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Bartley D.M.

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# Genetics and breeding in aquaculture: Current status and trends

**D.M. Bartley**
Fisheries Department
Food and Agriculture Organization of the United Nations
00100 Rome, Italy

**SUMMARY -** In 1984 aquaculture production data from the Mediterranean were reported to FAO on only six species, mostly shellfish and a few mullet; culture of seabream and seabass was just beginning. Today there are between 20 and 30 Mediterranean farmed species for which data are reported. In contrast with livestock and plant crops where improvements in production have been based on modern breeding approaches, only a few examples of such breeding programmes exist for fish (e.g., Atlantic salmon in Norway). Thus, principles of genetics can be applied to the farming of marine species to increase cost effectiveness through improved breeds. The application of such technologies can be divided into two broad groups; those for short-term and those for long-term improvement. Hybridization, chromosome set manipulation, and sex reversal can be considered short-term improvements made over 1 - 2 generations; the improvements generally are non-cumulative, i.e., one time events. Selective breeding represents a long-term improvement programme where small gains accumulate over generations; gene transfer may be considered long-term where the gains may be substantial, but may not accumulate each generation. Many of these technologies can and should be combined and used together. Recently, there has been a call for the application of genetic technologies to reduce the risk of adverse environmental effects should a farmed species escape into the natural environment. At the same time, some genetic technologies are being criticized on moral and ethical grounds. As breeding of aquatic species becomes easier and more aquatic species become domesticated, genetically differentiated strains will undoubtedly increase and aquaculture development will be faced with the problem of how best to manage and promote the new diversity, while conserving the natural genetic diversity of aquatic species. Socio-economic, as well as technical and biological, factors, will play a vital role in this regard.

**Key words:** Aquaculture, genetics, conservation, economics.

***RESUME -*** *"Génétique et amélioration en aquaculture : Situation actuelle et tendances". En 1984 les données rapportées à la FAO pour la production aquacole de la Méditerranée représentaient seulement 6 espèces, la plupart mollusques et quelques mulets; la culture de la dorade et du bar était à ses débuts. Aujourd'hui les données représentent entre 20 et 30 espèces cultivées de la Méditerranée. Contrairement aux productions animales et végétales où les améliorations productives ont été axées sur des approches modernes de sélection, pour les poissons il n'y a que quelques rares exemples de tels programmes de sélection (par exemple le saumon de l'Atlantique en Norvège). Par conséquent les principes de la génétique peuvent être appliqués à l'élevage d'espèces marines afin d'augmenter l'efficacité des coûts à l'aide de races améliorées. L'application des technologies génétiques pour l'amélioration de la production aquacole peut être divisée en deux groupes principaux: ceux pour l'amélioration à court terme et ceux à long terme. L'hybridation, la manipulation de chromosomes, le renversement de sexe peuvent être considérés comme des améliorations à court terme faites durant 1 - 2 générations ; en général les améliorations sont non-cumulatives, elles ne se produisent qu'une seule fois. La reproduction sélective représente un programme d'amélioration à long terme où le profit peut être inférieur, mais qui s'accumule pendant plusieurs générations; le transfert des gênes peut être considéré à long terme lorsque le profit est important, mais il ne s'accumule pas toujours pour chaque génération. La plupart de ces technologies peuvent et devraient être jointes et utilisées ensemble. Dernièrement, le besoin d'une application de technologies génétiques s'est fait ressentir pour réduire le risque des effets de renversement sur l'environnement au cas où des espèces cultivées s'échapperaient dans l'environnement naturel. En* *même temps, certaines technologies génétiques sont critiquées pour des raisons morales et éthiques. A mesure que la reproduction des espèces aquatiques deviendra plus facile et que plus d'espèces aquatiques seront domestiquées, les souches génétiques différenciées augmenteront et le développement de l'aquaculture devra affronter le problème de comment mieux gérer et promouvoir la nouvelle diversité tout en conservant la diversité génétique naturelle des espèces aquatiques. Les facteurs socio-économiques ainsi que techniques et biologiques joueront un rôle vital à cet égard.*

***Mots-clés :*** *Aquaculture, génétique, conservation, économie.*

## Introduction

Although genetic improvement of common carp probably started several thousand years ago (Balon, 1995), the application of genetic principles to most aquaculture species is a relatively recent phenomenon. Thus, the majority of farm-raised aquatic animals and plants are very similar to the wild forms. Genetic improvement programmes are beginning to be applied to more and more aquatic species, but when compared to the levels of domestication in livestock and crops, the aquatic sector is very far behind (Eknath *et al.*, 1991). In 1984 aquaculture production data from the Mediterranean were reported to the Food and Agriculture Organization of the United Nations (FAO, 1995) on only six species, mostly shellfish and a few mullet; culture of seabream and seabass was just beginning. Today there are between 20 and 30 Mediterranean farmed species for which data are reported; many important species cultured in the region are high value marine species (Fig. 1). As the husbandry improves for more and more species, so will the application of genetic improvement technologies.

