Exploring the Role of Captive Broodstock Programs in Salmon Restoration

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Abstract

Severe population declines have occurred in many Pacific salmon stocks. Stock declines have been attributed to both anthropogenic and natural environmental causes. These declines have been so dramatic that resource agencies have not had the time or means to quantitatively describe stocks and develop rapid, reliable methods of conserving rare genes. One method to prevent extinction is gene banking by means of rearing broodstock in captivity for use in supplementing rare and endangered stocks. With varying degrees of success, several captive breeding programs have been initiated to provide "insurance" against genetic loss of imperiled stocks. Captive breeding is expensive, requiring long-term intensive fish husbandry. It is not an alternative to habitat restoration. In certain situations, such as small runs (20 to 100 spawning adults) combined with habitat undergoing restoration, captive breeding may be a desirable supplementation strategy. It is certainly a beneficial option for any stock on the edge of extinction. There are several salmon captive broodstock programs on the west coast of North America, each employing different approaches and technologies. Captive breeding techniques are evolved to a point where the progeny of wild fish can be reared with a high degree of success. However, this kind of intervention is costly and must be weighed against other factors that will determine stock recovery. It is incumbent upon managers and scientists to define the uncertainty, or risk, of captive breeding. Risk assessment is an essential component of any captive breeding program. Emerging captive breeding programs can benefit from the range of experience and technological development that has evolved over the past decade. Molecular genetics, captive broodstock technology, conservation biology, and fisheries supplementation risk assessment have matured to a stage where salmonid captive breeding can be planned as an intervention with a measured effect.

Captive Breeding as a Response to Declining Salmon Stocks

During the last four hundred years, approximately 490 described animal species are known to have become extinct (Magin and others 1994). Approximately 24,600 species of fish (in 482 families) exist worldwide, although this number may reach 28,500 as more species are described (Nelson 1994). The International Union for the Conservation of Nature (IUCN) has compiled a list of threatened or extinct fish species, documenting the downward trend in aquatic biodiversity (IUCN 1996). Moyle and Leidy (1992) estimated that 20% of the freshwater fishes of the world is at risk of extinction, yet this figure is likely very conservative (Leidy and Moyle 1998).

Anadromous salmonids, including many stocks of Pacific salmon along the west coast of North America, have experienced severe population declines. The Northwest Power Planning Council (1987) reported that annual returns of anadromous salmon and trout decreased from an estimated 12 to 16 million in the 1880s to 2.5 million fish in the 1980s. At least 106 major populations of salmon and steelhead have been extirpated from the West Coast (Nehlsen and others 1991). Nehlsen and others (1991) identified 214 stocks of Pacific salmonids from California, Oregon, Idaho, and Washington that face a high or moderate risk of extinction. Stock declines have been attributed to both anthropogenic and natural causes including land-use practices such as urbanization and logging, reduction of genetic diversity in native stocks and introduction of disease through hatchery production, overharvest, and flood and drought events (Nehlsen and others 1991; Pearcy 1992; NRC 1996).

The role of hatcheries in the conservation of wild salmon populations depends upon a keen appreciation of the reproductive interactions among and between hatchery and wild salmon (Fleming 1994). True "gene banking" efforts based on sperm cryopreservation to avoid the loss of valuable genotypes have been initiated for Snake River sockeye salmon (*Oncorhynchus nerka*) and chinook salmon (*O. tshawytscha*) in the Columbia River of the northwestern United States (Thorgaard and others 1998). Captive breeding can be considered a form of gene banking in that it relies on the captive rearing of the living genetic resource. Unlike conventional salmon hatcheries that rear animals to fry or smolts in single cohorts, captive breeding requires the maintenance of multiple age classes, in numerous family groups, to maturation. As such, captive breeding programs are costly and labor intensive.

