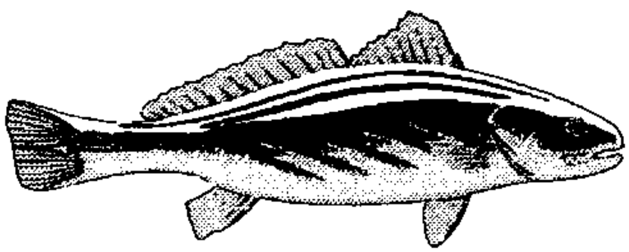
Enhancement/Conservation



Genetic Resources for Future Finfish Aquaculture

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Abstract

As background for gaining some insights into the genetic resources for future finfish aquaculture, this report defines some of the major characteristics of the current industry and the genetic resources utilized. Based on the growth exhibited by aquaculture, the diversity of the industry and the resources utilized, and the identified need to genetically characterize and maintain the genetic resources, the current and future effects of various factors on the natural genetic resources are explored. In addition, the status and potential for stock development are examined. While the major impacts on genetic resources result from insults to the aquatic environment and overfishing, aquaculture will play a major role in restoration efforts, although some operational changes will be needed. Aquaculture will become increasingly involved in both *in situ* and *ex situ* genetic conservation efforts and will, perhaps, provide the impetus for development of techniques to facilitate these efforts. Intensive aquaculture is projected to need to develop more efficient production stocks through the increased use of selection and breeding approaches, as well as through biotechnological advances. Overshadowing all of the projections and needs for genetic resources for future finfish aquaculture is the lack of a coordinated genetic information base on which decisions can be centered. The challenge for the future is the wise utilization of available genetic resources and, at the same time, their effective conservation.

Introduction

Attempting to define the genetic resources needed for the future of any food production industry is difficult, if not impossible, with the rapid changes that are occurring in many sectors of the industry. Changes in areas such as market demand, price structures, governmental policies, global warming and biotechnology can change the characteristics of an industry very rapidly. Finfish aquaculture is equally, if not more, susceptible to such changes, making projections about the future very tenuous. However, since finfish aquaculture is a relatively new commercial endeavor that still relies to a large extent on natural resources, it would be wise to consider what directions should be taken to ensure the wise use and conservation of the available genetic resources.

Before looking into the genetic resources for future finfish aquaculture, some of the current features of the industry that could have an impact on these resources should be examined. First, finfish aquaculture is a rapidly growing industry. In 1990 the harvest of finfish from aquaculture was about 8.2 million metric tons (MMT) (FAO 1992a). When this is compared to the total worldwide harvest of aquatic species (excluding seaweeds) of 97.2 MMT (FAO 1992b), it does not seem to be a very major part. However, considering that this is a 62% increase in production over a five year period (1985-1990) and that, on a weight basis it comprises well over half (68%) of the total aquaculture production, (Fig. 1) places a little different light on the vitality of finfish aquaculture. This growth is projected to continue (Nash 1988; Sandifer 1988; New 1991) and the appropriate genetic resources will be needed to underpin and enhance increased production.

Second, this industry is very diverse and multifaceted. Finfish aquaculture is conducted in many different environments, using a variety of techniques and guided by a diversity of goals. The largest quantity of fish produced on a worldwide basis is derived from freshwater aquaculture in tropical climates (FAO 1992a) and much of this production is obtained from "extensive" aquaculture, which utilizes rather low technology husbandry methods. On the other hand, one of the most rapidly growing segments of the industry is Atlantic salmon (*Salmo salar*) culture, which are grown in cold water marine environments and utilize relatively high technology approaches. Further, while most of the production in the above two examples are for direct consumption or marketing, a large portion of Pacific salmon aquaculture is directed toward the "enhancement" of natural resources and ultimate harvest by the commercial capture or sport fisheries. Such variety in aquaculture operations mandates that the genetic resources for future finfish aquaculture must be approached with diversity in mind.

