Foundations of Fisheries Science

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Section 5

Managing Fisheries Enhancements

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5.1. SYNTHESIS

Articles in this section deal with the use of hatchery programs in fisheries enhancement and restoration—the third approach to managing fisheries after harvest and habitat management, and possibly the most controversial. Hatchery programs have been used successfully to maintain fisheries where natural recruitment of target species is low or absent, to enhance certain wild fisheries, and to conserve or restore threatened or endangered fish populations. At the same time, many hatchery programs have been associated with deleterious ecological or genetic impacts on wild fish populations and fisheries. In addition to biological interactions, hatchery programs have brought about varied and often significant human responses. Some have provided the impetus for fish conservation and habitat restoration initiatives, while others have encouraged overexploitation of wild stock components in mixed fisheries or masked fisheries impacts of habitat loss and thereby reduced incentives for restoration.

Even this brief introduction suggests that evaluating hatchery programs and using them effectively where potential exists for them to improve fisheries outcomes is a complex endeavor—quite the opposite of the "quick fix" that hatcheries are sometimes believed to offer. Among the issues that need to be considered are the dynamics of the fish population enhanced or created by stocking, hatchery techniques and their implications for post-stocking survival, strategies for releasing hatchery fish successfully into natural environments, genetic management, and the behavior of stakeholders and governance systems. Moreover, these facets need to be integrated into a coherent enhancement system framework to assess whether a hatchery program may meet its intended fisheries management goals and to design, implement, or reform the program where this is the case.

Hatchery programs have been used in fisheries management for well over a century, yet much of our current understanding of their potentials and limitations has emerged only over the past few decades. The articles assembled in this section are milestones that have advanced our understanding of hatchery programs through visionary and critical reviews that have defined the place of hatchery programs in fisheries management and the critical issues that need to be considered, and through primary research on these issues. This section aims to provide a unifying context for the selected, seminal articles and to point the reader to key subsequent studies that may have confirmed or challenged the conclusions of the selected articles.

Setting the Scene

The two articles in this section ask "what are hatchery programs useful for from a fisheries management perspective" and "what needs to be considered in order to make it work?" Both articles appeared around the same time and were motivated by a prevailing sense that many hatchery programs operated without a clear rationale, without consideration of key factors likely to be crucial to outcomes, and without evaluation. Cowx (1994) draws mostly on experience and examples from European freshwater systems where hatchery programs have been long established, while Blankenship and Leber (1995) focus on marine hatchery programs with a much shorter history. Cowx (1994) emphasized decision making frameworks such as flow charts, while Blankenship and Leber (1995) outlined a set of broad recommendations. The articles independently arrive at many of the same conclusions—the need for a strategic approach with defined objectives, targeted program design, and rigorous evaluation being the overarching one. Others include the need to consider stocking/release strategies, ecological interactions with wild fish, genetic management, and disease control. Some differences in approach are evident that may be traced to differences between freshwater and marine hatchery programs and the degree to which they have become part of operational management rather than research. Cowx (1994) differentiates between uses of hatchery programs (for mitigation, enhancement, restoration or creation of new fisheries) and emphasizes the need to quantitatively assess the status of the fishery (e.g., abundance relative to carrying capacity, size and age structure) to identify the need and scope for enhancement. At the time, such assessments were more practical in freshwater systems where empirical yield and stocking models had been developed from comparative studies across multiple lakes or streams than in marine systems where stocks were assessed individually using mathematical models that were not set up to deal with the issues surrounding stocking. This and other aspects of the disciplinary elements of hatchery programs are further explored below. As for overarching, strategic approaches to hatchery programs, the articles by Cowx (1994) and Blankenship and Leber (1995) have remained important points of reference. In 2010, Lorenzen, Leber, and Blankenship published a comprehensive update of the responsible approach that integrates and expands on key recommendations from both articles. The updated responsible approach has fifteen key elements arranged in three stages as follows: (Phase I) initial appraisal and goal setting; (Phase II) research and technology development including pilot studies; and (Phase III) operational implementation and adaptive management. Stages are ordered in this sequence to ensure that broad-based and rigorous appraisal of enhancement contributions to fisheries management goals is conducted prior to more detailed research and technology development and operational implementation.

Population Dynamics

The central aim of most hatchery programs is to increase the abundance of fish populations to enhance, rebuild, and/or conserve small fisheries. Hence, understanding and predicting the dynamics of fish populations subject to stocking is crucial to managing hatchery programs effectively.