Captive propagation is becoming accepted as one component of species enhancement (Gipps 1991; Johnson and Jensen 1991; Olney and others 1994). For example, the U.S. Fish and Wildlife Service uses captive propagation to enhance populations of nearly 30% of the non-anadromous North American fish species listed under the federal Endangered Species Act (USFWS 1990;

Johnson and Jensen 1991). With varying degrees of success, several captive breeding programs have been initiated to provide "insurance" against genetic loss of imperiled stocks. While captive breeding may be less cost-effective in the long-term than *in situ* preservation, it may provide the only mechanism to prevent extirpation of a stock, especially before or during the early implementation of an environmental recovery program. Indeed, the National Research Council (1996) now recognizes that long-term sustainability requires conservation of both wild populations and their natural habitats. Ecosystem-wide approaches are beginning to be recognized and adopted on both the theoretical and practical levels.

One aspect of the ecosystem approach to salmon restoration that is gaining attention is the role of salmon in the regeneration of forest-stream systems (Bilby and others 1996, National Research Council 1996). It is possible, given the multiple pathways salmon create for marine-derived nutrients to enter watersheds, that there is a critical abundance threshold necessary to stabilize runs. The precipitous stock declines witnessed during the past twenty years are likely some combination of ecosystem and population effects. If this is the case then supplementation becomes a more important part of the restoration equation.

Captive breeding may entail *in situ* gene banking ("insurance" only) or it may include a supplementation to the watershed. In the case of salmon and anadromous trout, captive breeding typically involves the propagation and early life stage rearing of a stock with subsequent release at the fry, parr, or smolt stage. Snyder and others (1996) described several limitations of captive breeding in endangered species recovery and asserted that it should be viewed as a last resort to avoid species extinction instead of a prophylactic or long-term solution. Artificial propagation in itself is not the remedy to stock declines. On the contrary, it may even contribute to the decline of native populations (Goodman 1990), risking further loss of genetic resources (Waples 1991). Case-specific economic, biological, and conservation-related variables must be considered in determining the appropriateness of captive propagation for a particular species (Balmford and others 1995; Snyder and others 1996). For example, *ex situ* conservation for the purpose of supplementing wild stocks depends on successful reintroduction, which in turn depends on the availability of suitable habitat (Griffith and others 1989; Wilson and Stanley Price 1994). For threatened and endangered species, artificial propagation and release may not assist in their recovery, particularly in instances where population declines are the result of altered or unsuitable habitat for self-sustaining reproduction. In the case of natural salmon populations, supplementation is appropriate in two scenarios: (1) when short-term extinction risk for the population is high, and (2) in re-seeding vacant habitat that is unlikely to be colonized naturally within a reasonable time frame (Robin S. Waples, personal communication, see "Notes").

Surprisingly, Balmford and others (1996) found that existing captive breeding efforts in zoos for mammals failed to focus on species subject to potentially reversible pressures such as overexploitation or small-scale habitat deterioration. Captive breeding efforts for fish have received similar criticism. For Pacific salmon, the use of hatchery techniques in conservation has been criticized as being a "halfway technology" since supplementation of wild stocks with hatchery produced fish addresses a symptom (declining fish stocks) but not the causes (Meffe 1992). The World Conservation Union's Conservation Breeding Specialist Group (CBSG) has developed a series of Conservation Assessment and Management Plans (CAMPs) calling for long-term captive breeding of numerous taxa (Seal and others 1994). In 1993, Tear and others reported that of the current 314 approved recovery plans for U.S. endangered and threatened wildlife, 64% recommended captive breeding. In the case of salmonids, the Forest Ecosystem Management Assessment Team (FEMAT) identified 314 native stocks as being threatened with extinction (FEMAT 1993). Yet with only limited resources for conservation and recovery measures, Allendorf and others (1997) asserted that priorities should be established for stocks which are candidates for preservation. Limited resources dictate that only a few stocks can be identified for intervention potential. Given the uncertainty in predicting extinction rate using measures of cohort replacement rate and population growth rate for Pacific salmon (Botsford and Brittnacher 1998), this task is indeed daunting.

