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SPECIAL SECTION: HaMAR

Introduction to a Special Section: Hatcheries and Management of Aquatic Resources (HaMAR)—Considerations for Use of Hatcheries and Hatchery-Origin Fish

Jesse T. Trushenski*
Center for Fisheries, Aquaculture, and Aquatic Sciences, Southern Illinois University Carbondale, Life Science II, Room 251, Carbondale, Illinois 62901, USA

H. Lee Blankenship
Northwest Marine Technology, Inc., 976 Ben Nevis Loop, Tumwater, Washington 98501, USA

James D. Bowker
U.S. Fish and Wildlife Service, 4050 Bridger Canyon Road, Bozeman, Montana 59715, USA

Thomas A. Flagg
National Marine Fisheries Service, 7305 Beach Drive East, Port Orchard, Washington 98366, USA

Jay A. Hesse
Nez Perce Tribe Department of Fisheries Resources Management, 28761 Salmon Lane, Lapwai, Idaho 83540, USA

Kenneth M. Leber
Mote Marine Laboratory, 1600 Ken Thompson Parkway, Sarasota, Florida 34236, USA

Don D. MacKinlay
Department of Fisheries and Oceans, 200 Kent Street, Ottawa, Ontario K1A 0E6, Canada

Desmond J. Maynard
National Marine Fisheries Service, 7305 Beach Drive East, Port Orchard, Washington 98366, USA

Christine M. Moffitt
U.S. Geological Survey, Idaho Cooperative Fish and Wildlife Research Unit, University of Idaho, 875 Perimeter Drive, Moscow, Idaho 83844, USA

Vincent A. Mudrak[1]
U.S. Fish and Wildlife Service, 5308 Spring Street, Warm Springs, Georgia 31830, USA

Kim T. Scribner
Michigan State University, 13 Natural Resources Building, East Lansing, Michigan 48824, USA

© Jesse T. Trushenski, H. Lee Blankenship, James D. Bowker, Thomas A. Flagg, Jay A. Hesse, Kenneth M. Leber, Don D. MacKinlay, Desmond J. Maynard, Christine M. Moffitt, Vincent A. Mudrak, Kim T. Scribner, Scott F. Stuewe, John A. Sweka, Gary E. Whelan, and Connie Young-Dubovsky

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*Corresponding author: saluski@siu.edu

[1] Retired.

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Scott F. Stuewe
HDR, 5201 South Sixth Street Road, Springfield, Illinois 62703, USA

John A. Sweka
U.S. Fish and Wildlife Service, 308 Washington Avenue, Lamar, Pennsylvania 16841, USA

Gary E. Whelan
Michigan Department of Natural Resources, 525 West Allegan Street, Lansing, Michigan 48933, USA

Connie Young-Dubovsky
U.S. Fish and Wildlife Service, 134 Union Boulevard, Denver, Colorado 80225, USA

The American Fisheries Society (AFS) has routinely assessed the contributions of hatcheries to natural resource management and issued recommendations to guide natural resource managers in the best uses of hatchery-origin fish. For the past several decades, AFS has explored these issues in a formalized process at approximately 10-year intervals. In response to changes in fisheries management policy, new information on supplementation and rehabilitation, and fisheries issues that had arisen since the previous cycle, AFS undertook the latest cycle of this iterative process in 2012. Dubbed Hatcheries and Management of Aquatic Resources (HaMAR), the process brought together representatives from many fisheries disciplines to generate the present guidance document. Distilled from information gathered from a scoping survey, symposia, and other sources, this AFS-approved document is intended to provide aquatic resource managers with timely and comprehensive guidance regarding hatcheries and their products.

BACKGROUND

The American Fisheries Society (AFS) is the oldest, largest, and most influential professional organization devoted to fisheries conservation. In this capacity, AFS has routinely assessed the contributions of hatcheries to natural resource management and issued recommendations to guide natural resource managers in the best uses of hatchery-origin fish. AFS has explored these issues in a formalized process at approximately 10-year intervals. Representatives of the Fish Culture and Fisheries Management sections came together at Lake of the Ozarks, Missouri, in 1985 to address the question "Fish culture—fish management's ally?" in a symposium entitled "The Role of Fish Culture in Fisheries Management" (Stroud 1986). In 1994, AFS reexamined the issues of fisheries enhancement in the context of emerging ecosystem-based approaches to resource management in a symposium and workshop entitled "Uses and Effects of Cultured Fishes in Aquatic Ecosystems" (Schramm and Piper 1995). A similar process was undertaken in 2003–2004 to again review the uses of hatchery-origin fish and new scientific findings by means of a symposium, a Web-based survey of fisheries professionals, and a facilitated workshop. These efforts were collectively referred to as "Propagated Fishes in Resource Management" (PFIRM).

In 2012, AFS initiated the next cycle in this iterative process, dubbed "Hatcheries and Management of Aquatic Resources" (HaMAR). Each of the previous cycles yielded proceedings publications: *Fish Culture in Fisheries Management* (Stroud 1986), *Uses and Effects of Cultured Fishes in Aquatic Ecosystems* (Schramm and Piper 1995), and *Propagated Fishes in Resource Management* (Nickum et al. 2004), and most recently a guidance document, *Considerations for the Use of Propagated Fishes in Resource Management* (Mudrak and Carmichael 2005; see Supplement A in the online version of this paper, hereafter referred to as "PFIRM Considerations"). The PFIRM Considerations guide provided resource managers with general recommendations for decision making and successful implementation of fisheries supplementation, rehabilitation, and restoration programs. The present guidance document represents an update and expansion of the PFIRM Considerations publication. It is intended to provide aquatic resource managers with timely and comprehensive guidance regarding hatcheries and their products, including finfish, crustaceans, mollusks, reptiles, and other aquatic biota.

FORMATION OF THE STEERING COMMITTEE

In response to changes in fisheries management policy, new information on supplementation and rehabilitation, and fisheries issues that have arisen since the previous cycle, AFS President William Fisher established the HaMAR steering committee in 2012. The steering committee was charged with reengaging AFS in addressing issues related to hatchery operation and the role of hatchery-origin fish in aquatic resource management. The steering committee represented the perspectives of interested AFS sections as well as state, provincial, and federal agencies, Native Americans and First Nations, and the Science Consortium for Replenishment of the Oceans. Collectively, this group worked to develop, organize, and implement the HaMAR process. Following completion of a scoping survey and a fact-finding symposia (see below), the authors prepared the present guidance document.

FIGURE 1. Demographics of the respondents to the HaMAR scoping survey conducted in 2012. The results are summarized by geographic region, employer type, major fisheries discipline, and affiliation with AFS sections. A total of 431 responses were received by the deadline. Fisheries professionals working in Mexican states were targeted during the survey process, but no responses were received.

SCOPING SURVEY

A scoping survey was conducted to help develop fact-finding sessions to elucidate current and emerging issues related to the use of hatchery products in aquatic resource management. In consultation with their “constituencies,” the HaMAR steering committee members prepared a list of topics regarding hatchery operation and the use of hatchery-origin fish. These topics formed the basis of a scoping survey that asked respondents to rank them with respect to their importance. The respondents were also asked to comment on the current relevance of the PFIRM Considerations guide and provide any additional insights that they had regarding the status of hatcheries and the use of hatchery-origin fish. Requests to complete the survey were distributed by various means, including AFS and AFS unit listserv lists, the Association of Fish and Wildlife Agencies listserv, and other mechanisms.