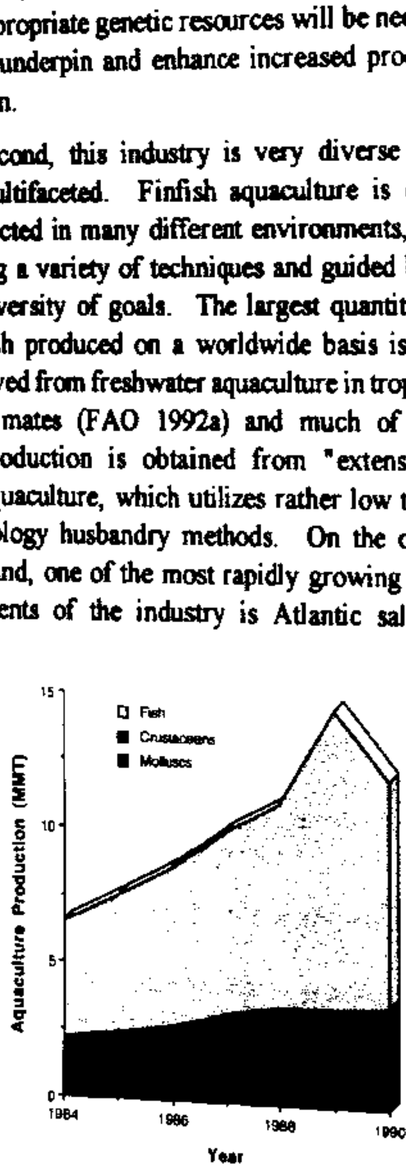

Figure 1. Worldwide annual aquaculture production (Million Metric Tons - MMT) of molluscs, crustaceans and finfish between 1984 and 1990 (FAO, 1992a).

Part of the diversity seen is a reflection of the variety of species utilized in aquaculture. About 200 species are currently produced worldwide in aquaculture facilities (Nash 1987), a number which is predicted to increase in the future (New 1991). While this is a rather small sampling of the more than 20,000 fish species that are estimated to inhabit aquatic environments worldwide (Nelson 1984), it represents a much larger array of animals than is currently raised in terrestrial agriculture. It also comprises a very large genetic resource that is available for development of aquacultural stocks. On the other hand, such a broad array of animals and potential genotypes presents a formidable challenge for genetic characterization and conservation. Thus, while there is a vast genetic "reservoir" to tap for aquaculture development, defining the genetic diversity in these species and maintaining these resources will be formidable tasks.

Finally, "tracking" and maintaining finfish genetic resources are made even more difficult by multiple interests in the harvest of fish. Many species are important to the commercial capture and the sport harvest, as well as to aquaculture. Consequently, in these situations the interests of all three types of harvest are intertwined; not only do they harvest some of the same species, but aquaculture is utilized to "enhance" species for the capture fisheries (e.g., Pacific salmon in the U.S. Pacific Northwest and Japan). Further, since aquaculture is still utilizing, for the most part, undomesticated stocks of fish, the same natural genetic resource harvested by the capture fisheries is a major source of genetic raw material for aquaculture. Therefore, all methods of harvest must be considered in making decisions regarding finfish genetic resources for the future.

With the obvious diversity and breadth of finfish aquaculture and the resources that are utilized, it is not possible to cover, in detail, how the genetic resources of individual species should be handled for the future of the industry. However, there are a number of areas where action will be beneficial for the genetic resources, irrespective of the species of fish produced or the husbandry techniques employed. Thus, it is the purpose of this report to highlight these areas, to identify their effects on the genetic resources, and to propose steps that should be taken to ensure the continuation and, perhaps, improvement of available genetic resources for the future. Hopefully the ideas presented will help catalyze more definitive action to develop methods to both make effective use of fish genetic resources and to conserve them.

Natural Resources

The first area that needs consideration with regard to genetic resources for future finfish aquaculture is the relationship of the industry and its production to natural resources. Currently, most of the industry is relying, directly or indirectly, on the genetic resources provided by the natural environment. Few truly domesticated and genetically "designed" broodstocks have been developed for commercial finfish aquaculture, so production stocks are usually derived from available natural resources. Further, when genetic problems arise, either from decreases in variability or from the consequences of inadvertent selection (Doyle 1983; Hershberger 1988), they are usually addressed by use of natural genetic variability. From a more long-term viewpoint, natural genetic resources will be the only available source of new genetic material for future stock enhancement or changes. With the current dependence of finfish aquaculture on natural genetic resources and the future importance of these resources as a source of new genetic material, more attention should be given to this area.

- **Factors Affecting Natural Resources**

Two factors currently have a major effect on natural genetic resources and will continue to do so unless changes occur. The most significant factor impacting finfish genetic resources is the deterioration of the environments in which fish live. The physical, chemical and biotic features of aquatic environments in this country (Reisner 1986), and around the world, are being altered at an alarming rate. These changes have already had major effects on the genetic resources of aquatic species. For example, as a result of the construction of hydroelectric dams on the Columbia River in the Pacific Northwest region of the United States, it is estimated that as many as 200 populations of Pacific salmon (*Oncorhynchus* spp.) uniquely adapted to specific freshwater environments were lost (NPPC 1987). This and other environmental changes have led to more than 100 stocks of anadromous salmonid fishes in the states of California, Oregon, Idaho and Washington being characterized as at "high risk of extinction" (Nehlsen et al. 1991). While it is not the purpose of this paper to delve into the problems with the degradation of aquatic environments, it is imperative to emphasize that the abuse of these environments needs to be halted if finfish genetic resources are to have any future.

