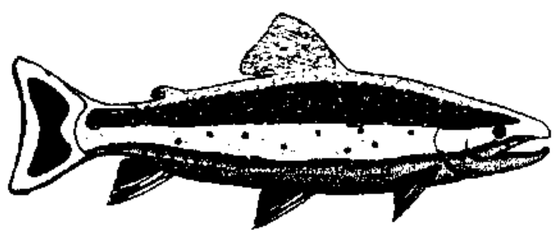
Part II:
Aquaculture/Conservation



Development of Fish Breeding and Conservation Programs

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Abstract

The development of effective conservation programs for fish is only in the initial stages of discussion. One of the most perplexing aspects of the discussion has been identifying a basic framework for the development of effective strategies. There are three basic elements to any conservation program; the objective (target stock or species), the time scale and the management protocol of the program. It also is necessary to distinguish between preservation, a short-term static approach; and conservation, a long-term dynamic approach that ensures the continuing evolution of the program target. There are three basic conservation strategics: provide sufficient resources so all species can continue to evolve; accept extinction and preservation of some species in zoological gardens; and provide special management for specific populations of species requiring protection. The third, management of specific populations, appears to represent the only viable strategy.

Genetic management of wild species can take many tenants from programs for domestic crops and livestock. Breeders of domestic species have programs to conserve the genetic resources essential for recombination and selection of genetic material so future generations can respond to changes in the physical, biological and economic environment. Species in nature require the same reservoirs of genetic diversity to adapt and survive. Based on this experience, it is clear that management strategies for natural species must address the basic question of whether the use of nature reserves is likely to facilitate the continuing evolution of the target (ecotype, species, ecosystem). Secondly, management discussions must address alternative opportunities, the viability of managing the general landscape and the impact of human activity so that a multitude of species can prosper.

Conservationists have suggested the "metapopulation" concept of population structure for wild species, based on population genetic theory and the kinds of activities used by domestic crop and livestock breeders. The concept is very appealing and offers a framework for utilizing the general landscape. It assumes a species naturally is subdivided into a large number of subpopulations with some local adaptation of subgroups, but with continuous or intermittent gene flow among subgroups. Implementation of this type of conservation strategy requires a careful inventory of the target, an assessment of the causes of numerical decline of the target, the current status of the target and common sense application of population genetic principles.

Introduction

There are three basic elements to any conservation program, the objective of the program, the time scale of the program and the management protocol of the program (Frankel 1983). The objective specifies the target and purpose with regard to the specific biological material considered by the program. The target can be anything from a group of subpopulations of a species, a subspecies, all members of a species, a community of species, an ecosystem or a geographic region. The time scale of the program is critical, as it defines the expected degree of intervention. For cases where the causes of concern are few in number and readily amenable to corrective action, the time required to ensure survival of the target may be no more than one or two generations. However, for critical cases with no apparent solutions to the causal factors, the conservation program is likely to be required into perpetuity.

Many believe all biological resource management activities should be considered conservation programs and so continuous input and control are essential in all cases. Thus, the management element of a conservation program is generally an ongoing activity. Direct attention to the genetic nature of the target resource and whether management activities impact the target, positively or negatively, has often been absent in the past. It also must be recognized that all management activities affect both the abundance and genetic status of species. Even the absence of specific management plans can affect the genetic status of target resources exposed to human activities.

The three basic elements of a conservation program are not independent, but are interactive. Programs with broad objectives generally have a longer time scale than programs designed to remedy a narrowly focused objective. Long-term conservation programs are generally faced with major habitat disturbances and greatly reduced abundance of a specific species. Thus, the objective almost always must include the ecosystem, either as a direct or implied target. A constant limitation to many conservation programs is that management inevitably focuses on the present with little regard for long-term implications. Long-term management goals must be defined in policy that focuses attention on the future, be based on biologically sound principles and provide specific objectives that are realistic and manageable. Management's focus on the present, in the absence of well established policy, can have many unexpected consequences. Experience has provided numerous examples, including the negative impacts of policies for the prevention of forest fires, the complex aspects of fishery enhancement and the impacts of selective harvest management on single species.