Nearly 450 responses were received from employees of state, provincial, and federal agencies; academics; tribal–First Nation authorities; and representatives from the private sector, nonprofit groups, and nongovernmental organizations as well as a wide range of AFS unit affiliations (Figure 1). Responses were received from 48 states and 3 Canadian provinces. Respondents identified habitat restoration and management efforts as critical companions to fish stocking programs. The most important contemporary issues related to hatcheries and hatchery-origin fish included monitoring and the adaptive management of stocking programs; the development of propagation techniques that result in genetically appropriate and healthy hatchery-origin fish; fish health and access to disease management tools; and understanding the limitations of hatchery-origin fish and stocking programs (Figure 2). These and the other highest-ranking topical areas became the central foci of the planned fact-finding symposia. Respondents indicated that the core considerations identified in the PFIRM process were still relevant but that the relative importance of each had changed, with greater priority being given to the creation of comprehensive fishery management plans, consideration of biological and environmental feasibility, and risk–benefit analysis (Figure 3). The new structure and focus of the present guidance document was chosen, in part, to reflect these apparent shifts in fisheries professionals’ priorities.

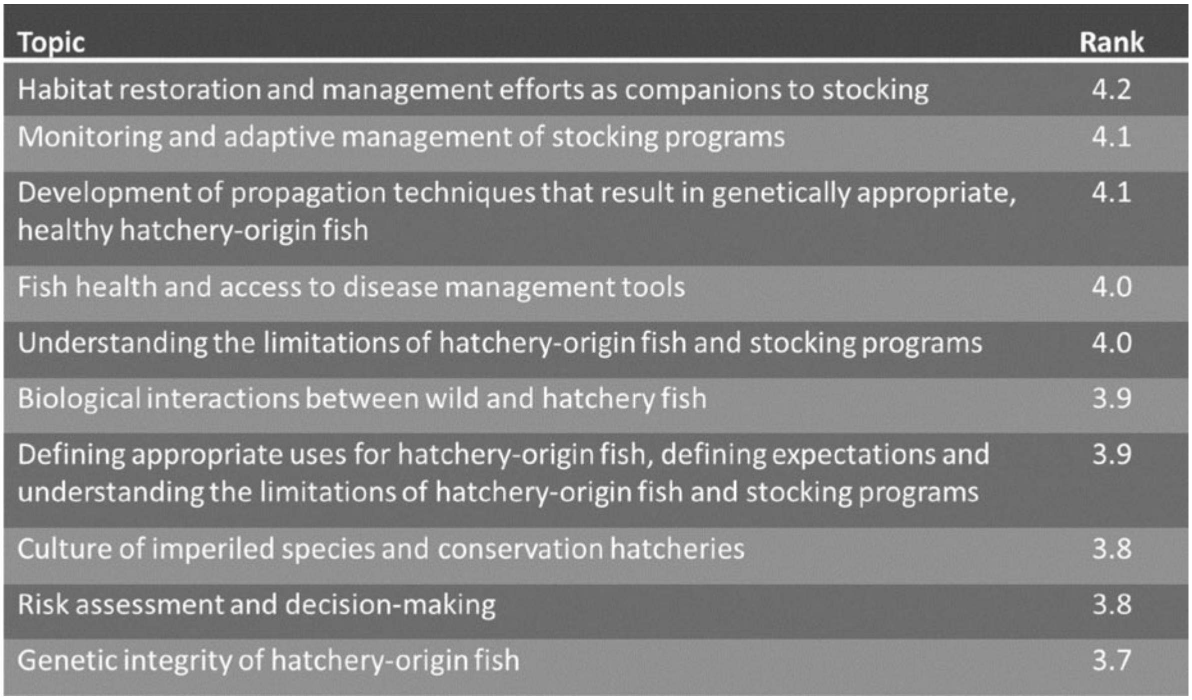
SYMPOSIA

Based on the priority topics identified by the scoping survey, presentations were solicited for the AQUACULTURE 2013 conference (Nashville, Tennessee, February 21–25, 2013). Ten papers were presented on topics such as hatchery reform in Washington, Idaho, and South Carolina; emerging disease issues and how these affect hatchery operation; and the effectiveness of nontraditional restoration partnerships. Many participants also made presentations in related sessions organized by others involved in hatchery operation and the use of hatchery-origin fish.

A larger symposium was developed for the AFS annual meeting in 2013 (Little Rock, Arkansas, September 8–12, 2013). Underwritten by the AFS Fish Culture, Introduced Fishes, and Fisheries Management sections and organized with help from the Fish Habitat, Fish Health, Fisheries Administration, Genetics, Marine Fisheries, Physiology, and Water Quality sections, the symposium featured topics related to each of these disciplines and others such as tribal–First Nations trust responsibilities and human dimensions.

DELIVERABLES

Information gathered from the scoping survey, symposia, and other sources was distilled by the authors into the present guidance document. It is intended to provide timely information regarding hatcheries and their products to aquatic resource managers and decision makers. It is further intended to provide



Topic	Rank
Habitat restoration and management efforts as companions to stocking	4.2
Monitoring and adaptive management of stocking programs	4.1
Development of propagation techniques that result in genetically appropriate, healthy hatchery-origin fish	4.1
Fish health and access to disease management tools	4.0
Understanding the limitations of hatchery-origin fish and stocking programs	4.0
Biological interactions between wild and hatchery fish	3.9
Defining appropriate uses for hatchery-origin fish, defining expectations and understanding the limitations of hatchery-origin fish and stocking programs	3.9
Culture of imperiled species and conservation hatcheries	3.8
Risk assessment and decision-making	3.8
Genetic integrity of hatchery-origin fish	3.7

FIGURE 2. Top 10 topics identified by the scoping survey. Approximately 40 topics were ranked by the respondents on a scale ranging from 0 (not important) to 5 (extremely important). The values shown are the average ranks.

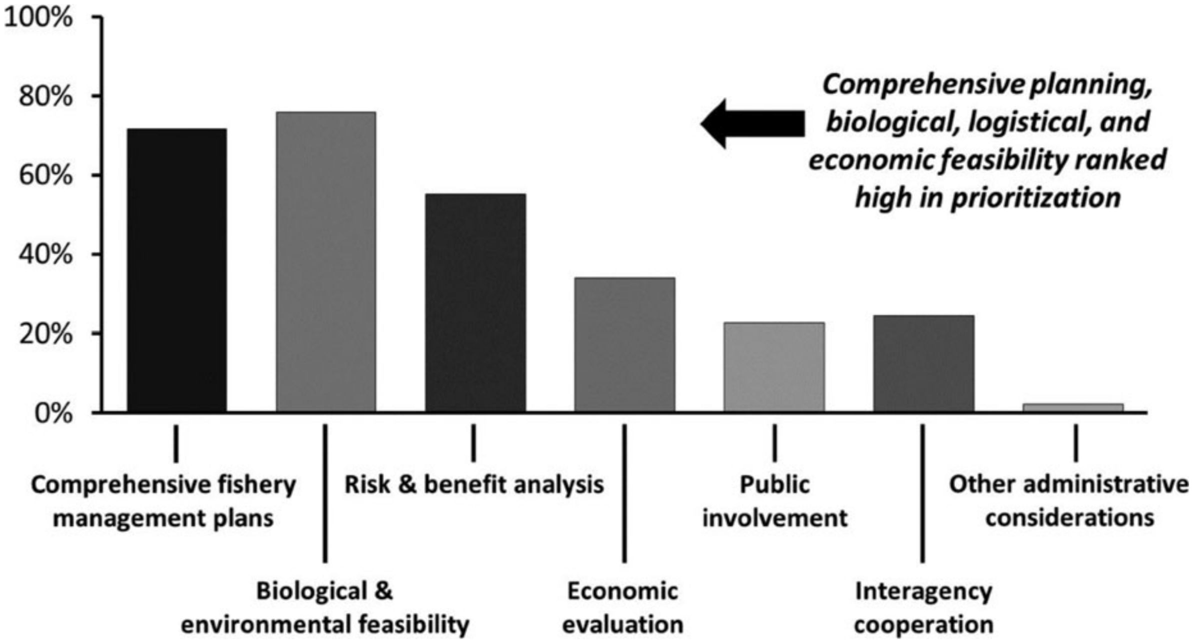


FIGURE 3. Elements of the decision-making process described in *Considerations for the Use of Propagated Fish in Resource Management* ranked according to the priorities identified by the respondents to the scoping survey. The values are the percentages of the respondents who indicated that those elements were among the three most important considerations in determining whether or not to initiate a stocking program.

a set of guiding principles for resource management efforts that may call for the use of hatchery-origin fish, including the conservation of commercial and recreational fisheries, the creation of new fishing opportunities, imperiled species restoration, and others. Herein we present a summary of the PFIRM Considerations and then discuss the wide range of considerations for the use of hatcheries and hatchery-reared fish. These considerations involve such topics as habitat restoration and management; the uses, expectations, and limitations of hatcheries and hatchery-reared fish; and monitoring and adaptive management. We then discuss hatchery operations and techniques, the use of conservation hatcheries, fish health and disease issues, biosecurity, the genetic integrity of stocks, interactions between hatchery and wild fish, and risk assessment. Finally, we conclude with a summary of concerns yet to be resolved.

