

Conservation Aquaculture and Endangered Species:

Can Objective Science Prevail over Risk Anxiety?

By Paul J. Anders

Aquaculture has been used with varying degrees of success to conserve endangered fish populations, and its use continues to be a controversial recovery issue in fisheries. Fisheries management decisions involving the design, implementation, and evaluation of conservation aquaculture programs can be complex and difficult. Such decisions often must be made in the midst of considerable uncertainty. In fact, one of the tenets of conservation biology states that in a crisis, as is usually the situation with endangered species management, one often must act before knowing all the facts (Soulé 1985). This notion virtually guarantees some degree of uncertainty in many management decisions. This is especially true with threatened or endangered fish populations because small population sizes confound data collection and analysis necessary to develop scientifically sound management policies. Furthermore, many public and political groups as well as fisheries professionals demand precise, rigorous definition of the uncertainties associated with management decisions.

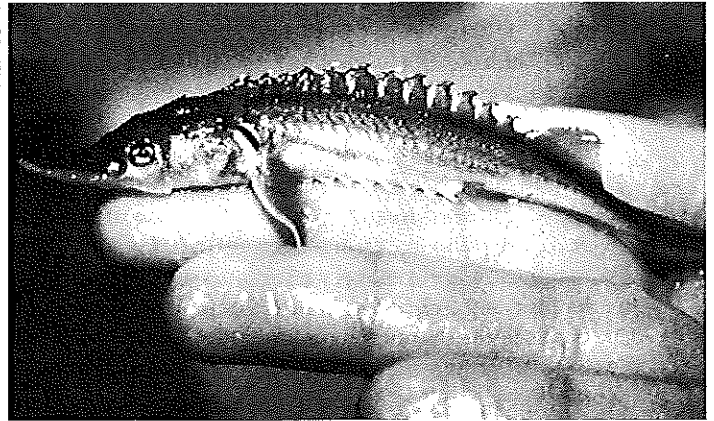
In some cases, a rift seems to exist between principles of population biology and fish management policy regarding the use of aquaculture to conserve endangered fish populations. In particular, a management policy that considers aquaculture as a "last resort" for conserving threatened and endangered fish populations can be counterproductive when it allows a population to dwindle to near-extinction in order to "keep it wild." The objectives of this article are (1) to discuss several basic tenets of endangered species management from a population biology perspective; (2) to define conservation aquaculture and discuss its role in endangered species management; and (3) to discuss the potential dangers of fisheries management policies that consider aquaculture as a last resort for conserving endangered fish populations.

Conservation and management strategies may be strongly influenced by a number of problems associated with small population size. Of considerable concern is that natural and artificial recovery options are rendered ineffective when populations decline below a threshold size, which is rarely defined. Thus, the key to successful management of threatened and endangered populations must be to apply appropriate conservation measures that minimize risk and

maximize benefit before their potential for success is overly compromised by small population size or reduced population viability. Although this conservation philosophy may read nicely on paper, in the real world its successful implementation is a complex and difficult task.

The important point here is that when fish populations get too small, effective population size (N_e) may become a better predictor of recovery success than hypothesized outcomes of available management strategies. (For the purposes of this article, N_e is defined as the number of reproducing individuals in a population in a given year). Empirically, an extremely low N_e through time becomes an accurate predictor of extinction (Lacy 1987). Populations

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Healthy juveniles from the wild, like this young white sturgeon from the lower Snake River, Idaho, or from conservation aquaculture programs contribute to production of broodstock and population persistence.

with low N_e values can suffer from reduced viability and persistence through linked mechanisms of reduced gene flow, genetic drift, reduced within-population genetic variation, and inbreeding fitness depression; these populations ultimately may face high risks of extinction (Gilpin and Soulé 1986; Lande and Barrowclaw 1987). In such a case, it is difficult to develop a fisheries management strategy that facilitates population recovery. Thus, maintaining an adequate N_e is necessary for natural population viability and persistence mechanisms to function properly. When comparing characteristics of large and small populations (Table 1), virtually all the listed population persistence mechanisms suggest overwhelming ability for a large population to persist relative to a small one. This overwhelming superiority of large populations argues strongly against fisheries management policies that consider aquaculture

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as a last resort for managing threatened and endangered fish populations.

Conservation aquaculture is simply what the term implies—use of aquaculture for conservation and recovery of endangered fish populations. The term does not embrace standard hatchery practices used as a past baseline of evaluation. Conservation aquaculture involves working adaptively with the local gene pool and allowing sufficient migration of genes to allow allelic representation. It requires careful selective breeding programs to provide sufficient diversity within a fish population of interest. It necessitates eliminating as much artificial conditioning as possible. When successful, it provides the increased population base on which natural selection can operate. As a result of its design, conservation aquaculture can reduce the commonly considered risks associated with hatchery production such as competitive feeding behaviors, reduced growth rates, domestication selection, and increased incidence of disease. Finally, conservation aquaculture by no means presents the same risks associated with letting nature take its course when nature is no longer able to sustain a wild, native fish population.