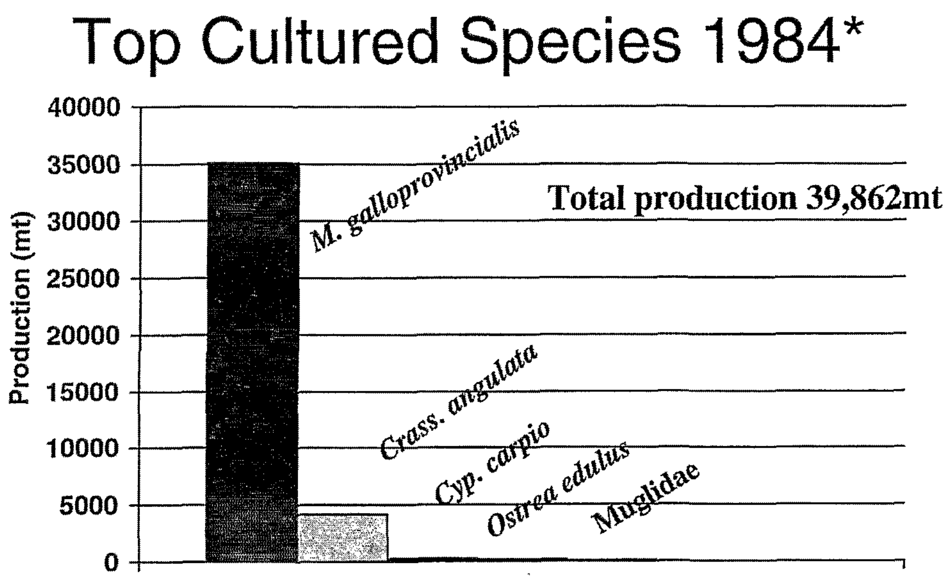
As production from aquaculture increases, prices for many aquaculture products have declined (Fig. 2). Therefore increased efficiency of production and diversification of aquaculture products will be necessary to keep the industry economically viable. Genetic technologies are one strategy to increase this efficiency and promote diversification (Gjerde and Rye, this volume).

The growth of the aquaculture sector has raised concerns on its risk to the environment and native species through the large-scale release or escape of farmed animals and their subsequent breeding with, competition with, or predation on local species; farmed aquatic animals may also be a vector for disease transmission to wild stocks. Aquaculture has been recognized as the primary reason for the purposeful movement (introduction) of aquatic species (Welcomme, 1988) and experience has shown that cultured species usually escape into the wild. Hatchery or farmed fish have been assumed to represent a risk to the native gene pool by introducing maladapted genes, i.e., genes adapted to the farm and not to the wild (Hinder *et al.*, 1991). However, Campton (1995) pointed out that direct evidence for adverse effects resulting from the mixing of hatchery and wild stocks is difficult to come by. As genetic techniques increase in their frequency of application and in their alteration of the phenotype, there may be more concern for environmental biosafety.

The importance of genetic principles to aquaculture development was recognized by the international community when it drafted the FAO Code of Conduct for

Responsible Fisheries. Article 9.3 requires that "States should conserve genetic diversity and maintain integrity of aquatic communities and ecosystems by appropriate management". General technical guidelines to help implement the Article have been developed that address broodstock selection and management, release of gmo's, interaction of wild and farmed animals, and the use of introduced species (FAO, 1997).

It is the purpose of this paper to cite some representative examples of the genetic technologies applied in aquaculture and also to identify some relevant key issues for sustainable aquaculture development.



