Conservation Aquaculture Approaches for Hatchery Reform

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Development of the North Pacific salmonid hatchery system began in the late 19th century and has played a prominent role in enhancement of the salmonid fisheries in the Pacific Northwest (states of Washington, Idaho, and Oregon, USA) since the 1950s. Most public hatcheries in the Pacific Northwest were originally built to mitigate for loss of natural spawning habitat. Hatchery production goals focused on enhancing harvest of adults in commercial fisheries. The hatcheries were established at a time when many wild salmon stocks were healthy and genetic diversity of stocks was not a concern. Hatcheries have played a major role in supplying salmon and trout to the common property fishery, benefiting commercial, sport, tribal, and nontribal fishers. In fact, hatcheries are so instrumental in supplying fish that it is nearly impossible to separate the management of the salmonid fisheries from the management of the hatcheries. Today in the Pacific Northwest, nearly 400 artificial production programs for anadromous salmon and steelhead (*Onchorynchus spp.*) are producing over 200 million hatchery fish annually. These hatcheries now provide up to 80% of the fish in several of the key fisheries.

Despite the great success of hatcheries in supplying fish for fisheries, the philosophy of salmonid resource management has changed to include a focus on resource management for wild stocks. A number of stocks of anadromous salmonids in the Pacific Northwest are currently listed by the National Marine Fisheries Service (NOAA Fisheries) as threatened or endangered under the U.S. Endangered Species Act (ESA). The need to preserve biodiversity has brought about a new era of conservation of wild stocks that cannot help but impact the operation and management of production hatcheries and the traditional users of hatchery fish.

Since 1999, NOAA has been a partner in a formal process of hatchery reform that has been ongoing in the Pacific Northwest (Mobrand et al. 2005). The Hatchery Scientific Review Group (HSRG) is funded by the U.S. Congress and is a systematic, science-driven redesign of how hatcheries will be used to achieve the goals of: 1) helping to recover and conserve naturally spawning populations, and 2) supporting sustainable fisheries. Initial work by the HSRG included developing a Scientific Framework for Artificial Propagation of Salmon and Steelhead, a Benefit/Risk Assessment Tool, Hatchery Operational Guidelines, and Monitoring and Evaluation Criteria (see **www.hatcheryreform.org**; **http://hatcheryreform.us**; and **www.managingforsuccess.us** for information on the Hatchery Reform process). These tools are being used by the HSRG in a comprehensive Pacific Northwest region-by-region review that evaluates hatchery programs for consistency with established scientific principles and the objectives of hatchery reform.

Where hatchery operations conflict with recovery of ESA-listed stocks, the options appear to be either 1) isolation of hatchery production (e.g., near-tidewater rearing/release and aggressive terminal harvest of hatchery fish) or 2) altering hatchery operation to include a conservation mandate (see Flagg and Nash 1999, Flagg et al. 2004, and Mobrand et al. 2005 for details of conservation hatchery approaches). What follows is a brief discussion of major emerging issues relating to the operation of hatcheries in the Pacific Northwest and examples of what we feel are critical needs for hatchery reform. These discussions provide an example for Pacific salmon

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of the general shift in aquaculture philosophy from a production-based focus to one that also considers effects of the actions on health and sustainability of the natural ecosystem.

Potential Impacts of Hatchery Rearing--The overall impact of hatchery fish on wild populations can be divided into three broad categories. 1) Over-harvest of wild stocks in mixed stock fisheries can have a profound impact on survival of wild stocks. When productive hatchery stocks are targeted for high harvest, less productive wild stocks cannot withstand the high exploitation rates, resulting in under-escapement of wild fish. 2) A number of ecological interactions can occur between hatchery and wild fish. These can take the form of: competition for food and territory, predation with larger hatchery fish preying on smaller wild cohorts, and other negative social interactions when large numbers of hatchery fish are released on top of small numbers of wild fish. 3) Genetic risks associated with hatchery rearing, including intentional and unintentional events such as domestication selection, inbreeding, and outbreeding depression.

Traditional hatchery rearing for Pacific salmon is most commonly conducted in outdoor raceways and tanks over uniform concrete substrate. Fish in rearing vessels are conditioned to minimal raceway flow regimes; provided no structure in which to seek refuge from predators, or dominant cohorts; held at high, stress-producing densities; surface fed; and conditioned to approach large, moving objects at the surface. The protective nature of hatchery rearing increases egg-to-smolt survival. However, the postrelease survival and reproductive success of cultured salmonids is often considerably lower than that of wild-reared fish. The hatchery practices mentioned above are often considered prime factors that may induce genetic change (e.g., domestication) and reduce fitness of hatchery fish for natural ecosystems. However, it is likely that the most immediate impact of traditional rearing practices is to disrupt innate behavioral repertoires.