Conservation Strategies

The concepts of genetic resources conservation are not the same as those generally associated with the preservation of genetic material. Although both ideas can apply to genotypes and species, preservation implies a short-term static process while conservation denotes a long-term dynamic process, one that provides "continuing evolution" (Frankel 1970). Collections of genetic material placed in storage, or a few individuals of a specific genotype held in a genetically closed group, are examples of preservation management. Conservation programs maintain the target genetic resource in a dynamic interbreeding state and in an environment either typical for or native to the target. Under such conditions, the target is free to evolve as the biological and physical environments change.

There are three conservation strategies available to managers of species-specific genetic resources. One is to provide sufficient nature reserve space of diverse types to ensure the continuing evolution of all species. The second is to accept extinction as inevitable for some species, and to attempt the preservation of a sample of some species by moving remnant material to zoological or botanical gardens. The third strategy is to manage the population size, the population structure and the relevant ecosystem to offer protection to selected, presumably "threatened" species. The first strategy is an abstraction, not a reality. The number and size of nature reserves necessary to effectively conserve at-large biodiversity is beyond the capacity of available habitat given the size and continued expansion of the human populations (Gall and Orians 1992). The second strategy has become the only alternative for some species but should be avoided if the species in question can be maintained in its natural environment and is compatible with human presence. Gall and Orians (1992) include a discussion of the issue of compatibility. The third strategy of utilizing the general landscape probably is the only realistic approach (Gilpin et al. 1992). Such an approach requires that all resource utilization activities (urban and industrial development, farming, fishing, forestry, recreation, etc.) be managed in an integrated way as to insure a place for all species. A benefit of this approach, in addition to conservation of native species, is the development or maintenance of a landscape that is aesthetically pleasing to humans, and thus has redeeming social value (for example, an attractive agricultural landscape). However, for this approach to represent a viable alternative, management protocols must embrace the integration of conservation with resource exploitation and utilization.

Genetic Management

One of the central issues in assessing conservation strategies should be genetic management of biological resources. This is particularly critical when the target of the conservation program is a species or subpopulation within species. The notions and requirements of genetic management for wild and domesticated fish species have close affinities to genetic management tools employed for domestic crops and livestock. The notions used for the genetic resource conservation of domestic crops and livestock arose from a need to conserve genetic material for future breeding programs.

Two ideas, genetic resources and genetic diversity, are given careful attention in genetic management by crop and livestock breeders. The genetic resource of interest is the genetic diversity available to animal and plant breeders for future genetic recombination and selection. Genetic diversity, the sum total of all the genetic variation within a species, is essential for the breeder to respond to changes in the physical, biological or economic environment.

Natural populations require the same reservoirs of genetic diversity for adaptation and survival as crop and livestock breeders require for successful breeding programs. The most frequent response to the need for genetic conservation of wild species is the development of nature reserves. As Frankel

(1983) has pointed out, the central questions concerning the value of nature reserves as a viable conservation strategy are: do nature reserves facilitate, restrict, or inhibit the continuing evolution of species; and can the general landscape be managed to ensure the continuing evolution of species? As a general rule, populations in nature reserves are small and fragmented so genetic management must deal with the associated problems of inbreeding, genetic drift, and the random loss of alleles. If these forces cannot be controlled satisfactorily, maintenance of a species in nature reserves can result in populations that are gradually weakened and genetically impoverished. In addition, it is essential to assess the probability of long-term stability of large complex nature reserves within the framework of global and local politics.