Concurrent with the development of the present guidance document, some of the HaMAR-related symposium presentations were appropriately peer-reviewed and are published here in this special section of the journal.

CONSIDERATIONS FOR USE OF HATCHERIES AND HATCHERY-ORIGIN FISH

Summary of Findings from PFIRM

The PFIRM process identified seven primary concepts that should be considered when stocking fish: (1) comprehensive fishery management plans, (2) biological and environmental feasibility, (3) risk and benefit analysis, (4) economic evaluation, (5) public involvement, (6) interagency cooperation, and (7) other administrative considerations (Mudrak and Carmichael 2005; Supplement A). The participants in PFIRM also addressed several narrower topics, some of which were considered controversial at the time: risk and resource assessment, outbreeding depression, the propriety of stocked fishes, and fisheries management terminology. Some of these issues are highlighted below, but readers are encouraged to review the PFIRM Considerations document for more in-depth discussion of the PFIRM-era topics.

- Comprehensive fishery management plans: these plans should guide resource managers through their choices with respect to stocking fish, evaluating stocking programs, and managing fisheries in an adaptive, responsive fashion. The comprehensive management planning process should recognize and consider alternatives to stocking and include inputs from various resource partners. When stocking is recommended, specific goals and objectives should be considered. The objectives should be specific, measurable, accountable, realistic, and time-fixed (Meffe et al. 2002).
- Biological and environmental feasibility: decisions to stock propagated fish should be predicated on science-based evaluations that indicate that the environment can support the stocked fish and that stocking will achieve the identified management objectives.
- Risk and benefit analysis: scientific evaluations should be conducted to determine the effects that stocked fish may have on the environment and on native and naturalized biota (including humans), along with the benefits and risks of the various approaches. Of particular importance are the potential beneficial or harmful effects of increased and directed public use of aquatic environments; particular caution should be exercised when introducing fish to an area where they did not occur previously.
- Economic evaluation: benefits and costs should be comprehensively evaluated and quantified as well as possible.
- Public involvement: Decision makers should try to keep the public informed about pending changes in fisheries management, encouraging dialogue and providing a forum for public input. Moreover, when appropriate, they should educate the public on legal and interjurisdictional issues, including tribal and First Nations treaty rights and responsibilities.
- Interagency cooperation: Managers should share technical, science-based fisheries information to strengthen interagency coordination and interjurisdictional fisheries monitoring programs. They should also recognize the regulatory and legal differences pertaining to the different jurisdictions involved (the United States, Canada, Mexico, tribes, provinces, states, territories, and special federal lands such as national parks and military reservations).

The PFIRM Considerations provide a good summary of the issues that fisheries managers considered important at the time for their comprehensive planning process and subsequent decisions involving the use of stocked fish. We believe that the PFIRM Considerations are still a primary resource for managers in developing fisheries management plans that include stocking propagated fish. However, much scientific progress has been made in the decade since publication of the PFIRM Considerations on the issues of hatcheries and hatchery fish. The HaMAR process was initiated to attempt to capture the current information on the stocking of propagated fish and to examine how the related issues and priorities have changed.

Priority Shifts Identified during HaMAR

The HaMAR scoping survey respondents were asked to assess the current relevance of the major elements identified in the PFIRM Considerations. More specifically, they were asked to identify which three of the seven elements they considered to be the most important in terms of contemporary stocking programs. Whereas all seven elements remain relevant, the creation of comprehensive fishery management plans, consideration of biological and environmental feasibility, and risk–benefit analysis were emphasized as the highest priorities (Figures 2, 3). For example, establishing appropriate uses for hatchery-origin fish, defining expectations for stocking programs, and understanding the limitations of both are integral to the creation of a comprehensive fishery management plan, as is consideration of complementary habitat rehabilitation and other management efforts. Similarly, developing propagation methods that ensure the genetic integrity and health of hatchery-origin fish is essential to success. The importance of risk–benefit analysis was directly reaffirmed in the context of risk assessment and decision making. From these results, it is clear that the PFIRM Considerations remain relevant, but there is now even more emphasis on integrated management and a need for greater specificity in considering the use of hatcheries and hatchery-origin fish. In the following sections, each of the priority topics identified during the HaMAR process is addressed in detail.

Habitat Restoration and Management Efforts as Companions to Stocking

Whereas the focus of the present guidance document is the use of hatcheries and hatchery-origin fish, it is imperative to note that stocking is just one leg of the "three-legged stool" of fisheries management. Stocking is unlikely to be successful in the absence of complementary habitat rehabilitation and harvest management strategies. Increasingly, management approaches must also be inclusive of strategies to control or eradicate competing invasive species. Walters and Martel (2004) noted a few instances when stocking went wrong, and these were primarily related to disconnects between stocking, habitat, and harvest control. In these cases, the lack of an integrated approach resulted in the replacement of wild fish with hatchery recruits with no net increase in stock size; excessive pressure following stocking, resulting in overfishing of wild fish; overexploitation of the available forage by the stocked species (because the number of stocked fish exceeded the carry capacity of the system); and genetic effects on the long-term viability of the wild stock. Walters and Martel (2004) stressed the importance of identifying relevant metrics and benchmarks, closely monitoring the effects of stocking, and collecting targeted data on stocking effectiveness or ineffectiveness. This information is essential to adaptive management and engaging regulatory authorities and stakeholders in scientifically justifiable decision making (see Leber and Leber et al. abstracts in Supplement B).

Establishing Appropriate Uses for Hatchery-Origin Fish and Defining Expectations for Stocking Programs

Hatchery-origin fish are used to achieve a number of management objectives that are discussed further in the section Hatchery Operation and Propagation Techniques below. Appropriate propagation and stocking methods vary based on the intended use of the fish, and it is impossible to apply the principles of adaptive management if the goals and objectives are not clearly articulated and agreed to by decision makers and stakeholders. Stocking may or may not be an effective management action, depending on the targets identified for the fishery and the current status of the receiving system. If quantitative assessments indicate that stocking is advisable, species selection processes should take a broad range of biological, economic (including tangible and intangible costs and benefits), and risk management criteria into consideration, as described above in the section Summary of Findings from PFIRM (see Gainer et al. abstract in Supplement B). Lorenzen et al. (2010) recommend a series of three stages for implementing stocking programs that may aid in defining expectations:

- Stage I: initial appraisal and goal setting. In this stage, decision makers and stakeholders establish a decision-making process, evaluate the potential for enhancement to further fisheries management goals, prioritize species for enhancement based on biological criteria, and assess the potential economic and social costs and benefits of enhancement.
- Stage II: research and technology development, including pilot studies. In this stage, the "nuts and bolts" of hatchery operation and fish production are established, including identification of proper rearing systems, husbandry methods, and release protocols. During this phase, genetic resource management and fish health management plans are developed and implemented to ensure the genetic and physiological integrity of the cultured fish.
- Stage III: operational implementation and effectiveness analysis. In this stage, management plans are defined and implemented so that the effects of stocking are monitored and decision points and metrics are established and used to best meet program objectives.