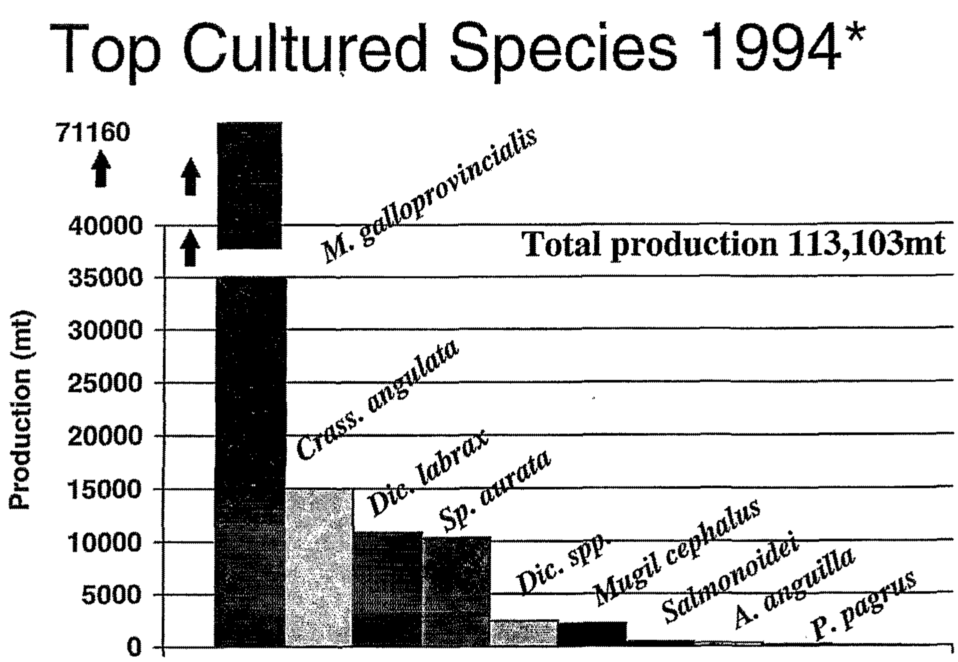




Fig. 1. Main aquatic species farmed in the Mediterranean and Black Sea Region in (a) 1984 and in (b) 1994 (*FAO, 1995).

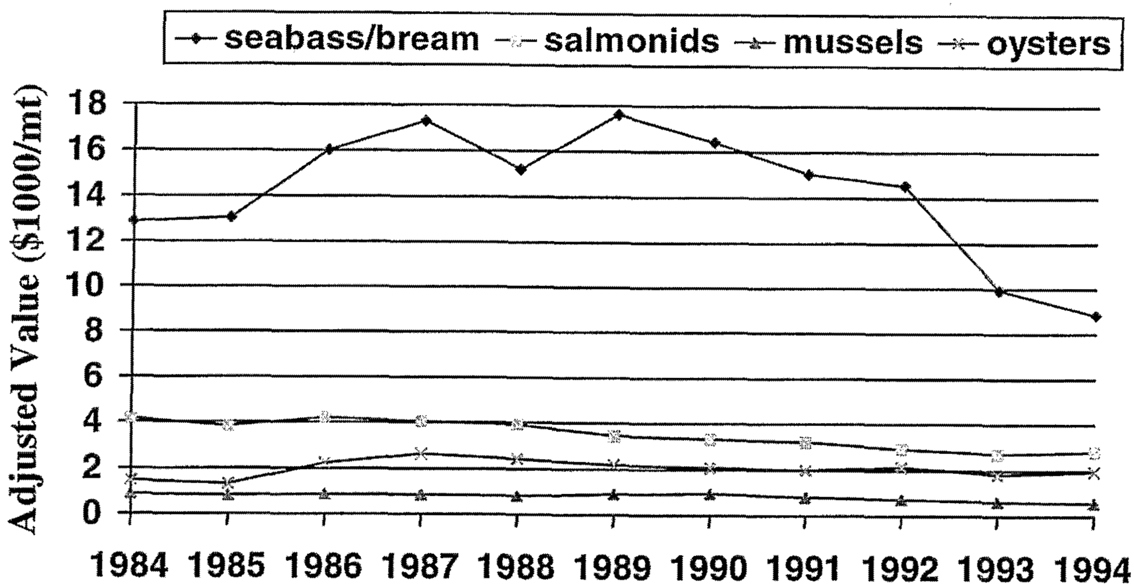



Fig. 2. Change in the value of some main aquaculture commodities in the Mediterranean region. Values are adjusted for inflation by using a 1990 standard Consumer Price Index for industrialized countries (IMF, 1997).