The solutions that have evolved in crop and livestock breeding programs involve the systematic management of fragmented populations. The genetic health of domestic genetic resources has been achieved through maintaining sources of material for manipulation in the form of germplasm collections, propagation of special genetic stocks, the development and maintenance of specific varieties and breeds, and the development of inbred lines. In the case of crop plants, effort also has been placed on understanding the genetic nature of wild relatives. The best example of the use of inbred lines has been the development of a broad array of inbred lines of the mouse and their deliberate manipulation to provide the genetic diversity of research material essential for biological and medical research. Specific breeds of livestock, although maintained in fragmented herds, have retained a healthy genetic status through the constant exchange of germplasm among herds (the genetic equivalent of gene flow).

Conservation genetics requires a framework that encompasses the same issues and factors of concern to crop and livestock breeders. One common theme of this framework is that populations do not exist as a single group of breeding individuals kept in isolation. Rather, the total population is made up of many smaller units with significant gene flow among the subunits. In contrast, nature reserves represent spatial conditions that restrict population size so survival and long-term genetic adaptation are restricted. Thus, conservation of genetic diversity should be viewed as a space-demanding process.

The metapopulation concept has been proposed as an appropriate framework for understanding and describing the population structure of natural populations (Levins 1971). The concept considers populations of a species to exist as a continuum of a large number of subgroups with gene flow among the subgroups. There is potential for local adaptation within subpopulations or groups of subpopulations. The gene flow may be continuous or intermittent and the rate of gene flow among subgroups may be uneven. The level of differentiation between any two subpopulations is determined by the balance between the effects of random and selective forces driving allele frequencies apart and gene flow pulling gene frequencies together. Theoretical models of population dynamics under the metapopulation concept are being developed (Soulé 1987). However, it is clear that this notion of population structure is consistent with the need to use the general landscape for conservation programs (Henry et al. 1991). Fragmentation of habitat can be beneficial if partitioned appropriately and if barriers to movement of individuals or gametes are not excessive.

Implementation for Wild Species

Understanding and implementing the metapopulation concept to a particular species will require special effort to describe population structure. Thus, an inventory of the genetic resource is essential. At a minimum, the inventory should establish which species are present in the ecosystem and critical to the target species, the status of the species including any that appear to be threatened with extinction, the population structure of the target species, what constitutes the principal breeding or evolutionary unit within the population structure and the distribution of genetic variability within and among various subdivisions in the population structure.

When threatened species are identified, the causes of the threatened condition, such as habitat loss, overexploitation, or forced hybridization, must be delineated. For species that are threatened, the remaining populations generally are small in size, and subpopulations are usually disconnected and occupy fragmented habitat. Such conditions bring into play two central concepts of population genetics: fitness and how it is affected by inbreeding; and genetic variance and its importance to adaptation. Both are population size dependent (Frankel 1983) and have received preliminary attention. For example, it has been suggested that an effective population size of 50 is sufficient to restrict inbreeding to an acceptable level. On the other hand, Frankel (1983) suggested that an effective size of 500 would be minimal for the maintenance of additive genetic variance. Both of these numbers are little more than educated guesses and neither considers the importance of non-additive genetic variance or the effects of selection and gene flow. In addition, it is unlikely that any single set of values will be appropriate for all species. Thus, intensive work is needed to determine the population size parameters that will ensure viability for any species under conservation (genetic) management.

Stock Enhancement and Conservation

Enhancement of fisheries through hatchery propagation represents a special case. It involves genetic manipulation of a species in a culture environment, as well as the potential disruption of the natural population structure and rates of gene flow. In addition, stock enhancement is often proposed as a conservation strategy. Thus, it is worthwhile to consider briefly, as a final section of this paper, the issues involved in integrating stock enhancement and natural production of a species.

There are four major genetic issues involved in establishing and maintaining hatchery populations for enhancement of natural production or as a conservation strategy: sampling broodstock from the natural population, domestication of the broodstock, management and operation of the hatchery and defining the genetic and breeding goals of the program. Establishing a protocol for sampling the natural population should consider potential founder effects (poor or modified performance caused by limited sampling of the genetic material in the natural population), the range of phenotypic variation present, and the importance of sampling the full range of genetic variation. Thus, attention must be given not only to the total number of individuals sampled, but to the spatial and temporal range over which the genetic variation may exist. It is likely the total number of individuals sampled will be large if an honest effort is made to identify and sample the full range of phenotypic variation present in the target population.