Experimental stocking studies have been conducted in freshwater systems since the early 20th century, often for the dual purpose of studying fundamentals of production ecology and developing stocking strategies. Of these studies, Homer Swingle's experiments on the management of fisheries in farm ponds in the southeastern United States are the most well-known and influential. In the article reproduced here, Swingle (1951) designed a stocking regime that quite reliably produced a good annual crop of harvestable size fish from a predator-prey community of Largemouth Bass *Micropterus salmoides* and Bluegill *Lepomis macrochirus* stocked into small impoundments. The study systematically applied ecological concepts and quantitative indicators Swingle had developed earlier through a large number of pond experiments (Swingle 1950), and which are well laid out in the introduction of the article reproduced here. The article makes several important contributions to the development of fisheries enhancement science. First, it sets out to use stocking for a specific fisheries management goal (a balanced fish community yielding good catches) that, in small impoundments, cannot reliably be achieved by harvest or habitat management alone. That is a far cry from the many *ad hoc* hatchery programs that have motivated Cowx (1994) and Blankenship and Leber (1995) to call for systematic and responsible approaches to enhancement. Secondly, in addition to using his community indices to guide stocking strategies, Swingle carefully analyzed survival and the effects of stocking regimes and inter-specific interactions upon it, making this an early empirical study of population dynamics of stocked fisheries. Swingle's studies, with some extensions and modification, have continued to inform the management of small impoundments in the southeastern United States to this day.

Pacific Salmon *Oncorhynchus* spp. stocks have been subjected to the world's largest and longest-running hatchery programs. The relative ease of quantifying abundance of juveniles and spawners during their migrations out of and into their natal rivers means that some of the best quantitative data on enhanced populations are available for these stocks. Hilborn and Eggers (2000) took advantage of such long-term data for Alaskan Pink Salmon *O. gorbuscha* stocks and most importantly, evaluated the impact of hatchery programs by comparing long-term variation between enhanced stock and non-enhanced controls. While the focal hatchery program in Prince William Sound was associated with a substantial increase in salmon catches, similar increases were observed over the same period in stocks not enhanced with hatchery fish—suggesting that catch increases were due to large-scale changes in ocean conditions and that a substantial contribution of hatchery fish to catches in Prince William Sound signified displacement of wild by hatchery fish rather than a net positive contribution to catches. The study sparked some debate (Wertheimer et al. 2001; Hilborn and Eggers 2001), which served to further highlight the risk of displacing the wild stock component in enhanced fisheries, and the importance of adopting a sound experimental design with non-enhanced controls and replication when evaluating enhancements experimentally.

While experimental and comparative observation studies have played a major role in informing the management and enhancement of freshwater and anadromous fisheries, such approaches are less suited to marine fisheries and those in larger freshwater systems which rely on fewer, larger stocks and offer only limited opportunities for replicated experiments. Population dynamics modeling, therefore, is the primary tool for assessing management options in such fisheries. The same approach holds promise for assessing the potential or actual contribution of hatchery releases to fisheries management goals. However, the dynamic pool models commonly used in fisheries assessment are based on a simplified representation of population dynamics that is appropriate to the assessment of harvesting of recruited fish, but precludes the evaluation of enhancements. Lorenzen (2005) extended the dynamic pool theory of fishing to stock enhancement by unpacking recruitment, incorporating regulation in the recruited stock, and accounting for biological differences between wild and hatchery fish. Lorenzen (2005) then used the extended model to analyze the dynamics of stock enhancement and restocking and its potential role in fisheries management. He showed that due to multiple density-dependent processes in the life histories of fishes, enhancements can be designed to increase total yield and stock abundance, but will almost inevitably reduce abundance of the naturally recruited stock component; that is, re-stocking of overfished populations is likely to be beneficial only in combination with fishing restrictions and only when populations have been very severely depleted. Releasing hatchery fish of compromised fitness will be most deleterious to wild stocks if fitness is only moderately compromised. Along with the enhanced fishery model of Walters and Martell (2004), this study paved the way for fisheries enhancement and restoration through hatchery programs to be evaluated quantitatively alongside conventional fishing regulations and, with other extensions to commonly used dynamic pool models, habitat management.

