity for productive work. These tools are no substitute for ideas, but there have been many important conceptual advances and syntheses as well. The publication of two books (Roff 1992; Stearns 1992) spurred the application of life history theory to many topics in behavior and evolutionary ecology, including such topics of phenotypic plasticity and norms of reaction that are central to the life histories of many diadromous fishes (Hutchings 2004). The past two decades have also seen the fields of conservation biology and climate change grow from relative infancy to the forefront of ecological research. For perspective, the journal *Conservation Biology* was first published in 1987, and *Global Change Biology* began in 1995. The fields of fisheries and oceanography have grown together in many ways, reflected in part by the journal *Fisheries Oceanography*, first published in 1992, and many important papers linking climate, the ocean, and salmon have been published in the past decades (Beamish and Bouillon 1993; Mantua et al. 1997; Friedland et al. 2003). The concept of metapopulations (Hanski 1999) has come to prominence, as have the concepts of biodiversity, biocomplexity, ecosystem management, and many others. Some might feel that these are merely “old wine in new bottles,” but there is little doubt that the study of diadromous fishes is changing rapidly, along with the rest of science and natural resource management.

Unfortunately, all the technological breakthroughs and conceptual advances have not always resulted in healthier fish populations. The past decades have seen declines of many fishes to the point where the list of threatened or endangered anadromous fishes under the U.S. Endangered Species Act includes four species of sturgeon, bull trout *Salvelinus confluentus*, and Atlantic salmon *Salmo salar* and two evolutionarily significant units (Waples 1991; Waples 1995) of sockeye salmon *Oncorhyncus nerka*, two of chum salmon *O. keta*, three of coho salmon *O. kisutch*, nine of Chinook salmon *O. tschawytscha*, and 11 of steelhead (nonadromous *O. mykiss*). The Committee on the Status of Endangered Wildlife in Canada (COSEWIC) is charged with assessing the status of species, and designatable units (DUs) within species, for possible listing under the Species at Risk Act (SARA). Atlantic salmon in the inner Bay of Fundy Atlantic are listed as Endangered under SARA, as are several DUs of white sturgeon *Acipenser transmontanus* and Atlantic whitefish *Coregonus hoyi*. There are other diadromous species that COSEWIC has designated at some degree of risk but have no official protection under SARA at this time, including populations of coho, Chinook, and sockeye salmon; striped bass *Morone saxatilis*; and American eel *Anguilla rostrata*.

Given these increases in knowledge, new perspectives, and ongoing crises for diadromous fishes, it is appropriate that the 2007 symposium’s stated goal was not only to “review the current state of scientific knowledge with respect to biology, ecology, and conservation of diadromous fishes,” but also to “address how recent alterations to the environment and human activity have affected diadromous fishes with respect to their sustainability and role in aquatic ecosystems.” The 1986 meeting had sessions devoted to habitats (freshwater, marine, and transition) and recruitment. In contrast, the 2007 meet-
ing’s sessions were on life history, climate change and human influences, ocean migration, ecosystem linkages, restoration of populations and habitats, and socioeconomic aspects, reflecting the explicit shift in focus towards conservation and the connection between life history and the human element in the management of diadromous fishes.

The 2007 symposium includes papers that reveal the expansion of new technologies such as those applied to tracking fish movements (Stokesbury et al. 2009, this volume), analysis of paleolimnology data from sediment cores in lakes (Gregory-Eaves et al. 2009, this volume), stable isotopes (Naiman et al. 2009, this volume), elemental analysis of otolith microchemistry (Howland et al. 2009, this volume), and the insights of molecular biology for fish phylogeny and the evolution of anadromy (Dodson et al. 2009, this volume). These diverse perspectives and techniques are also brought together to advance our understanding of many kinds of migratory fishes. For example, work on eels has drawn from the fields and techniques of fisheries oceanography, behavior, life history, electronics, chemistry, and more (e.g., Jellyman and Bowen 2009; Miller et al. 2009; Tsukamoto et al. 2009; all this volume).

In addition to the fascinating new information on diadromous fishes presented at the symposium, however, we were also reminded of the problems that many species face. Mixed stock fisheries are a common problem for management, especially when the fish migrate across governmental boundaries in coastal areas or enter international waters (e.g., Hammer 2009, this volume). These problems are all the more complex when applied to species such as anguillid eels, which can be fished and managed in specific areas but breed in common at a remote location. Thus, a degraded stream might continue to attract juveniles as long as they are produced by adults that survived in other rivers, unlike the river-specific stock and recruitment relationship typical of anadromous fishes. In addition to these general issues, the precise timing patterns that characterize many diadromous fishes only make them more vulnerable to fishing. The most obvious effect of fishing, the reduction in density, necessarily attracts the most attention, but there is also increasing awareness of the possible evolutionary effects of size-selective fishing (Conover and Munch 2002; Conover et al. 2005). The long-term effects of size-selective fishing will depend on the balance between genetic and environmental effects on growth and age at maturation in the population and the intensity of selection (Hard 2004). Likewise, many fisheries are selective with respect to migratory timing because of exploitation patterns (Consuegra et al. 2005) and management regulations, though this has attracted less scientific attention. Documenting such selection and then considering the possible long-term consequences will provide scientists working on such species with plenty of work in the future.

Fisheries management, however, involves much more than traditional scientific disciplines such as population dynamics and genetics, but also a thorough consideration of socioeconomic aspects of the people involved in the fisheries, as exemplified by the hilsa shad *Tenualosa ilisha* fishery in Bangladesh (Siddique 2009, this volume), and the complex facets of managing many tropical fisheries (Blaber 2009a, 2009b, both this volume). All of these processes will play out in the 21st century as we experience changing climate conditions (Beamish et al. 2009, this volume), posing even greater challenges for the fishes and those working on them. These challenges are exacerbated by the growing human population, with all the demands for water, space, and other resources, causing many scientists to take a pessimistic view of the prospects for Pacific salmon (Hartman et al. 2000; Lackey et al. 2006) and, by extension, other diadromous fishes. Without denying these problems and the inherent vulnerability of diadromous fishes, it is important to also recognize that diadromy confers some measure of resilience to their populations. The success of striped bass management, leading to the rebound of the species along the east coast of North America, and the increasing abundance of pink salmon *Oncorhynchus gorbuscha* in Puget Sound, in less than pristine habitat at the southern end of their range, should give us reason for hope if not optimism. I look forward to the next symposium on the exciting topic of diadromous fishes, sometime in the future, and I can only wonder what themes, techniques, and findings will be emphasized there.

References


Northcote, T. G. 1978. Migratory strategies and produc-