The second factor affecting the genetic resources of natural fish populations has been the changes in the commercial capture fishery. In the last decade the market demand for fish products increased dramatically; for example, per capita consumption in the U.S. increased nearly 25% (from 5.7 kg to 7.1 kg) between 1980 and 1990 (NRC 1992). Demand for fish products is projected to continue to increase on a worldwide basis (New 1991). The increased demand, accompanied by price increases and diminishing resources, resulted in the evolution of the capture fisheries from small, subsistence-level operations to sophisticated, highly mechanized fish capture systems. The enlarged harvesting capacity and the improved efficiency of the capture fishery have led to the rapid depletion of some fish populations and, in some cases, their complete elimination (Larkin 1977). Further, the recurring pattern of resource depletion has led to increased management regulation that utilizes increasingly selective fishing practices. The practices of over-exploitation and selective regulation of the harvest have had a demonstrable effect on salmonid genetic resources (Ricker 1981). The extent of the genetic change caused by capture fisheries can only be estimated in a few instances, since genetic data are available on a relatively small sampling of the species that are harvested. Consequently, a much more extensive genetic data base is needed to get an understanding of the natural genetic resources.

Stock Enhancement

Aquaculture has been utilized for a long time in attempts to restore/enhance the production lost from diminished or polluted environments and from overfishing (Eschmeyer 1955). For a variety of reasons the history of this use of aquaculture has shown extremely variable results (Radonski and Martin 1986). However, with improvements in technology and better scientific information aquaculture has been successful in a number of commercial capture and sport fisheries (Liao 1988; Sandifer 1988). Further, New (1991) suggests that stock enhancement will have a major role to play in meeting future fish production needs. Increased use of this type of aquaculture will present problems for the natural genetic resources if changes are not made in some operational procedures.

Inherent in attempting to raise natural populations of fish under artificial conditions and introducing them into the natural environment are a series of genetic consequences that have the potential to affect the natural genetic resources. These problems, while most extensively studied in salmonids, are not unique to a particular group of fish, nor even to fish in general (Harlan 1981). Several reviews have been published that cover the specifics of the genetic impacts that may be realized with fish (Allendorf and Ryman 1987; Hindar et al. 1991; Waples 1991). Concerns center on three basic issues shown in Table 1. While the relative importance of each of these may vary with the species, they suggest some areas that will need to be addressed for future finfish aquaculture.

Table 1. Levels of potential genetic effects on natural resources from the use of enhancement culture to restore populations (Waples 1991).

Genetic Effects of Concern from Enhancement	Causative Agents
Direct genetic effects	Hybridization, introgression
Indirect genetic effects	Altered selection regimes or reduction in population size resulting from competition, disease, or other factors.
Genetic changes to hatchery stocks	Selection, genetic drift, stock transfers

First, the genetic composition of natural resources must be more thoroughly and completely defined. Currently, only a small fraction of the species utilized for stock enhancement has been genetically characterized. Further, for the most part, only a single analytical tool has been used to define genetic variability, electrophoretic separation of genetically variable proteins, (Utter et al. 1987). More recently, electrophoretic analyses of mitochondrial and nuclear DNA have been employed (Wilson et al. 1987; Wirgin et al. 1991), but these data are not yet very extensive. Although results obtained to this point have been very informative and have yielded a wealth of previously unavailable information, additional traits should be analyzed to allow better definition of the natural genetic resources. Also, utilization of the information is problematic since the results are generally found in a wide array of journals and publications. Future plans should include the development of a genetic data management system for fish.

Second, future stock enhancement must take steps to follow sound reproductive approaches and, to the extent possible, use husbandry procedures that enhance performance in the natural environment. Because the fecundity of many finfish species is relatively high and because aquaculturists have become proficient at maximizing early survival, it has been rather common practice to use as few adults as possible for reproduction. This leads to severe and haphazard genetic changes through the process of genetic drift (Crow and Kimura 1970) and there have been numerous studies to document that this is a problem in stock enhancement (Simon et al. 1986; Allendorf and Ryman 1987; Waples and Teel 1990). In addition, husbandry practices (e.g., feeding rate, time of feeding, and rearing density), through their effect on the innate behavior of fish, can have a major impact on the survival and genetic composition of a population (Huntingford and Thorpe 1992). For example, research has shown that modification of the physical methods of presenting feed (Noakes and Grant 1992) and changing feeding times (Eriksson and Alnärä 1992) lead to increased efficiency and decreased environmental impact on the fish.