Conservation Hatchery approach-Three foundational principles (Table 1) have been described for operation of hatcheries under a conservation aquaculture approach (Mobrand et al. 2005)

Principle 1: *Every hatchery stock must have well-defined goals in terms of desired benefits and purpose*. Well-defined goals provide both targets and measures for success. The goals for each hatchery stock must reflect the purpose and desired benefits of the program (e.g., harvest, conservation, research, education). Wherever possible, goals should be quantified.

Hatcheries should operate as part of an integrated strategy that includes short-term and long-term goals for habitat and harvest. Goals should be related to measures of success, including: (a) the desired number of fish to be harvested each year, (b) the number of fish returning to a hatchery or spawning naturally in a watershed (i.e., escapement), (c) the expected results of scientific research, and (d) the educational benefits to be derived from outreach.

Principle 2: *Hatchery programs must be scientifically defensible*. Hatchery programs and operations must be consistent with stated goals, and they must be defensible scientifically. Once the goals for a program are established, the scientific rationale for the design and operation of the program must be explicitly stated and understood by all personnel. These requirements may necessitate a written, comprehensive management plan for every hatchery program. Scientific oversight and peer review should be integral components of every hatchery program.

Every hatchery program needs to have *operational guidelines and standard operating procedures* (e.g., selection of adults for broodstock, spawning protocols, feeding protocols, etc.) that are scientifically defensible. These guidelines should include decision-making pathways for dealing with potential contingencies.

Principle 3: *Hatchery programs must respond adaptively to new information*. Scientific *monitoring and evaluation* (M&E) of hatchery programs need to be increased. M&E should assess smolt-to-adult survivals, return rates of adults, contributions of adults to harvest and natural spawning, the proportion of naturally

Table 1. Principles for hatchery management and system-wide recommendations developed by the Hatchery Scientific Review Group (HSRG), modified from Mobrand et al. 2005.

1) Well-Defined Goals:
   - Set Goals for all Stocks and Manage Hatchery Programs on a Regional Scale
   - Measure Success in Terms of Contribution to Harvest, Conservation and Other Goals
   - Have Clear Goals for Educational Programs
2) Scientific Defensibility:
   - Operate Hatchery Programs within the Context of Their Ecosystems
   - Operate Hatchery Programs as either Genetically Integrated or Segregated Relative to Naturally-Spawning Populations
   - Size Hatchery Programs Consistent with Stock Goals
   - Consider both Freshwater and Marine Carrying Capacity in Sizing Hatchery Programs
   - Ensure Productive Habitat for Hatchery Programs
   - Emphasize Quality, Not Quantity, in Fish Releases
   - Use In-Basin Rearing and Locally-Adapted Broodstocks
   - Spawn Adults Randomly throughout the Natural Period of Adult Return
   - Use Genetically-Benign Spawning Protocols that Maximize Effective Population Size
   - Reduce Risks Associated with Outplanting and Net Pen Releases
   - Develop a System of Wild Fish Management Zones
   - Use Hatchery Salmon Carcasses for Nutrification of Freshwater Ecosystems, while Reducing Associated Fish Health Risks
3) Informed Decision Making:
   - Adaptively Manage Hatchery Programs
   - Incorporate Flexibility into Hatchery Design and Operation
   - Evaluate Hatchery Programs Regularly to Ensure Accountability for Success

spawning fish composed of hatchery-origin adults, and stray rates of adults to non-target watersheds. Where possible, M&E should include assessments of genetic and ecological interactions (e.g., interbreeding, competition, predation) between hatchery- and natural-origin fish. Centralized databases need to be developed for collating, storing, and retrieving data. Results need to be evaluated annually to allow programmatic adjustments.

Hatcheries need to be flexible and managed adaptively. Many scientific uncertainties are associated with salmon hatcheries. Hatchery programs and facilities must respond to new goals, new scientific information, and changes in the status of natural stocks and habitat. A structured adaptive management program is necessary for the success of hatcheries. Institutional resistance to programmatic flexibility and change needs to be overcome.