These steps reflect the recommendations identified in the PFIRM Considerations document in many ways, but the full document (Mudrak and Carmichael 2005; Supplement A) provides a greater level of detail and specific guidance to decision makers and resource managers (see Lorenzen et al. 2010 for further information; see also the Leber and Leber et al. abstracts in Supplement B).

Understanding the Limitations of Hatchery-Origin Fish and Stocking Programs

Hatcheries and hatchery-origin fish are an essential component of many fishery management plans. However, there are limitations to stocking, and failure to recognize and address these limitations may lead to unintended consequences. In the 19th century, hatcheries were viewed as technological marvels that could turn degraded waters, newly formed reservoirs and impoundments, and underused waterways into bountiful sources of food and recreation (often in the form of nonnative species) as well as address declining catches in established fisheries (see the Moffitt abstract in Supplement B). It is still tempting to view hatchery-origin fish as a "quick fix," but like other quick fixes, they are unlikely to resolve systemic issues unless applied as part of a comprehensive solution. If not implemented responsibly, enhancement may lull regulatory authorities into false confidence or dissuade them from addressing the root cause of the identified problem (Leber 2013).

Successful enhancement programs are closely connected to the fishery management process and are integrated with ongoing fishery monitoring programs. Flexible and adaptive management of hatcheries and their associated fisheries management plans enable refinement, progress, and success in stocking programs. Lorenzen et al. (2010) identified several common weaknesses that can limit the success of enhancement programs:

- Lack of a clear fishery-management perspective;
- Lack of fishery stock assessments and modeling to explore the potential positive and negative effects of stocking;
- Ignoring the need to establish a structured decision-making process;
- Lack of stakeholder involvement in the planning and execution of the stocking program from the beginning; and
- Failure to thoroughly integrate flexible and adaptive management into the stocking plan.

Leber (2013) underscored these issues, emphasizing the need for better integration between hatcheries and the fisheries management programs they are intended to support, and suggested that greater stakeholder awareness of the issues, pitfalls, progress, and opportunities related to a stocking program will lead to more realistic expectations and better fisheries for all.

In the U.S. Pacific Northwest, the Hatchery Scientific Review Group (HSRG; http://www.hatcheryreform.us/) established by the U.S. Congress described three foundational principles for best management practices for the operation of hatcheries (Mobrand et al. 2005; HSRG 2009; Paquet et al. 2011):

- Principle 1. Every hatchery stock must have well-defined goals in terms of desired benefits and purpose. Goals and objectives should be well defined and explicit and include (1) the number of fish intended to be harvested, (2) the number of fish returning to a hatchery or spawning naturally in a watershed (i.e., escapement), and (3) the expected results of any associated scientific research. Goals must reflect the purpose and desired benefits of the program (e.g., harvest, conservation, research, and education), and monitoring plans need to be in place to track progress.
- Principle 2. The goals of hatchery programs and the day-to-day operations of hatcheries must be scientifically defensible. Once the goals for a program are established, the scientific rationale for the design and operation of the program must be explicitly described so that it can be understood by all personnel and, ideally, the general public. The approach must represent a logical progression to achieve the management goals and should be based on knowledge of the target ecosystem and the best scientific information available. Scientific oversight and peer review should be integral components of every hatchery program.
- Principle 3. Hatchery programs must be flexible and respond adaptively to new information. Scientific monitoring is necessary for all stocking programs and, ideally, programs should be evaluated annually to allow timely adjustments. Hatcheries should be managed flexibly and adaptively to respond to new goals, new scientific information, and changes in the status of natural stocks and habitat. If possible, evaluations should include assessments of survival, the contributions of hatchery-origin adults to harvest and natural reproduction, and genetic (e.g., inbreeding and outbreeding depression) and ecological (e.g., competition, predation, and disease transmission) interactions between hatchery- and natural-origin fish.

The HSRG also emphasized that maintaining healthy habitat is critical not only to maintaining viable, self-sustaining, natural populations but also to adequately controlling the risks of hatchery programs and realizing their benefits.

Monitoring and Flexible and Adaptive Management of Stocking Programs

As noted above, it is absolutely essential that fishery management plans include preestablished timelines and criteria for evaluating enhancement and deciding whether to continue, modify, or terminate the stocking program. Such recurrent decisions require the adoption of a formal adaptive management framework (Williams et al. 2007). The specific objectives and benchmarks of effectiveness will vary from one situation to another depending on the nature of the stocking program and the stakeholders involved and their values. Stocking may be conducted in perpetuity to support a put-and-take fishery, but such an approach would not be an appropriate benchmark for enhancement efforts intended to establish or reestablish a self-sustaining population. Decision points and triggers must be developed and accepted by regulatory authorities and stakeholders before they are needed. The decision to continue or discontinue a long-standing stocking program can be fraught with political discord without agreed-upon criteria and quantitative measures to reference, leading to the decision-making process's being easily delayed or derailed and resulting in lost time and resources as well as low cost–benefit ratios (see the Johnson et al. abstract in Supplement B).

Monitoring provides decision makers with the evidence needed to objectively evaluate stocking effectiveness. Given the size of many stocking programs, annual assessment of all receiving systems/target populations may not be feasible. In these cases, monitoring programs should be designed to maximize the value of the information collected (e.g., by assessing "type" populations/systems that are representative of others within the stocking program, using stratified sampling techniques to address geographical scope, or employing other such approaches). Walters and Martel (2004) identified the following recommendations for the evaluation of fishery enhancement:

- Mark all, or at least a known proportion, of the fish released from hatcheries;
- Mark as many as possible wild fish of the same size and at the same location as the hatchery fish being released;
- Experimentally vary hatchery releases over a wide range from year to year and from area to area, rotating stocking annually to break up the confounding effects of competition and predation with shared environmental effects;
- Monitor changes in total recruitment, production, and fishing effort in targeted fish populations, not just the percentage contribution of hatchery fish to production;
- Monitor changes in the fishing mortality rates of both wild and hatchery fish directly, through carefully conducted tagging and recovery programs that measure short-term probabilities of capture; and
- Monitor the reproductive performance of hatchery-origin fish and hatchery–wild hybrid crosses in the wild using genetic information from both hatchery and wild fish (see Leber, Leber et al. and Hesse et al. abstracts in Supplement B).

These requirements emphasize marking hatchery-origin fish. Marking or tagging all hatchery releases so that they can be easily distinguished from conspecific wild fish is an especially valuable tool for broodstock management, selective fisheries, and evaluation of the ecological and genetic implications of stocking. However, identifying hatchery-origin fish with physical tags or external marks may be costly, affect poststocking fitness and survival, or be inconsistent with stakeholder values, particularly those of some native peoples. Minimizing the intrusive marking and handling of fish supports cultural and spiritual beliefs, shows respect for the fish, and maximizes their survival. Alternative means of identifying hatchery-origin fish, such as genetic "fingerprinting" (parentage-based tagging), thermal otolith marking, and otolith microchemistry are becoming increasingly popular as generating and managing the associated data becomes increasingly feasible and cost effective. Such marking techniques can also be valuable in assessing the fate of hatchery-origin fish with large home ranges or complex life histories (i.e., anadromous stocks; ISRP/ISAB 2009). Hatchery programs with multiple releases should consider tagging a portion of each group released (the constant fractional marking strategy), recognizing that the number of tagged fish influences the rigor and statistical power of the analysis.

Hatchery Operation and Propagation Techniques

Types of enhancements and complementary modes of hatchery operation.—Not all fish tolerate the same environmental conditions, and husbandry methods vary substantially among the hundreds of finfish species that are reared throughout the world. Just as propagation techniques vary from fish to fish, what constitutes best management practices for a hatchery depends on the operation's requirements. Examples of such requirements include the taxa to be raised, the size required by managers, and whether the fish are expected to recruit to the fishery following release or simply satisfy angler demand for catchable-sized fish. The answers to these and related questions will determine what propagation methods, fish quality and genetic requirements, and operational standards are appropriate for the hatchery.