Benefits and Risks of Captive Breeding

Captive breeding programs can serve multiple objectives in salmon restoration. The Sacramento River Winter-Run Chinook Salmon Captive Broodstock (WRCCB) project was developed with multiple goals. WRCCB's primary objective is to maintain broodstock in captivity as an insurance program in the event the remaining wild population is further reduced or is extirpated. In this situation captive broodstock could serve as a gene bank to assist in rebuilding the stock. Alternatively, this propagation program can provide gametes for supplemental breeding. The supplementation strategy is based on the premise that an appropriate genetics program, developed in parallel with the broodstock technology, could guide the spawning of wild caught broodstock in tandem with captive broodstock. In this manner captively reared spawning candidates could expand the spawning options of the supplementation program, which can be limited if dependent solely on wild trapped fish.

Captive breeding differs significantly from conventional hatchery practice. Sound captive breeding should be based on rules of conservation biology that recognize the potential effect of creating a population of captive progeny that, if released, will influence the genetic variation of the remaining wild stock it is intended to enhance. Models of effective population size described by Ryman and Laikre (1991) provide a means characterizing the interaction of two or more populations of salmon (in this case wild versus captive) at various production levels if the genetic variation is known. These models are essential if a captive broodstock program is going to operate as a true supplementation mechanism that enhances the genetic resource and contributes to species' recovery. Due to the high fecundity of salmon the risk of disproportionately supplementing the captively bred population can be serious and jeopardize the wild population. However, precise measures of genetic variation require sophisticated and expensive techniques such as molecular genetic analysis. This expense will limit application of these preferred methods of monitoring and evaluation. Without these techniques and proper evaluation captive breeding programs can easily introduce unacceptable risk to salmon recovery efforts aimed at assisting threatened and endangered populations. However, it should be recognized that integrating supplementation in a captive breeding program with interannual variation of the wild salmon counterpart links a captive breeding intervention with ecosystem function. This is a desirable model for the evolution of all hatchery practice.

If implemented as a basic element of stock recovery, captive breeding warrants assessment and evaluation to minimize risk posed to the stock it is addressing. Some of the ways risk can be manifested in captive breeding programs can be subtle. A major difference between conventional hatchery operation and captive breeding is that the gene banking aspect of captive rearing often includes rearing multiple cohorts of salmon from embryo to sexual maturation. This long-term husbandry increases the opportunity for artifacts of the captive setting to create differential mortality in the captive population or among captive family groups. Such artifacts lend themselves to various genetic sinks and are a cause for concern (Waples 1991). Allendorf and Waples (1996) have described genetic risks associated with supplementation programs including effects of broodstock collection on wild populations, reduction of fitness, and changes in reproductive potential in naturally spawning fish as a result of lack of control in restocking efforts.

In the last few years a few salmonid captive breeding projects have attempted to share information and develop methods based on sound science. A major obstacle of captive breeding is that by the time a population warrants such a serious intervention, the population is likely so reduced that true experimental approaches cannot proceed due to the limited number of fish available. And, for threatened and endangered species the protective nature of the federal Endangered Species Act (ESA) usually precludes invasive techniques such as tissue or serological assays and other conventional laboratory analyses of animal health and reproductive physiology. Given these unusual limitations captive breeding programs have been slow to evolve new techniques aimed at the special conditions of captively rearing and spawning undomesticated fish. However, new technologies have emerged that set captive breeding programs apart from conventional hatcheries.

The Sacramento River winter-run chinook was the first anadromous salmonid population to be protected under the ESA. In November, 1990, the National Marine Fisheries Service (NMFS) issued a final listing of the Sacramento River winter-run chinook salmon as a threatened species (54 Federal Register {FR} 32085), and in February 1994 the stock was listed as endangered (59 FR 440). The WRCCB Project, now in its ninth year, has made substantial progress in both fish survival and gamete production (Arkush and others 1995). Application of advanced technologies in systems design such as computer controlled salinity systems that create seawater environments for smoltification have increased fish survivorship and simplified maintenance. Veterinary techniques such as the use of ultrasonography to assess maturation and even predict spawning time have been developed in concert with this project (Petervary and others, forthcoming). Moreover, the project has enabled significant advances in the areas of fish health and genetics, particularly with the development of molecular markers for genetic discrimination among stocks that have wide application in fisheries management (Banks and others 2000).