Conservation Hatchery Operation--Flagg et al. 2004 described an operational approach for Conservation Hatchery rearing for Pacific salmon (Table 2). The process requires application and integration of a number of rearing protocols, all of which are known individually to affect the inherent fitness of the creature to survive and breed in its natural ecosystem. A Conservation Hatchery approach for salmonids will require a specialized rearing facility to breed and propagate a stock of fish genetically equivalent to the native stock, and with the full ability to return to reproduce

Table 2. Operational comparisons between production and Conservation Hatchery strategies for rearing of Pacific salmon (modified from Flagg et al. 2004).

		Production Hatchery		Conservation Hatchery	
Parameter	**Factor**	**Action**	**Objective**	**Action**	**Objective**
Egg collection	spawn timing	directed (e.g., early or late component, etc.)	synchronize adult return/harvest opportunities	synchronized to wild, representative numbers collected over range of run	maintain wild timing
	number	directed (probably large number of eggs taken)	maximize output	directed (relatively small number of eggs needed)	stage production to habitat carrying capacity
Egg fertilization	mating strategy	directed (for characteristics)	select desired attributes (e.g., return size and age)	directed (to maintain genetic diversity)	maintain diversity
Egg incubation	incubator type	use accepted guidelines for species	maximize output	include substrate	approximate wild conditions/maximize hatch size
	temperature	surface or well	time hatch to production needs	controlled to ambient for stock	synchronize hatch with wild timing
Fish rearing	vessel type	standard (typically smooth with no internal structure)	maximize output	altered to include enriched (seminatural) habitats with cover, structure, substrate, etc.	reduce domestic conditioning
	temperature	surface or well	time rearing to production needs	controlled to ambient for stock	synchronize rearing with wild stock
	culture s	standard (designed to maximize fish output)	maximize output	innovative (designed to maximize fish quality)	reduce domestic conditioning and improve fitness
	pond timing	variable	maximize culture opportunity	synchronized to wild	approximate wild rearing scenario
	photoperiod	natural	provide ambient conditions	natural	provide ambient conditions
	density	up to maximum safe levels	maximize space use	use low rearing density	minimize behavioral and health aspects of fish quality
	growth	use accepted guidelines for species that maximize adult return.	maximize output	use growth modulation targeted to approximate wild rearing scenario at all cultured life stages	target fish growth to wild size
	survival	maximum possible	maximize output	maximum possible	maximize output
	Prerelease conditioning	none	maximize output	provide antipredator conditioning	reduce predator vulnerability/ increase postrelease survival
				use substrates that enhance crypsis	reduce predator vulnerability/increase postrelease survival

						provide exercise conditioning	increase postrelease survival
						provide forage training	increase postrelease growth and survival
Health	diseases		fish often released with subclinical health problems	maximize output		release only healthy fish	maximize survival and minimize impacts to wild fish
Fish release	fry release		not used under most circumstances			secondary strategy	seed critical habitats at or below carrying capacity
	presmolt release		not used under most circumstances			primary/secondary strategy	seed critical habitats at or below carrying capacity
	smolt release		primary strategy	maximize adult return opportunity		primary/secondary strategy	maximize adult return opportunity

naturally in the habitat. The fish quality goals and operational approaches for a Conservation Hatchery may be considerably different then for a standard production hatchery. Therefore, a Conservation Hatchery must be equipped with a full complement of culture strategies to produce very specific stocks of fish with specific attributes. Where and when implemented, fish rearing in a Conservation Hatchery must be conducted in a manner that 1) mimics the natural life history patterns, 2) improves the quality and survival of hatchery-reared juveniles, and 3) lessens the genetic and ecological impacts of hatchery releases on wild stocks.

Operational guidelines for conservation hatcheries to help mitigate the unnatural conditioning provided by hatchery rearing described in Flagg et al. 2004 include: 1) Mating and rearing designs that produce minimal genetic divergence of hatchery fish from their wild counterparts to maintain long-term adaptive traits; 2) Simulation of natural rearing conditions through incubation and rearing techniques that approximate natural profiles and through increasing habitat complexity (e.g., cover, structure, and substrate in rearing vessels) to produce fish more wild-like in appearance, and with natural behaviors and higher survival; 3) Conditioning techniques such as anti-predator conditioning to increase behavioral fitness; 4) Release of fish at a size, stage, and condition which approximates the wild population to reduce potential negative ecological interactions and to promote migratory homing; and 5) Aggressive monitoring and evaluation to determine success of conservation hatchery approaches.