Impacts of Hatchery Rearing on the Biology of Stocked Fish

Rearing of fish in hatcheries and other culture facilities subjects the organisms to an inadvertent or intentional process of domestication. Domestication involves plastic developmental responses to the culture environment, an altered selection regime, and has strong, almost always negative impacts on the capacity of fish to survive, grow, and reproduce in the wild (Lorenzen et al. 2012). The review by Olla et al. (1998) synthesized experimental evidence for domestication effects on the most plastic aspect of fish biology: behavior. Evidence suggested that being reared in a simple, psycho-sensorily deprived hatchery environment tends to lessen the innate capabilities of fish to avoid predation and to forage for prey. The authors also outline a number of approaches to improve post-release behavioral capabilities in hatchery-reared fish, including exposure to predators or predatory stimuli, alteration of spatial and temporal distribution of food, mitigation of rearing and transport stress, and control of the social environment. Olla et al.'s (1998) review was the first synthesis of this research area which has seen a great deal of activity since. A later, much cited review (Brown and Dey 2002) focused on life-skills training of hatchery fish.

Post-release Ecology and Release Strategies

Hatchery fish are typically stocked as juveniles, at a life stage characterized by fairly specific food and habitat requirements and high vulnerability to predation. As discussed in Olla et al. (1998), hatchery juveniles are also often deficient in life skills compared to their wild conspecifics. Not surprisingly, the size, time, and habitat of release can have major impacts on post-release survival of hatchery fish and systematic studies on release strategies can yield very substantial improvements. Santucci and Wahl's (1993) study on release strategies for Walleye *Sander vitreus* is remarkable in not only testing for the effect of stocking size on survival, but elucidating ecological mechanisms underlying the observed patterns. It shows how stocking of hatchery fish can be used to gain ecological insights through manipulations that are otherwise difficult to undertake. At the same time, by analyzing economic returns for different release sizes, the study provided very practical information for management.

Genetic Management

Three main sets of issues are associated with the genetic management of hatchery programs: (1) potential disruption of neutral and adaptive spatial population structure due to translocation; (2) impacts of hatchery spawning and rearing on genetic diversity of stocked fish and the enhanced, mixed stock; and (3) impacts of hatchery rearing on the fitness of released fish and their naturally recruited offspring. The issue of disruption of spatial genetic populations structure is discussed in the article by Cowx (1994) reproduced in this volume, while Blankenship and Leber's (1995) section on genetic resource management emphasized maintenance of genetic diversity in hatchery and mixed populations.

By far the best known study on the implications of mixing wild and hatchery populations of different genetic diversity is the short note by Ryman and Laikre (1992) (Honorable Mention). Ryman and Laikre (1992) developed a simple model for predicting the genetically effective population size of an admixture of populations with different effective population size. Results showed how stocking of large numbers of fish from a population of small effective size risks lowering the effective size of the combined population, while supplementing small natural populations with hatchery fish of larger effective population size (note here that techniques such as factorial or minimum kinship mating can be used in hatcheries to raise the ratio of genetically effective to census population size) can have the opposite effect.

While genetic diversity implications of hatchery programs have received much attention in research, they are arguably more tractable through appropriate sourcing and management of brood stock than the third issue; loss of fitness in hatchery-reared fish. Hatchery populations experience regimes that relax selection pressure on many traits, while exerting pressure in others that result in adaptation to the hatchery environment. Both these changes result in loss of fitness in the wild. Reisenbichler and McIntyre (1978) reported the first rigorous study on loss of fitness related to hatchery rearing. Comparing fitness in the wild, in a pond of hatchery fish, hatchery-wild hybrids, and wild fish all derived from the same local population, they showed that wild fish outperform hatchery fish in natural streams, while the reverse is true for hatchery ponds. The performance of hybrids was intermediate in both cases. Overall, this demonstrated a loss of fitness in hatchery fish with possible implications for the productivity of wild populations if hatchery fish interact with them ecologically or genetically. Reisenbichler and McIntyre's (1978) work has been broadly confirmed by subsequent studies summarized in Araki et al. (2008).

Ford (2002) (Honorable Mention) used a combined quantitative genetic and demographic model to explore consequences of the loss of fitness due to captive rearing for wild populations supplemented or enhanced by hatchery programs. Assuming that the hatchery and wild environments select for different optimal trait values, the model showed that when the captive population is closed to gene flow from the wild population, even low levels of gene flow from the captive population to the wild population will shift the wild population's mean phenotype so that it approaches the optimal phenotype in captivity. If the captive population receives gene flow from the wild, the shift in the wild population's mean phenotype becomes less pronounced. He also showed that a decline in fitness of around 30% can occur over a broad range of scenarios. For a recent re-evaluation (which has broadly confirmed Ford 2002 and other previous results) see Baskett and Waples (2013).