Perhaps more than a specific set of culture techniques, conservation aquaculture is an adaptive, creative approach that prioritizes preservation of wild populations along with their locally adapted gene pools and characteristic phenotypes and behaviors. Thus, the conservation aquaculture approach directly contrasts the ideology underlying more-traditional hatchery supplementation programs, in which success was largely a function of total numbers of fish released from a hatchery. Conservation aquaculture should be viewed as one component of multifaceted fish restoration and recovery programs, many of which include important habitat improvements. Some supplementation programs have treated the symptom of declining fish populations in lieu of addressing serious issues of degraded and lost fish habitat or other causal factors. In contrast, conservation aquaculture is designed to be implemented simultaneously with habitat improvement and watershed or ecosystem restoration activities. Conversely, the goal of

many traditional hatchery supplementation programs has been to create a harvestable surplus of fish. The goal of conservation aquaculture is to conserve wild fish populations along with their locally adapted gene pools and characteristic phenotypes and

behaviors. The importance of this distinction between approaches cannot be overemphasized. The fact that conservation aquaculture is not concerned with producing record numbers of fish for release alleviates many stress-mediated problems associated with high-density fish rearing. In addition, due to the complementary nature of conservation aquaculture, commonly raised concerns that fish hatcheries “divert attention away from the real problems” or somehow usurp the need to address causal factors of fish population declines do not apply to conservation aquaculture.

Concerns and risks associated with aquaculture, including inbreeding fitness depression, domestication selection, manifestation of disease, hybridization, and introgression are often readily observable and have been well documented (Allendorf and Ryman 1987; Waples 1991). However, such observations may result from what Brannon (1993) referred to as “the perpetual oversight of hatchery programs” rather than from aquaculture per se. That is, when hatchery programs ignore the fact that fish populations are both the product of and an integral part of a complex ecosystem, their success is jeopardized. Brannon (1993) further suggested that if hatchery programs neglect the requirements of natural populations and, therefore, the traits they possess that allow them to synchronize their life history with specific environmental constraints, failure is certain.

Several views have been offered regarding the appropriateness of various conservation and management strategies for endangered species (Flagg et al. 1991). One approach relies primarily on habitat improvement for recovery of endangered fish populations, after which populations should be left to rebound naturally. However, if a significant portion of the gene pool or important locally adapted genes are lost, the endangered fish population becomes permanently modified, and no amount of habitat protection or alteration can restore it. Conversely, if habitat needed to support an endangered population is unavailable or of poor quality, potential benefits of a conservation aquaculture program could be limited due to insufficient

Table 1. Comparison of specific population characteristics illustrates how large populations possess greater potential for long-term persistence than small ones.

Population Characteristics	Large Populations	Small Populations (Threatened or Endangered)
Effective population size (N_e)	Large	Reduced, small
Genetic drift	Non-detrimental	Detrimental
Within-population genetic variation	High	Reduced, low
Within-population gene flow	Higher	Reduced, lower
Inter-population gene flow	Higher	Reduced, lower
Inbreeding depression	Low	Increased, high, detrimental
Recruitment to age-1	Frequent, strong	Infrequent, weak when present
Population viability	High	Reduced, low
Probability of population persistence	High	Reduced, low
Extinction risk	Low	Increased, high, detrimental
Probability of successful conservation aquaculture	High (may be inappropriate)	Reduced, lower

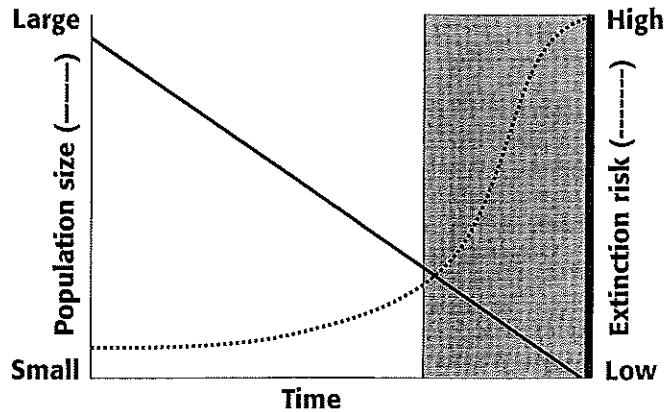


Figure 1. The general relationship between population size and extinction risk illustrates the potential danger of fisheries management policies that consider conservation aquaculture as a last resort for recovering endangered populations. Such policies may dictate implementation of conservation aquaculture when a population has already entered an extinction vortex (shaded rectangle at right). This condition may limit the success of any population recovery effort. The dark vertical bar (far right) represents extinction.


habitat to support a restored population. A second approach suggests that aquaculture is a necessary interim measure to maintain the viability of endangered populations. Critics of this second approach suggest that risks such as catastrophic loss due to culture facility failure or fish loss resulting from disease outbreak may outweigh its intended benefits. Rather than debating the strengths and weaknesses of these two approaches, one should realize that the success of each approach may be jeopardized if either is implemented exclusively. With the exception of overharvest, fish population crashes are rarely univariate problems. Thus, univariate management solutions often have failed to restore fish populations due to unresolved underlying problems. Fisheries managers need to acknowledge that several conservation measures can be complementary, and should seek combined strategies to immediately address conservation of gene pools while reestablishing habitats to support restored populations.