Genetic Integration vs. Segregation of Hatchery Broodstocks Relative to Natural Populations--A first step towards "hatchery reform" is to develop a detailed genetic management plan or strategy for every hatchery broodstock. Morbrand et al. 2005 described two genetic management options: (1) manage a hatchery broodstock as a reproductively distinct population that is genetically segregated from naturally spawning populations, or (2) manage a hatchery broodstock as a genetically integrated component of an existing natural population. Each of these broodstock strategies leads to a different set of operational guidelines (detailed information on integrated vs segregated approaches can be found on the HSRG websites described above).

Genetically segregated broodstocks are generally derived strictly from hatchery-origin adults returning back to the hatchery each year. Segregated hatchery programs create a genetically distinct, hatchery-adapted population. Segregated hatchery populations will diverge genetically from naturally spawning populations over time because of founder effects, genetic drift, and domestication selection in the hatchery environment. Such changes may be intentional (e.g., via selective breeding) to maximize benefits or the operational efficiency of a hatchery program. However, natural spawning by hatchery-origin fish from a segregated program may pose unacceptable genetic and ecological risks to natural populations, and the HSRG recommends for segregated programs the percent of hatchery origin spawners (HOS) on the spawning grounds should be less than five percent of the naturally-spawning population (pHOS < 5%). Often, to achieve these goals will require a combination of directed selective fisheries and control structures such as weirs to remove segregated populations prior to arrival on spawning grounds.

Conversely, genetically integrated broodstocks systematically include a prescribed proportion of natural-origin fish in the broodstock each year to maintain genetic integration with a natural population. One goal of integrated hatchery programs is to minimize the genetic effects of domestication by allowing selection pressures in the natural environment to drive the genetic constitution and mean fitness of the population as a whole. For an integrated program, the percent of natural origin fish taken into the broodstock each year (NOB) must be greater than the percent of hatchery origin fish allowed to spawn in the wild (pNOB > pHOS). An integrated program will require methods (such as those described for segregated populations) to remove hatchery origin fish prior to spawning grounds to adequately control hatchery/wild fish ratios.

Integrated hatchery programs require, as a long-term goal, a self-sustaining naturally spawning population capable of providing adult fish for broodstock each year. Integration thus requires suitable natural habitat capable of sustaining a natural population. Under this concept, an integrated hatchery does not replace habitat but adds to existing habitat. An implicit goal of an integrated program is to demographically increase the abundance of a natural population while minimizing the genetic effects of artificial propagation. The size of an integrated hatchery program will necessarily be limited by the habitat available to the natural populations with which it is integrated and by the ability of the hatchery program to restrain natural spawning by hatchery-origin adults.

Risks and Benefits--Salmon hatcheries are a major source of controversy in the Pacific Northwest. The HSRG was mandated by Congress to identify potential solutions to widely-recognized problems to ensure that hatcheries contribute to supporting sustainable fisheries while supporting conservation, restoration, and recovery of natural populations. The review focused on identifying scientific uncertainties and proposing solutions based on the best available science. The need to develop broodstock genetic management plans for every hatchery program with the goal of managing each broodstock as either a genetically *segregated* "hatchery population" or as a genetically *integrated* component of an existing "natural population" became a fundamental foundation for the recommendations. Both strategies require the ability to distinguish hatchery and natural-origin adults, both in the hatchery when adults are spawned for broodstock and on the natural spawning grounds to assess the genetic risks and gene flow rates of hatchery-origin fish to natural populations. Commensurate with these reforms is the need for increased monitoring and evaluation, scientific oversight, and accountability of hatchery operations.

In this context, hatcheries cannot be regarded as surrogates or substitutes for lost habitat. Hatcheries need to operate in scientifically-defensible modes with well-defined goals and substantially increased data collection and evaluation. Hatcheries also need to be flexible and adaptable; that is, they need to operate and be evaluated in the context of both the ecosystem (watersheds) in which the hatcheries occur and other ecosystems and ecological processes on which hatchery-origin fish depend.

Scientific uncertainties associated with hatchery operations are numerous. The science to manage these risks is still inadequate, and some of the risks are still poorly understood. However, one point is clear. Maintaining healthy habitat is critical not only for viable, self-sustaining natural populations, but also to adequately control risks of hatchery programs and realize the benefits of hatcheries to recover populations and sustain healthy harvests in increasingly populated environments.

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