Human Dimensions

Considering human dimensions of hatchery programs is crucial for several reasons. First, individual and collective responses of fishers are intended outcomes of many hatchery programs (e.g., those aimed at increasing recreational fishing participation), but may also have unintended consequences such as an increase in fishing pressure on wild stock components. Secondly, hatchery programs involve active replenishments of common pool resources and are likely to be initiated and sustained only where effective governance arrangements allow for regulation of resource use and ensure that benefits of enhancements accrue to those bearing the costs. Three articles included here as "Honorable Mentions" explore these human dimensions of hatchery programs.

Loomis and Fix (1998) (Honorable Mention) conducted an empirical analysis of the effects of fish stocking on license sales and the fishing effort expended in lakes and streams in Colorado. Their results showed that total license sales were unresponsive to fish stocking, suggesting that a reduction in the state's stocking efforts would not result in a reduction in fishing participation or license income. Fishing effort in individual water bodies was found to be responsive to stocking of catchable fish, but only moderately so (with a 1% increase in stocking causing effort to increase by 0.43% in lakes and 0.23% in streams). Stocking in recreational fisheries is often intended to yield an increase in fishing effort, either to generate economic benefits or to divert effort away from pristine or vulnerable fisheries. Conversely, effort increases may negatively affect wild components of mixed stock fisheries or dissipate benefits from stocking in commercial fisheries (where effort is associated with economic costs rather than benefits). In either case, quantifying the effort response to fish stocking is important to understanding and managing the outcomes of a hatchery program. The moderate, less-than-proportional responsiveness found by Loomis and Fix (1998) is not surprising, because to most recreational fishers, expectation or experience of a higher catch rate associated with stocking is only one of several factors influencing the decision on how much and where to fish.

Anderson (2002) (Honorable Mention) considered the interrelationship between the strength of property rights and the degree of control exercised over biological production and product marketing in a fishery. He showed that fisheries enhanced by hatchery programs tended to occupy an intermediate position along the continuum from traditional capture fisheries (typically weak property rights and weak control over production) and aquaculture (strong property rights and control over production). This result can likely be generalized from "property rights" to "governance arrangements" (effective community-based, governmental, or cooperative governance arrangements may substitute for individual property rights where appropriate) and from commercial to recreational fisheries (where the product marketed is the fishing experience). The interaction between governance and production control may work both ways; strengthening of governance arrangements (as is happening in many fisheries) can provide incentives for the development of hatchery programs and other forms of production enhancements, while the availability of promising hatchery technologies may provide incentives for strengthening governance arrangements in order to take advantage of the technical opportunities.

Complementing Anderson's (2002) comparative analysis, Pinkerton (1994) (Honorable Mention) provided a detailed case study of the technical and governance interactions in the Prince William Sound, Alaska hatchery program that has become effectively integrated into the fisheries management framework. She showed how the salmon hatchery program has facilitated the emergence of cooperative fishery management involving the state and fishing communities and how the greater control over production achieved through the hatchery program resulted in economic benefits related to the more consistent volume and quality of product and collective marketing arrangements. Note that many of the social, economic, and political benefits of the hatchery program discussed here are related to qualitative changes in management and marketing rather than an overall production enhancement (the occurrence of which has been challenged for this fishery in the article by Hilborn and Eggers 2000).

Closing Remarks

The articles and citations reproduced in this section provide the scientific foundations for our understanding of hatchery programs and their role in fisheries management. At the same time, the articles are testament to the advances and insights that research on hatchery programs has made to the fundamentals of fisheries science. This research has enhanced our understanding of size and density-dependent processes in fish populations (Lorenzen 2005), the role of foraging and predator avoidance behavior in the fitness of wild fish (Olla et al. 1998), the role of continuous natural selection in maintaining fitness and the rapidity with which such fitness can be lost in altered selection regimes, and the close connection between use rights, resource stewardship, and enhancement (Pinkerton 1994; Anderson 2002). Continued development of hatchery technologies for more fish and invertebrate species, the expansion of rights-based governance systems that provide incentives for active resource enhancement and replenishment, and impacts of global environmental change that may motivate increasingly interventionist approaches to resource conservation and management suggest that the role of hatchery programs in fisheries management is unlikely to diminish. Applying the insights from the seminal studies reprinted here and from the studies they have motivated will be crucial to the responsible development of hatchery programs.

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