All of these developments demonstrate a divergence from conventional hatchery practices and set the stage for new possibilities in salmon restoration. In this way sound captive broodstock conduct creates the potential for changes in future hatchery practice. Scientifically-based captive broodstock programs have the ability to serve as research hatcheries, which have been proposed as one of several requirements for salmon restoration (Moyle 1993). Research hatcheries, based on sound conservation biology and captive breeding advances, can balance the need to continue salmon supplementation while identifying the changes required to move towards a larger conservation strategy (Hilborn 1992).

Integration with Habitat Recovery Plans

Threatened and endangered species restoration requires implementation of a carefully designed and comprehensive recovery plan as the ultimate goal. Artificial propagation programs can play a pivotal role in preventing extirpation of stocks. If such an intervention is warranted, it is critical that implementation is initiated before, and during, the early phases of recovery plan action. However, restoring naturally sustaining populations is the only way to address ecosystem-wide concerns; supplementation provides no equivalent. In accordance with Section 4(f) of the ESA, a recovery plan must be developed for species listed as endangered or threatened, and this plan must be implemented unless it is found not to promote conservation of the species. A recovery plan must include: (1) a description of site-specific management actions necessary for recovery, (2) objective, measurable criteria, which when met, allow delisting of the species, and (3) estimates of the time and cost to carry out the recommended recovery measures.

The National Marine Fisheries Service (NMFS) identified several factors as major causes of the decline of the winter-run chinook salmon, such as elevated water temperatures in the upper Sacramento River and impediments to upstream and downstream migration at the Red Bluff Diversion Dam (Hedrick and others 1995; Botsford and Brittnacher 1998). However, there is a wide range of factors that affect winter-run chinook salmon survival, and all factors must be addressed to assist in its recovery. Hence, NMFS has concluded that no single action will suffice, and a comprehensive plan will require the participation of federal agencies, state and local governments, private industry, conservation organizations, and the public. Moreover, while the ESA is designed to recover individual species, the recovery plan for the winter-run chinook salmon must consider ecosystem restoration. Concurrent with the winter-run chinook salmon decline is the reduction of other native species of plants and animals in the Sacramento River ecosystem. Moyle and Williams (1990) described 46% of the native fish stocks of the Sacramento River drainage as extinct, endangered, or in need of special protection. The loss of native fish genetic resources is further complicated by the invasion of non-native species that increases the level of complexity in ecosystem restoration. Moyle and Light (1996) describe how invasive species and invaded systems interact in idiosyncratic ways that are difficult to predict. Further, the degree of integration of an invasive species will depend on the level and degree of human and natural disturbance to the aquatic system (Vermeij 1996). One hundred State and federal candidate, proposed, and listed plants and animals, and California Department of Fish and Game species of special concern occur in the present habitat range of the Sacramento winter-run chinook salmon (NMFS 1997). Clearly, recovery plans must incorporate some form of adaptive management plan to protect the endangered or threatened stocks as well as other flora and fauna identified as species of special concern during implementation. And, recovery plans need to be "plastic" so as to allow the inclusion of newly identified components of the ecosystem during the monitoring phase.

Conclusions

Captive breeding is an expensive and labor intensive effort. Programs such as the Winter-run Chinook Salmon Captive Broodstock Project have made significant contributions to the evolution of hatchery management practice while functioning as stop gap measures in the decline of natural stocks. Captive breeding programs that are defined by the rules of conservation biology can calibrate supplementation to increase abundance without loss of the genetic variation they are intending to preserve. Captive breeding programs that operate as conservation hatcheries can be a template for future hatchery practice.

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