The extent of domestication of the broodstock due simply to hatchery culture, and the effect of some degree of domestication on the future genetic health of the natural population have not received extensive attention (Doyle 1983). However, a few affects are likely to be common to all stock enhancement programs. There will be some selection, even under management conditions designed to select future parents randomly. The selection pressure will come from the physical nature of the culture system and the adaptability of the sampled genotypes to the hatchery environment. Restrictions on physical facilities available for hatchery culture almost always limit the population size that can be managed within the facility. Thus, it is likely there will be some loss of genetic variability. Finally, hatchery reproduction most generally requires some degree of manipulation, either environmental or behavioral, so change due to selection is likely as a result of differential responses of individuals to induced spawning or artificial removal of gametes.

The type of management and the operational protocols of a hatchery program represent major sources of affects on the genetic variation among individuals produced by the program. It is suggested by some that the protocols must be benign with regard to genetic effects. However, this is not realistic since any manipulation of the natural life-cycle carries the potential of causing genetic change. Some obvious management options can at least be minimized. Discarding (culling) of individuals to improve production efficiency should be avoided since it could impose size selection. On the other hand, sorting by size may be a viable method of reducing cannibalism of smaller individuals for some species, but will probably result in higher survival than would be expected in nature. Taking care not to restrict the reproductive period should reduce the likelihood of loss of genetic variation for season of spawning. However, achieving successful reproduction over the full reproductive period may be difficult due to distorted sex ratios among mature individuals or limited numbers of individuals maturing at any given time, particularly at the extremes of the reproductive season. The mating scheme can be controlled, at least within the limits of the maturation schedule of the broodstock. Generally, it is preferable to use single-pair matings to maximize genetic recombination and genetic variability rather than to mix gametes prior to fertilization. This is due to the fact that some gametes are likely to be dominant in a mix and cause a reduction in effective population size (Withler 1988).

Conclusion

Defining genetic and breeding goals for the program is critical to the outcome of the program. These must be established in concert with the objectives of the enhancement or conservation program. The major concerns are: is there a need to maintain any subpopulation structure within the broodstock? How will parents of the next generation be chosen? Is there a need to optimize genetic differences? And is artificial selection to be minimized or used as part of a genetic improvement program? The choice of answers to these questions must be determined on a case-by-case basis. There are situations where choice of parents could utilize non-random selection as a means of increasing among family variability. An enhancement program could adopt selection as an integral component to improve survival to the fishery. In other cases, conservation of natural variability may have a higher priority than improving performance, so the goal would be to minimize selection. Some cases may involve enhancement of several subpopulations within the target species so that strict management of mating and the rearing of progeny would be essential to maintaining the genetic integrity of the subgroups; gene flow would occur only among naturally reproducing segments of the overall population. These are a few examples, but clearly there will be many factors influencing decisions for each enhancement or conservation situation.

The most important effort in any enhancement or conservation program is obtaining the proper data of the requisite quality. Only then can intelligent decisions be made regarding the genetic needs and implications of the program. Past experience suggests that most programs have been defined on an *ad hoc* basis with little attention to the long-term genetic implications of the program. Consequently, many hatchery enhancement programs, and natural conservation efforts have come under attack not for lack of good intentions on the part of the program managers, but due to a lack of planning and evaluation based, at a minimum, on common sense and good genetic rationale. Few past programs have had the requisite data available, often because political pressure was impatient or the need for a conservation effort was so critical, time would not permit proper planning. We must try at every opportunity to increase our understanding, and that of fisheries managers, of the genetic implications of human intervention in natural lifecycles and the genetic significance of management options.

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