## Genetic Improvements

Genetic technologies can be utilized in aquaculture for a variety of reasons, not just to improve production (Table 1). Improvements in marketability, culturability, and the conservation of natural resources can be facilitated by the appropriate genetic technology. Genetic improvement programmes can be used to provide short-term or long-term gains (Table 1). The short term gains are usually immediate, within 2 generations, and generally not cumulative (unless combined with other long-term programmes), whereas the long term programmes such as selective breeding produce small gains that accumulate each generation (Falconer, 1981). In general, genetic improvement technologies have not been applied to marine species to the same extent as they have been applied to freshwater and anadromous (salmonid) species. Thus, as more marine species become farmed, genetic improvement can be expected to play an increasingly important role in improving production.

### Long term strategies

Domestication and the full potential for the utilization of aquatic genetic resources will undoubtedly only be realized by long-term breeding programmes utilizing additive genetic variance. Of the few breeding programmes applied in aquaculture, the Atlantic salmon breeding programme in Norway is an example of a long-term approach to breed improvement (Gjerde and Rye, 1997) that has been copied in other parts of the world, e.g., in the Philippines for the improvement of tilapia (Eknath *et al.*,1993) and in Chile for coho salmon (FAO, unpublished report). Selective breeding for increased growth in red sea bream in Japan has been ongoing for over 30 years (7 generations) and resulted in a shorter time required to produce a market sized (1kg) fish (Murata *et al.*, 1996).

Traits considered for improvement should be of economic interest to the aquaculture industry. Although growth rate is the character most often to be improved in selective breeding programmes, other traits have been shown to have additive genetic variance and therefore, amenable to improvement (Table 1 and Tave, 1986). Disease resistance is one character that is extremely important for some aquacultured species, but improving this trait by specific selective breeding programmes may be problematic (Tave, 1995) and due more to the problems of experimental design (are fish that do not get a disease resistant or have they merely not encountered the disease?) than to problems with additive variance for the trait "disease resistance". Resistance to polluted waters is also desirable in some areas, e.g., heavy metal tolerance in tilapia, but care should be taken not to use this as a justification not to restore degraded habitats (Lourdes *et al.*, 1995). Recently, due to the high prices that high quality products reach in the market, other traits, such as flesh quality (Gjedrem, 1997), are being considered by the industry.

Selection efficiencies may be enhanced by selecting for a particular gene loci, a process called marker assisted selection, if the proportion of additive genetic variance related to a locus or loci exceeds the heritability of a trait (Danzmann and Ferguson, 1995). However, identification of useful loci is still difficult in aquatic species. Micro-satellites probes reveal high levels of genetic variation and can help identify useful loci and help establish pedigrees in mixed family groups. Therefore, marker assisted selection may be practical for commercial or small scale farms because no special rearing facilities are needed, daily routine of fish farming is not interrupted and fish did not need to be marked; genetic analysis could be performed on small tissue sections or fin clips that would not detract from the marketability of the fish (Herbinger *et al.*, 1995). In general, care has to be taken in order to limit the negative effect of inbreeding when designing and running selective breeding programmes in aquaculture (Gjerde and Rye, 1997) and genetic markers such as micro-satellites can help determine family relationships.

Production of transgenic fish is considered here to be a long term breed-improvement strategy because of the time required to identify a useful gene and its promoter, to insert them into the host animal and then to conduct the screening required to confirm the stable inheritance of the transgene. Several commercially important species have received genes from other species. For example, coho salmon with a growth hormone gene and promoter from sockeye salmon grew 11 times (0-37 times was range of effects) as fast as non-transgenics (Devlin *et al.*, 1994). Private industry is promoting transgenic fish and testing transgenic Atlantic salmon that grow 400% faster than normal (during first year) at an inland aquaculture facility in Scotland (Elliot Entis, A/F Protein, pers. comm.).

Long-term breed improvement strategies require long-term data collection, record keeping, broodstock management, and monitoring. Specialized rearing facilities may be required, e.g., during the initial stages of a gene-transfer programme, or in order to keep track of a fish's pedigree and family groupings. Not all farms or regions would have the capacity, resources, or the desire to embark on such programmes (Tave, 1995).