Much progress has been made toward defining common stocking strategies (HSRG 2009; Lorenzen et al. 2010; Trushenski et al. 2010). However, standardized terminology and definitions remain elusive. We encourage the use of the following terms to broadly characterize managers' expectations of hatchery-origin fish and help to frame the principles of hatchery operation and propagation methods:

- Harvest augmentation: fish stocking with little to no expectations beyond return to the creel (also referred to as put-and-take and put-grow-take fisheries and sea ranching);
- Supplementation: recurrent releases of juvenile fish to compensate for poor recruitment caused by limitations related to habitat quantity or quality, environmental quality, or intense harvest pressure (also referred to as restocking or stock enhancement and related to terms including conservation and captive broodstock; note that harvest augmentation and supplementation may be conducted to address ecosystem balance as well as population-level concerns);
- Reintroduction: short-term releases to reestablish a locally extinct or extirpated population;
- Integrated hatchery program: a program that produces fish genetically similar to the wild population and has as a long-term goal the creation of a self-sustaining, naturally spawning population capable of providing adult fish for broodstock each year;
- Segregated hatchery program: a program that produces a distinct, hatchery-supported population that is reproductively isolated from wild populations (such a program creates a new, hatchery-adapted population intended to meet goals for harvest or other purposes, e.g., research, education); and
- Experimental: fish stocking to conduct or facilitate research projects or hypothesis testing.

Harvest augmentation or production hatcheries use industrialized rearing techniques and focus on the efficient, low-cost production of large numbers of fish to increase the number in a receiving system. These operations do not necessarily focus on genetic management or on mimicking natural rearing conditions. Fish originating from such facilities can be genetically or behaviorally distinct from wild fish and may not exhibit local adaptations or maximum fitness after they are stocked. As a result, these types of hatcheries are best suited to supplying fish for put-and-take or put-grow-take management plans.

Supplementation hatcheries often use the same rearing systems as production hatcheries but differ in that the fish they produce are generally intended to become naturally spawning individuals after stocking. These types of hatcheries generally use gametes from wild-origin broodstock and follow strict breeding and release protocols to minimize the loss of genetic diversity and artificial selection in the hatchery environment. Fish originating from supplementation hatcheries are raised to be similar to wild fish, and are best suited to management plans intended to increase the number of naturally spawning individuals or recruitment.

Conservation hatcheries are an extreme form of supplementation hatcheries and follow protocols to intensively manage the genetic integrity of the broodstock as well as the overall fitness of the progeny. Culture methods are typically modified to mimic natural conditions to the extent feasible. Fish originating from conservation hatcheries have been raised to be as genetically and behaviorally similar to wild fish as possible and are best suited to management plans focused on the restoration of imperiled populations. Conservation hatcheries also serve increasingly important roles as refugia for rare species or genetic profiles.

Many hatcheries are functional “hybrids,” operating as harvest augmentation, supplementation, or conservation hatcheries by turns or simultaneously to produce various fish in a manner consistent with their intended uses. Clear and well-documented objectives are essential for all hatchery programs, especially for facilities rearing fish for different uses.

Emerging concerns: conflicting mandates and balancing the use of hatcheries to support both conservation and harvest objectives.—(See the Flagg abstract in Supplement B). During the development and operation of hatchery programs, managers are often faced with having to address competing and often conflicting objectives or mandates. For instance, in the Pacific Northwest almost two dozen stocks of Pacific salmon *Oncorhynchus* spp. are now listed as threatened or endangered under the U.S. Endangered Species Act and require federal protection and rebuilding. At the same time, hatchery programs release almost 300 million fish to support harvest requirements associated with legally binding federal treaties, treaty trust responsibilities, and court mandates. Achieving a scientifically defensible but socially acceptable balance between harvest and conservation has proved to be challenging, both politically and biologically. During the last decade, the HSRG was charged by the U.S. Congress with examining and suggesting possible solutions to conservation and harvest conflicts in the Columbia River basin (HSRG 2009; Paquet et al. 2011). The HSRG review examined over 178 hatchery programs and 351 individual hatchery and wild salmon and steelhead *O. mykiss* populations to determine mechanisms for achieving managers’ goals for conservation and sustainable fisheries. The HSRG’s approach was to use the best available science and the principles of explicit goal identification, scientific defensibility, and flexible and adaptive management to shift the Columbia River hatchery system from an agrarian or aquaculture-based paradigm to a renewable natural resource paradigm. Best management “practices” should be applied as “principles” that (1) maintain site-specific flexibility, (2) integrate biological, legal, and political perspectives, and (3) ensure adaptive management based on program performance data (see the Hesse and Johnson abstract in Supplement B).

The HSRG approach used modeling based on the size and biological importance of a wild population, the size and location of the proposed hatchery release, the fraction of hatchery fish (pHOS) in the natural spawning escapement, and the fraction of natural-origin parents in the hatchery broodstock (pNOB) over time. The HSRG then calculated the proportionate natural influence (PNI) as a measure of the relative influence of the natural and hatchery environments on the mean phenotypic values of a population at equilibrium based on the relative rates of gene flow between the two environments (i.e., $0 < \mathrm{PNI} < 1.0$). The HSRG recommended standards for each population designation regarding the allowable levels of hatchery influence on naturally spawning populations in terms of pHOS and PNI, whereby (1) “primary populations” would need to experience the lowest level of hatchery influence (pHOS should be $<5\%$ of the naturally spawning population unless the hatchery population is integrated with the natural population; for integrated populations, pNOB should exceed pHOS by at least a factor of two, corresponding to a PNI value of ≥ 0.67, and pHOS should be less than 0.30), (2) “contributing populations” would have an intermediate level of influence (pHOS should be $<10\%$ of the naturally spawning population unless the hatchery population is integrated with the natural population; for integrated populations, pNOB should exceed pHOS, corresponding to a PNI value of ≥ 0.50, and pHOS should be <0.30), and (3) “stabilizing populations” would not require modification (no criteria developed for pHOS or PNI) (Paquet et al. 2011).

Using these parameters and precautions, the HSRG solutions were able to project improved conservation status for many Columbia River populations, usually exceeding the comanagers’ conservation goals for these populations while providing for increased harvest (HSRG 2009; Paquet et al. 2011). An important aspect of these solutions was the underlying assumption that the biological principles used to manage hatchery populations and programs had to be the same ones used for managing natural populations. Hatcheries and hatchery operations must be considered in the context of the ecosystem and should be as small as possible while achieving their conservation and harvest goals. The HSRG review emphasized that hatcheries and hatchery fish cannot replace lost or damaged habitat or the natural populations that rely on that habitat. Hatchery programs must be viewed not as surrogates or permanent replacements for lost habitat but as tools that can be managed as part of a coordinated strategy to meet watershed or regional resource goals, in concert with actions affecting habitat, harvest rates, water allocation, and other important components of the human environment. To be considered successful, hatcheries should be part of a comprehensive strategy in which habitat, hatchery management, and harvest are coordinated to best meet resource management goals that are defined for each population in each watershed.

Emerging concerns: controlling the costs of hatchery operations.—In the United States alone, state and federal fish hatcheries produce roughly 1.75 billion fish annually, corresponding to a production volume of more than 20 million kg (Halverson 2008). Tribal–First Nations and private hatcheries also produce fish for use in natural resource management. Hatchery operation involves both economic and environmental costs, much of which are associated with feeding practices. Even assuming high feed conversion efficiencies, rearing large volumes of fish requires even larger amounts of nutrient-dense aquaculture feeds and yields solid and dissolved wastes. Feed cost and effluent management are increasingly critical constraints for hatcheries; flat or declining budgets and stricter oversight of water usage make the prospect of producing the same or greater numbers of fish a difficult, if not impossible, proposition.