While stock enhancement will undoubtedly have an expanded role in future fish production, the lack of reproductive barriers between the cultured populations and the natural populations will mandate some operational changes to maintain the natural genetic resources. Additional genetic information will provide the base from which to assess changes. Alteration of hatchery procedures will assist in minimizing the differences between the two groups. However, sterility or other types of barriers (e.g., geographic separation) will need to be erected to implement effective conservation of natural genetic resources.

Conservation of Natural Resources

Although there is a crucial need for conservation of fish genetic resources, the methods for management of these resources are currently inadequate and diffuse (Ryman et al. 1993). Most of the conservation efforts with fish species have been directed toward ecosystem and species management (*in situ* management). However, the harvest of commercial capture and sport fisheries still has an impact on these *in situ* systems. Management of the capture fisheries has been based on maintaining a sustainable yield, which only takes into account numbers of fish and does not consider the genetic composition of the fish harvested. Further, the concept of maintaining a sustainable yield with natural resources has come under some scrutiny (Ludwig et al. 1993).

Most of the information available for guiding conservation efforts is derived from electrophoretic separation of genetically variable proteins, as well as of mitochondrial and nuclear DNA (Ryman and Utter 1987). The major goal in these investigations has been to determine the natural population structures of the various species and assess their potential genetic relationships. The results of these analyses have shown that, in general, local populations of freshwater fishes are genetically more divergent than those of marine species, and anadromous species exhibit somewhat intermediate values (e.g., Ryman 1983; Gyllensten 1985). For example, this means geographically proximate populations of some freshwater species may be sufficiently divergent genetically to warrant consideration as separate species (e.g., Allendorf and Leary 1988), whereas populations of some marine species on different sides of the ocean may be genetically indistinguishable (e.g., Grant 1984). Fewer geographic barriers to reproductive isolation in the marine environment can undoubtedly explain a lot of these differences, but there are documented exceptions to these generalities (Jörstad et al. 1991). However, these differences in the distribution of intraspecific genetic variability have some obvious implications for the conservation of finfish genetic resources.

First, where there is a high degree of genetic divergence between populations, these units are an important source of genetic variability. Consequently, the loss of a population has a proportionately larger impact on the genetic resources of the species. Further, geographic confinement generally means smaller population sizes; reduction in numbers in small populations can lead to large losses of genetic variability. However, the magnitude of the modern harvest can have a major impact even on the genetic resources of the more numerous marine species. It would seem advisable for future *in situ* conservation efforts to develop management approaches that incorporate genetic risk analysis in their formulation and implementation.

The technology for off site (*ex situ*) management systems is developing very rapidly with fish species. Due, in part to the increasing interest from commercial aquaculture, the capability of satisfactorily propagating a wider number of species for the maintenance of living collections is becoming a reality. The guidelines are being formulated for using aquaculture for the recovery of Pacific salmon (*Oncorhynchus* spp.) listed as threatened or endangered under the U.S. Endangered Species Act (Hard et al. 1992). However, obtaining a representative sampling of the genetic diversity of the population is still a problem, as is the cost of maintaining a long-term collection of these species. Contemporary research indicates that long-term storage of frozen gametes and even zygotes may be practical in the near future (Stoss 1983). However, serious constraints still exist with regard to the technologies for the storage of ova and embryos of aquatic organisms. Future conservation will, of necessity, place more emphasis on *ex situ* approaches and the use of "gene banks" to conserve genetic resources.

Use of Exotics

A final approach that should be discussed under this topic area is the transfer of populations and the introduction of exotics. This activity has a long history (about 150 years) and has been undertaken, for the most part, for man's benefit. Most often the rationale used has been to establish food or game fish (Courtenay and Robins 1975). In a review of introductions of inland species, Welcomme (1992) pointed out that 57 and 84 species have been recorded as being introduced for enhancement of sport fisheries and improvement of wild stocks, respectively. While only a few of these were successful, and fewer still have had negative impacts, the potential severity of their genetic effects when introduced into natural fish populations is too large to discount. Protection of future genetic resources will rely on stronger control of practices and should include some type of risk assessment (e.g., Kohler 1992).