An inflexible fisheries management policy that considers conservation aquaculture as a last resort for managing endangered fish populations can seriously jeopardize the potential for recovering wild fish populations and can increase the probability of serious or irreversible genetic bottlenecks. As population size decreases, so does its N_e . Depending on population age class structure or particular harvest regulations, N_e may decline at a disproportionately higher rate than total population size. In some cases slot limits, designed to prohibit harvest of fish of a particular size range, have been implemented to reduce the chances of disproportionate reduction of effective population size. If population size decreases in a relatively linear fashion (e.g., due to recruitment failure and natural mortality), the risks of reduced population viability and persistence may increase exponentially as N_e declines (Figure 1). This phenomenon is referred to as an *extinction vortex* (Gilpin and Soulé 1986). In this situation, risks take the form of reduced

or lost within-population genetic variation manifested by genetic drift and inbreeding in small populations. By applying this concept across the geographic range of a species with multiple populations, it becomes evident that demographic bottlenecks also can reduce among-population genetic diversity of the species as individual populations are lost or substantially reduced. Without timely implementation of appropriate conservation aquaculture, fish managers may unintentionally reduce the probability of population recovery after allowing N_e to fall to dangerously low levels. This is generally true regardless of the recovery measures undertaken.

The recovery process for the Kootenai River population of white sturgeon (*Acipenser transmontanus*) in Idaho, Montana, and British Columbia provides a good example of fisheries management that simultaneously incorporates conservation aquaculture and ecosystem restoration. In response to general natural recruitment failure since the mid-1960s, this aging and declining population was listed as endangered in 1994 under the Endangered Species Act. Rather than using a large-scale production hatchery to supplement this population, a breeding strategy was developed to preserve the population's remaining genetic variability. This conservation aquaculture program provides a systematic approach to preserving the Kootenai River white sturgeon gene pool while management agencies work to restore river habitat conducive to natural spawning, larval survival, and natural recruitment. Simultaneous research to determine the ecological factors contributing to natural recruitment failure has been ongoing since 1989. This research has primarily focused on white sturgeon life history and reproductive biology, river productivity, and fish community dynamics issues, as well as on alterations to the post-impoundment hydrograph, in an internationally coordinated attempt to reestablish natural recruitment.

In conclusion, it is absolutely critical to understand that persistence and viability of endangered fish populations are profoundly affected by the size and structure of the population, its genetic variability, and its adaptive potential. Conservation aquaculture is by no means proposed as a panacea for recovering endangered fish populations. However, in certain situations it may be the only viable, immediate solution for maintaining adequate N_e and preserving within-population genetic diversity, two requirements for long-term population persistence. Timely implementation of appropriately designed conservation aquaculture programs can, in some cases, provide a successful alternative to demographic and genetic bottlenecks, inbreeding depression, and loss of unique and important locally adapted genes. Such programs ultimately may reduce the immediate threat of extinction for endangered fish populations. Conversely, aquaculture for any purpose, especially with small threatened and endangered populations, is not risk-free. Therefore, the need for objective, case-by-case evaluation of conservation aquaculture is critical (Anders 1997). I suggest that a rational approach to assessing the role of conservation aquaculture is to understand that it is one component, with population-specific

risks and benefits, that may be appropriate for conservation of a particular endangered fish population. Furthermore, understanding its strengths and limitations, and their alignment with specific requirements for persistence of individual fish populations is critical for applying conservation aquaculture successfully. Of equal importance to the success of any conservation aquaculture program is the timing of its implementation relative to the demographic and genetic status of the population to be conserved. Anxiety about choosing the "best" fisheries conservation or management programs is natural and understandable, but it is the responsibility of fisheries professionals to ensure that objective science prevails over risk anxiety when assessing the use of aquaculture for conservation and recovery of endangered fish populations. 

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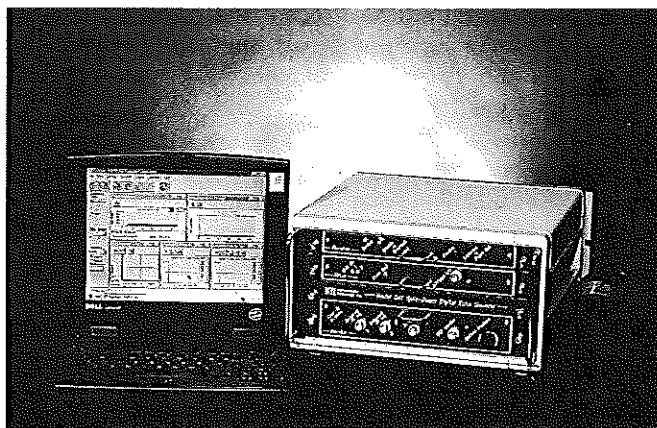
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