Unlike terrestrial livestock, fish demand diets rich in proteins and lipids (fats and oils), which increases the price of aquaculture feeds compared with the forage or prepared diets used in poultry, swine, and cattle production. To meet these requirements, feed manufacturers traditionally used nutrient-dense ingredients like fish meal and fish oil (produced by rendering small marine pelagic fishes such as anchovies or herrings) as primary ingredients. However, the price of such ingredients has increased dramatically, having grown by 400% over the last 20 years, including a twofold increase since 2004 (FAO 2008). To control feed prices, fish meal and fish oil can be replaced with lower cost, terrestrial-origin ingredients, such as derivatives of soy, corn, wheat, and various rendered animal products. However, these alternative ingredients do not provide the same nutritional value as fish meal and fish oil and may not be as palatable or digestible to cultured fish. Consequently, replacing marine-origin ingredients with terrestrial-origin products may help to control feed costs but may limit fish growth and performance as well as complicate water quality management and limit effluent discharges.

The costs of hatchery operation will continue to increase as a result of increasing feed prices and/or the need to implement more robust water treatment methods (see the Eisch abstracts in Supplement B) or transition to more intensive, water reuse–based rearing systems. Research and development on fish nutrition and low-cost, low-effluent feeds, water treatment technology, and energy efficiency has yielded incremental progress, but the growing financial burden of hatcheries jeopardizes the ability of agencies to operate these facilities and use their essential products and services in natural resource management. While reductions in effort or hatchery closures may offer short-term savings, it is important to recognize that curtailing hatchery programs will undoubtedly have broader economic consequences. Beyond the intangible value of imperiled species restoration and the strengthening of native fish assemblages, hatcheries support recreational fishing, which is valued at more than US$61 billion in total economic impact and is associated with more than 587,000 jobs in the United States (Southwick Associates 2011). In addition to their costs, the value of hatchery programs and their products must be considered. Although the economic benefit of sport and commercial fisheries is the most readily quantified, such assessments should also attempt to account for the "total economic value" of aquatic species, including their existence and bequest value (i.e., the value associated with preventing extinctions and the continued existence of imperiled species [also referred to as "nonuse" or "passive use" value]), their recreational value not related to fishing (e.g., photography and ecotourism), and the nonmarket services provided by aquatic species (e.g., ecosystem services, the use of aquatic species as management tools, and biomedical resources).

Culture of Imperiled Species and Conservation Hatcheries

The operational approaches and measures of success for a conservation hatchery may differ considerably from those designed for harvest augmentation and production or supplementation. The mission of a modern conservation hatchery is twofold: gene pool preservation and population recovery. Flagg and Nash (1999) described a generalized decision tree for the implementation of conservation hatchery strategies that includes the status of the population, its genetic composition, its rate of decline, and the impact of any actions on native fish. Each conservation program will therefore be site-specific and depend on the physical and management limitations of each individual hatchery. Consequently, the exact application of conservation hatchery strategies will depend on the particular stock of fish, its level of depletion, and the biodiversity of the ecosystem.

Once a conservation hatchery approach has been selected, program operation requires the application and integration of a number of rearing protocols that are known to affect the inherent ability of the fish to survive and breed in its natural environment. Fish husbandry in a conservation hatchery must be conducted in a manner that (1) mimics natural life history patterns, (2) improves the quality and survival of hatchery-reared juveniles, and (3) lessens the genetic and behavioral influences of propagation techniques on hatchery fish and, in turn, the genetic and ecological impacts of hatchery releases on wild stocks (Flagg et al. 2004). Operational guidelines for conservation hatcheries (Flagg et al. 2004) may include (1) using mating and rearing designs that reduce the risk of domestication selection and produce minimal genetic divergence of hatchery fish from their wild counterparts to maintain long-term adaptive traits; (2) simulating natural rearing conditions through incubation and rearing techniques that approximate natural profiles and increasing habitat complexity (e.g., providing cover, structure, and substrate in rearing vessels) to produce fish that are more wild-like in appearance and with natural behaviors and survival similar to wild fish upon release; (3) using conditioning techniques such as antipredator or increased water flow conditioning to increase postrelease behavioral fitness; (4) programming aspects of release size, stage, and condition to match the wild population in order to reduce the potential for negative ecological interactions and to promote homing; and (5) performing aggressive monitoring and evaluation to determine the success of conservation hatchery approaches. High priority must be given to basic scientific research to meet three principal goals: (1) maintaining the genetic integrity of the population, (2) increasing juvenile quality and behavioral fitness, and (3) increasing adult quality ("quality" being a somewhat plastic metric, determined on a case-by-case basis but based on preestablished criteria relevant to the specific circumstance).

In the future, the creation of gene banks using cryopreservation and other biotechnological tools for reproduction (e.g., gynogenesis, androgenesis, and cloning) may be increasingly important in the preservation or production of rare aquatic organisms. Gene banking allows for gametes or other genetic resources to be stored indefinitely or for nearly indefinite periods of time. Gene banking may be particularly beneficial for increasing effective population size when broodstock are limited (e.g., by means of intergenerational crossing) or when husbandry methods have not been adequately established beyond gamete collection and preservation (Harvey 2000). Gene banking and other reproductive biotechnologies are more refined in the agricultural sectors (including aquaculture: Hiemstra et al. 2006) and in the restoration of imperiled terrestrial species (Leibo and Songsasen 2002), but these approaches may prove essential to preventing future losses of genetic diversity or extinctions.

Fish Health and Access to Disease Management Tools

The goals of a model aquatic animal health program should include (1) keeping mortality low and maximizing production for each facility; (2) ensuring that hatchery-origin fish are fit and have a high likelihood of survival after stocking; (3) preventing the introduction of pathogens to naïve receiving waters and producing immunologically competent fish that are able to withstand exposure to pathogens found in the wild; and (4) ensuring that wild populations are not exposed to different or greater densities of pathogens as a result of stocking.

Establishing a relationship with or having a qualified fish health professional or veterinarian on staff is paramount to achieving these goals. Successful hatchery programs take a comprehensive approach to aquatic animal health, including the use of biologics (i.e., vaccines and bacterins), biosecurity measures and other preventative strategies; the use of therapeutants and other disease management techniques; broodstock conditioning and spawning; marking progeny; and reducing handling stress. Many of these activities require administration of fish drugs, including antimicrobials, spawning aids, marking agents, and sedatives. Virtually all hatchery-origin fish are considered to be food fish or fish that may be caught and consumed (though species that are listed as threatened or endangered at the state, provincial, or federal level are generally considered to be exceptions to this rule). As a result, the only drugs that can be legally used to treat hatchery-origin fish in the United States are those that have been approved by the U.S. Food and Drug Administration (FDA).

Only nine drugs are currently approved by the FDA for use on food fish. Drugs may be approved for specific groups of fish (e.g., freshwater salmonids) or for specific purposes (e.g., to control mortality caused by furunculosis, which is associated with the bacterium *Aeromonas salmonicida*). There is considerable confusion and misinformation regarding the legal and judicious use of drugs in fish culture, fisheries management, and research. To maximize the effectiveness of drug treatments and remain compliant with relevant regulations and aquatic animal health plans, hatcheries have to ensure that their personnel know what drugs are legal and how to apply them correctly. The FDA Center for Veterinary Medicine is the authoritative source of information on the legal and judicious use of all animal drugs (http://www.fda.gov/AnimalVeterinary/default.htm), but fish culturists may find the U.S. Fish and Wildlife Service Aquatic Animal Drug Approval Program Web site (http://www.fws.gov/fisheries/aadap/) and the Fish Culture Section Guide to the Use of Drugs, Biologics, and Other Chemicals in Aquaculture (http://fishculturesection.org/) to be more readily accessible resources.