Commercial finfish aquaculture also plays a role in the importation of exotics. Frequently, the argument employed for this type of activity in the U.S. is that the economy is based on exotics (Courtenay and Robins 1975). It is pointed out that virtually all of our agricultural livestock, most of our grains and vegetables, and many fruits are exotics. However, until fish have been subjected to controlled breeding for a large number of generations and they do not compete successfully without husbandry and cultivation by man, the severity of their impact on natural fish populations will be perceived to be too large to discount. Although about 117 species have been introduced into foreign inland environments for aquaculture purposes (Welcomme 1992) and some of these have been very successful (Hershberger 1991), the trend in commercial aquaculture currently seems to be directed toward exploring the potential of local species (Welcomme 1992).

Controls on the importation of exotics at any level, either state, national or international, are fragmented or ill-enforced and are based mostly on the threat of disease transmission rather than on genetic impacts. While prohibition of further introductions is unrealistic and would clearly hinder future development, greater public awareness of the perceived problems will make importation of exotics more difficult. Effective sterilization techniques will be developed for fish, as well as a larger genetic information base on which to judge the likely impact. Both of these will facilitate some use of exotics in finfish aquaculture.

Stock Development

Unlike the situation with traditional agricultural enterprises, aquacultural production is currently based on the husbandry of undomesticated stocks of fish. Consequently, the aquaculture industry is faced with the operational and genetic problems that accompany the development of domesticated populations. The major constraints to more rapid development of stocks for commercial aquaculture are the lack of reliable estimates of genetic parameters (e.g., genetic and phenotypic variances, covariances, genetic and phenotypic correlations) for commercially important traits and the lack of designed selection programs to test their validity (USDA 1988). A number of studies have been conducted to estimate phenotypic and genotypic parameters for many quantitative traits (Gjedrem 1983; Gjerde 1986; Tave 1986). In general, these studies have demonstrated the presence of adequate genetic variability in economically important traits to realize reasonable gains through selection programs. It has also been observed that, while the phenotypic variability in many traits in fish is much higher than in other agricultural animals, the heritabilities in fish are somewhat lower (Allendorf et al. 1987). This may be a reflection of the poikilothermic nature of fish and their consequent responsiveness to the external environment. It may be that habitat and husbandry changes will have more effects on fish than have been observed with terrestrial animals.

While there has been an expansion of efforts to conduct designed breeding programs that will lead to stocks with desirable genetic traits, few of these have been of adequate duration to yield defined aquaculture stocks. Probably the most extensively developed program for this purpose is in Norway, where the aquaculture industry has supported a large breeding and selection program to develop stocks of Atlantic salmon (*Salmo salar*) for marine net-pen rearing (Gjedrem et al. 1987). There are also large programs in Israel and Hungary for the development of carp (*Cyprinus carpio*) stocks for pond rearing (Moav and Wohlfarth 1966; Bakos 1976). In the U.S., several programs with salmonids have been conducted to develop stocks for industry (Donaldson and Olson 1957; Gall and Gross 1978; Hershberger et al. 1990). However, the results from these programs are, for the most part, still too preliminary to define the fish stocks as domesticated.

Future finfish aquaculture will need to develop more efficient animals for commercial operations. It is estimated that at least 30% of the increases in rate and efficiency of protein production in agricultural animals have resulted from genetic research and comprehensive industry breeding programs (Dickerson 1970). Similar levels of change will be required for some segments of the aquaculture industry, particularly those involving high-cost inputs, to retain viability. More severe environmental constraints and increasing competition for intensive cultivation approaches (New 1991) will necessitate the use of selection and breeding approaches, as well as biotechnology, to improve the efficiency of the finfish stocks used.

Fish exhibit a number of characteristics that make them amenable to extensive biotechnological manipulation (Lewis 1988) and a number of investigations are underway to explore the transfer of genes to provide desirable traits for aquaculture (Maclean et al. 1987). In a review of the use of gene manipulation in aquaculture, Maclean and Penman (1990) highlight the variety of biotechnological approaches that can be used to develop stocks for commercial aquaculture. However, the current lack of detailed genetic information on fish species limits the potential for more extensive studies and problems of containment in an aquatic environment are formidable.

Conclusion

The scenario that unfolds from considering genetic resources for future finfish aquaculture is one of a rather minimal, although expanding, information base on the genetics of natural resources and of program development for the design and production of domesticated stocks. There is a promise and a potential for accessing large amounts of genetic variability for future programs. For finfish aquaculture to realize the increased production that, from all projections, will be needed to meet market demands, a significant portion of this genetic resource will have to be utilized in one form or another. The challenge is to develop aquaculture programs that will meet the diverse needs of the industry and, at the same time, conserve adequate genetic resources to ensure future generations will also have access to them.

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