The use of therapeutic drugs use can be minimized with comprehensive fish health management plans that include the administration of biologics. Vaccines contain live organisms (bacteria or viruses) or killed viruses, whereas bacterins contain inactivated cultures of bacteria. Both increase the natural ability of the animal to resist the disease caused by the organism from which the biological product is derived. There are a number of licensed, commercially available veterinary biologics that are currently approved for use in fish. Autogenous vaccines are a specific subset of biologics that are derived from specific pathogens associated with a specific facility. As with drugs or any other compound used in aquaculture, it is recommended to seek professional advice about the specific biological product of interest before using it for the first time. The U.S. Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) Center for Veterinary Biologics is the authoritative source of information on licensed biologics, but this information may be more readily accessed in USDA APHIS Program Aid 1713, *Veterinary Biologics: Use and Regulation* (http://www.aphis.usda.gov/publications/animal_health/content/printable_version/vet_biologics.pdf), *Use of Vaccines in Finfish Aquaculture* (http://edis.ifas.ufl.edu/pdffiles/FA/FA15600.pdf) and the Fish Culture Section's *Guide to the Use of Drugs, Biologics, and Other Chemicals in Aquaculture* (http://fishculturesection.org/).

The Fish Health Section of AFS maintains an online registry of certified fish health pathologists and aquatic animal health inspectors who can provide hatcheries with guidance regarding the development and implementation of aquatic animal health plans (http://www.afs-fhs.org/certification.php). The American Veterinary Medical Association also maintains an online registry of licensed veterinarians with knowledge of aquatic animal health (http://www.aquavetmed.info/); the American Association of Fish Veterinarians is establishing a similar registry (http://fishvets.org/).

Biosecurity

The term "biosecurity" refers to practices used to prevent the introduction and spread of disease-causing organisms and nuisance and invasive species. Although many common fish pathogens and parasites are present in virtually all environments and are difficult or impossible to eradicate, others have a regional distribution or are easier to avoid or contain. In any event, biosecurity is an essential first line of defense against the introduction or transmission of undesirable organisms. Biosecurity is commonly associated with disinfection, but comprehensive biosecurity plans can go well beyond simple disinfection procedures to include everything from facility layout and design to livestock sourcing and quarantine and records keeping. Biosecurity practices vary from one situation to the next, based on the potential risks associated with the type of facility, culture species, and pathogens or invasive and nuisance species that are involved.

For more information about biosecurity, users can refer to an aquaculture biosecurity manual (http://fishdata.siu.edu/secure/bioman.pdf) and the accompanying annotated presentation (http://fishdata.siu.edu/secure/biopres.pdf), which were developed for Illinois aquaculture facilities; *Biosecurity Protection for Fish Operations* (http://www.jumpjet.info/Emergency-Preparedness/Disaster-Mitigation/NBC/Bio/Biosecurity_Protection_for_Fish_Operations.pdf), which focuses on Arkansas aquaculture operations; and the North Central Regional Aquaculture Center's *Biosecurity for Aquaculture Facilities in the North Central Region* fact sheet (http://www.ncrac.org/NR/rdonlyres/2C878A92-8D58-4DCB-AAE0-C88A2F3A1152/96237/FS115Biosecurity.pdf). Although originally developed with regional facilities and biosecurity concerns in mind, the strategies described in these resources are largely applicable to hatchery facilities throughout the United States. Users may also wish to review *Sanitation Practices for Aquaculture Facilities* (http://www.aces.edu/dept/fisheries/education/documents/SanitationpracticesforAquacultureFacilities.pdf) for further information.

Strategies to Maintain Genetic Integrity and Diversity in Hatchery-Origin Fish

Proper genetic management of and spawning strategies for hatchery-origin fish are critical to maintaining genetic diversity, minimizing inbreeding, maximizing effective population size, and reducing artificial selection (see the Fish et al. and Kozfkay et al. abstracts in Supplement B). The degree to which these elements are intensively managed depends, in part, on the type of hatchery and the intended use of the hatchery-origin fish (see the section Hatchery Operation and Propagation Techniques). Various spawning strategies can be employed in hatcheries to maintain genetic diversity, minimize inbreeding, maximize effective population size, and reduce adaptation in captivity and upon supplementation of these fish into wild populations (see the Fish et al. and Kozfkay et al. abstracts in Supplement B).

Genetic management is particularly complex for supplementation stocking programs, in which stocked fish are either intended to interbreed with wild fish or may have the unintended opportunities to do so. Two approaches are commonly taken in these situations: (1) hatchery-origin fish are managed as a distinct, genetically segregated population with a focus on keeping hatchery-origin and wild fish reproductively isolated (a segregated hatchery program) or (2) hatchery-origin fish are managed as a genetically integrated component of a natural population with a focus on minimizing the consequences of interbreeding between hatchery-origin and wild fish (an integrated hatchery program) (Trushenski et al. 2010). Whereas maintaining genetic diversity is an important element of both approaches, the specific protocols involved differ (Mobrand et al. 2005). A segregated program creates a new, hatchery-adapted population intended to divert harvest pressure away from the wild population. Gene flow is minimal between the hatchery-origin and wild populations, and over time a genetically distinct hatchery-origin population develops. An integrated hatchery program strives to increase the demographic size of the wild fish population while minimizing the genetic influence from hatchery rearing by maximizing gene flow between the hatchery-origin and wild populations. Through the continual supplementation of the broodstock with wild-origin fish, the hatchery-origin population remains integrated with and ideally indistinguishable from the wild population. Mobrand et al. (2005) described these two genetic management options in detail, and additional information can be found on the HSRG Web sites (http://www.hatcheryreform.org/ and http://hatcheryreform.us/).

Biological and Other Interactions between Wild and Hatchery Fish

Much of the concern over interactions between hatchery and wild fish has centered on the genetic effects of hatchery fish on wild populations (Hindar et al. 1991; Lynch and O'Hely 2001), and hatchery management strategies are often put in place to minimize genetic risks. However, ecological effects may be as important as genetic effects (Weber and Fausch 2003) and should be considered when releasing hatchery-origin fish into the wild. The ecological impacts of hatchery fish on wild populations have been reviewed by Weber and Fausch (2003) and Kostow (2009). Large releases of hatchery fish can increase competition with wild fish and increase density-dependent mortality. Hatchery fish may also exhibit different behavior than their wild counterparts. For example, hatchery salmonids may not out-migrate, remaining resident in the areas where they were stocked, and become precocious, with the ability to spawn shortly after release. Spawning by these individuals may alter the typical life history of the wild population. Alternatively, out-migrating hatchery fish may not be as adept at homing due to altered electromagnetic imprinting (Putman et al. 2014) and may stray upon return from the ocean. Studies aimed at evaluating the effects of competition between hatchery and wild fish have produced mixed results, some showing that hatchery fish have a competitive advantage, others that wild fish have a competitive advantage, and still others that neither type has a competitive advantage. Competition is difficult to evaluate experimentally, and the mixed results in the literature are likely due to differences in experimental design and the conditions under which they were conducted (Weber and Fausch 2003). Nevertheless, to be responsible, the use of hatchery fish in sympatry with wild fish should strive to minimize the risk of negative interactions with wild populations.

Kostow (2009) identified several management strategies to mitigate the ecological risks of hatchery programs. Some of these were specific to anadromous salmonids. Below are summaries of the strategies that would be applicable to any propagated species.

- Operate hatchery programs within an integrated management context. Hatchery operational plans need to be specific to the populations with which they interact and focus on restoring naturally producing populations. Operational plans should be formulated so that they are consistent with broader management objectives.
- Only implement hatchery programs that provide a benefit. Recent scientific studies have questioned the benefits of hatchery programs. Agencies should review hatchery programs periodically to determine whether they still contribute to meeting management objectives and discontinue programs that no longer serve a social or biological need.
- Reduce the number of hatchery fish that are released. Many of the risks associated with the release of hatchery fish are due to the sheer numbers released. Decisions regarding the number of fish released should incorporate biological and ecological metrics as well as social demands and legal responsibilities.
- Scale hatchery programs to fit carrying capacity. Agencies need to monitor wild populations and scale hatchery programs such that natural reproduction is not depressed by the addition of hatchery fish.
- Limit the total number of hatchery fish that are released at a regional scale. Ecological impacts can extend beyond immediate release sites and into major migration routes and even the ocean. Releases of hatchery fish from multiple facilities should be coordinated among managers from the different jurisdictions.
- Locate large releases of hatchery fish away from important natural production areas. This strategy helps to minimize negative interactions with wild fish and to decrease harvest risks to wild populations.
- Time hatchery fish releases to minimize ecological risks. The timing of release and out-migration should be considered. Releases could be made over time to allow dispersal from a release site and minimize concentrations that attract predators. Releases could also be timed to avoid predation on wild species during critical times.
- Restrict the number of hatchery adults allowed into natural production areas. Reproductive segregation of hatchery and wild fish minimizes genetic risks. Some methods used to reduce entry into natural spawning areas include removal at dams or weirs, selective fishing, and choosing release locations away from natural spawning areas.
- Be able to identify hatchery-origin fish and monitor the effects of hatchery programs. Adequate monitoring and evaluation of a hatchery program requires hatchery fish to be identifiable for the risks to wild fish to detected and managed. There are a number of approaches which can be used to physically mark or otherwise identify hatchery-origin fish after release.

Additional recommendations for minimizing risks may be found in HSRG (2014), Cowx et al. (2009), and FAO (1994).

Risk Assessment and Decision Making

Risk assessment is the process by which the likelihood of an event's occurring and the severity of its consequences are described. Risk itself is defined as the product of these two factors—likelihood of occurrence and negativity of consequences. Thus, scenarios involving unlikely events with only moderately negative consequences are considered low risk; scenarios involving events that are somewhat unlikely to occur, but would or could have very serious consequences are considered moderately risky; and scenarios involving highly negative events that are likely to occur are considered high risk. Risks should be delineated and integrated into the decision-making process in as quantitative a manner as possible, including the consequence of taking no action. Potential benefits should also be considered as part of such an assessment. Benefits often relate to society (such as angling days, fish yield, public access, and cultural value) but may also include ecosystem function, stability, productivity, and others.

Depending on the elements of the scenario and the availability of quantitative information, risk assessment can be a straightforward assembling of facts and figures or a challenging process involving considerable uncertainty. The latter is perhaps more common in risk assessments involving fisheries resources, where information is often incomplete or imperfect (e.g., stock assessments may be available for some but not all species and the effects of an action may be unknown or known only in a different type of ecosystem) or difficult to quantify or predict with certainty (e.g., the historical stock structure of nongame fish, ecosystem responses to ecosystem change, and the intangible value of fisheries to stakeholders). Assessing potential consequences and cumulative risk is complex. Acceptable risk levels and desired benefits vary across user and management entities; therefore, the application of a structured decision-making process is recommended (see the section Monitoring and Flexible and Adaptive Management of Stocking Programs). Management decisions tend to be risk-averse in pristine habitats dominated by native species where the primary management goal is species conservation. Management decisions tend to be more risk-tolerant, however, in more altered habitats dominated by nonnative fishes where the primary management goal is exploitation of a fishery.

These challenges should not dissuade resource managers from attempting to assess the relative risk of proposed actions (including stocking), with the caveat that decisions still need to be made even when the risks are not completely understood. In other words, stakeholders are not likely to be satisfied with tabling an important decision until a comprehensive risk assessment can be completed. Steps should be taken to reduce uncertainty, but it cannot be completely eliminated from the decision-making process. It is equally important to understand that all management actions, including the decision to do nothing, involve risk; whether that level of risk is acceptable to stakeholders is a separate question. Risk assessments can provide quantitative or semiquantitative estimates of the risk associated with stocking or other elements of a fishery management program, but decision makers must engage with stakeholders to determine the proper thresholds for risk.

Changes to hatchery programs in response to scientific recommendations can be successfully implemented only with concurrent integration of associated nontechnical factors and risks, including but not limited to (1) legally authorized and mandated mitigation obligations, (2) tribal and First Nations treaty-reserved fishing rights, (3) logistical challenges and infrastructure constraints, and (4) funding and operating budgets for implementing the changes and monitoring their effectiveness.

The decision to implement a hatchery program, and the type of hatchery program to implement, should stem from a structured decision-making framework (Gregory et al. 2012). Structured decision making is a formal decision-making process in which management objectives are defined on the basis of stakeholder values and alternatives are evaluated and selected based on predictive models. Adaptive management is a type of structured decision making that is becoming typical in fisheries management (Williams et al. 2007). Within an adaptive management framework, models can be employed that account for the uncertainty, risk, and constraints resulting from legal, economic, and logistical considerations to decide which of the possible alternatives has the greatest chance of achieving management objectives. An adaptive management framework also incorporates monitoring and evaluation to determine the accuracy of the original predictions from the models, where the models can be improved, and where uncertainty should be reduced to better inform the decision-making process (and in some cases, where uncertainty may have little bearing on the decision). Without an adaptive management framework, decisions on the use of hatcheries may appear to be arbitrary or unjustified to stakeholders. A formal adaptive management process maintains transparency and objectivity in the decision-making process.

ADDITIONAL CONCERNS

Effective Communication

The HaMAR process and predecessors to HaMAR were made possible by the willingness of a wide range of fisheries professionals to come together to discuss, fully understand, and resolve issues related to the use of hatchery-origin fish in the management of aquatic resources. Though the need for cooperative management, inclusive planning, and interdisciplinary approaches may seem self-evident today, this was not always the case. The issues surrounding hatcheries were once hotly debated by individuals with widely different and largely inflexible views, both within AFS and in other contexts. The use of hatcheries and hatchery-origin fish remains contentious at times, but fisheries professionals now recognize the need for hatcheries and their products as well as the need to closely monitor, critically evaluate, and frankly discuss stocking programs to ensure their effectiveness. Those participating in HaMAR exemplified a willingness to engage those with differing views and focus on science-based decision making, both of which are essential to the creation of effective fisheries management plans, including the use of hatcheries and hatchery-origin fish.

Issues Yet to be Resolved

Like any scientific endeavor, HaMAR effectively addressed many questions but raised others. Several of these questions are listed below. Whereas we may find quantitative responses or answers to some of them in the future, it may not be possible to address all of them in the context of traditional fisheries science. We offer them to the reader and future participants in AFS evaluations of hatcheries and the uses of hatchery-origin fish.

- Where is the progress in quantifying the socioeconomic impact of fisheries enhancement?
- Why are agency fisheries managers reluctant to resist stakeholder demands to judge stocking programs simply by the numbers of organisms stocked?
- Is there an urgent need to increase seafood production in North America and to be better prepared to maintain sportfishing?
- Why has there not been more assessment of the success in existing marine stock enhancement programs?
- Hatchery-based fisheries enhancement is not going away; so, despite differing opinions, what can be done to make this field more effective?
- It appears that the interactions between hatchery and natural fish populations are approached very differ-

ently depending on whether the fish in question are anadromous or freshwater and marine fishes. If this is true, why?
- Why has there been very little evaluation of supplementation for freshwater and marine species?

Further Reading

For additional information, readers are encouraged to review the works cited in the References and Bibliography (see Supplement C) as well as the selected abstracts of the presentations made at the HaMAR-related symposia (see Supplement B).

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The HaMAR process extended over several AFS presidencies and would not have been successful had past presidents Bill Fisher, John Boreman, and Bob Hughes not remained committed to the completion of this comprehensive, time-consuming exercise. Their diligence in seeing HaMAR through was essential. Finally, the strengths of HaMAR are derived, in large part, from the foundational work of its predecessors, most recently PFIRM. Many of those acknowledged above were also involved in the previous cycles and we thank them, as well as Pat Mazik, for their assistance in developing the HaMAR process and providing historical context.

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