Table 1. Genetic improvement strategies

| Genetic manipulation | Improvement |
|---|---|
| Long-term strategies: Selective breeding for: | |
| Growth rate | As high as 50% increase after 10 generations in coho salmon (Hershberger *et al.*, 1990); gilthead sea bream mass selection gave 20% increase/generation (Hulata, 1995); mass selection for live weight and SL in Chilean oysters found 10-13% gain in one generation (Toro *et al.*, 1996). |
| Body confirmation | High heritabilities in common carp, catfish and trout (Dunham, 1995; Tave, 1986) |
| Physiological tolerance (stress) | Rainbow trout selected for high response showed increased levels of plasma cortisol levels (Pottinger *et al.*, 1995). |
| Disease resistance | Increased resistance to dropsy in common carp (Kirpichnicov, 1981), but disease resistance difficult to select for (Tave, 1995). |
| Pollutant resistance | Tilapia progeny from lines selected for resistance to heavy metals Hg, Cd, and Zn survived 3-5 times better than progeny from unexposed lines (Lourdes *et al.*, 1995). |
| Maturity and time of spawning | 60 day advance in spawning date in rainbow trout (Dunham, 1995). |
| Gene transfer | Coho salmon with a growth hormone gene and promoter from sockeye salmon grew 11 times (0-37 range) as fast as non-transgenics (Devlin *et al.*, 1994). Atlantic salmon grew 400% faster than normal during first year (Elliot Entis, A/F Protein, pers. comm.). |
| Short-term strategies | |
| Intra-specific crossbreeding | Heterotic growth seen in 55 and 22% of channel catfish and rainbow trout crosses, respectively (Dunham, 1995). Chum salmon and largemouth bass showed no heterosis. |
| | Heterosis for wild x hatchery *S. aurata* (Hulata, 1995); crossbreeds of channel catfish common carp showed 30-60% heterosis. |
| Sex reversal and breeding | All male tilapia show improvements in yield of almost 60% depending on farming system (Mair *et al.*, 1995) and little unwanted reproduction and stunting. All female rainbow trout grew faster and had better flesh quality. |
| Chromosome manipulation | *Pagrus major* triploids had similar growth rate to diploids at 10 months of age, but were smaller and presumed to be sterile at 18 months (Sugama *et al.*, 1992). *Dicentrarchus labrax* triploids showed inconsistent growth in relation to diploids and had lower GSI (Knibb, 1997). |
| | Improved growth and conversion efficiency in triploid rainbow trout, channel catfish, at plaice flounder hybrids; triploid Nile tilapia grew 66-90% better than diploids and showed decreased sex-dimorphism for body weight, but other studies found no advantage. GxE interactions also influence performance (Dunham, 1995). |
| | Triploid Pacific oysters show 13-51% growth improvement over diploids at 8-10 months of age and better marketability due to reduced gonads (Guo *et al.*, 1996); triploid Sydney rock oysters showed 41% increase in body weight at 2.5 years (Nell *et al.*, 1994). |
| | Polyploidization makes certain interspecific crosses viable (Wilkins *et al.*, 1995). |

## Short-term strategies

Short-term genetic improvement programmes may not require the same level of record keeping nor management as long-term projects and can impart significant gains with simple technologies in a short period of time. That is not to say that everyone will view the technologies as "simple" or that proper broodstock management and accurate record keeping are not important, they will be necessary to maintain healthy and genetically appropriate stocks for manipulation.

Hybridization has been undertaken to combine favourable qualities from two genetically different groups and to take advantage of hybrid vigour (heterosis). Sterile or non-reproducing groups may also be produced through interspecific hybridization, but fertile hybrids also exist for several aquaculture species (Table 1). Usually, it is only the F1 generation that is of interest to aquaculturists, therefore the pure parental lines must be maintained and managed by the breeding centre. Several large groups of importance to aquaculture do not produce useful hybrids, for example salmonids and peneaid shrimp, (Benzie *et al.*, 1995).

As more and more marine hybrids are produced, their culture performance is and should be evaluated. The Kuwait Institute of Scientific Research has produced a hybrid bream, *Acanthopagus latus* (Sheim) *x Sparidentex hasta* (sobiaty), that is currently being investigated. It has good growth and body quality and appears to be fertile (Khaled Al-Abdul-Elah, Kuwait Institute of Scientific Research, pers. comm.). Evaluation should note the importance of the sex of interspecific crosses. In hybrid striped bass, the sunshine bass, a hybrid between male *Morone saxatilis* x female *M. chrysops*, is superior under culture to the Palmetto bass, the reciprocal hybrid. Approximately 80% of the culture of Clariad catfish in Thailand involves a *Clarius macrocephalus* and *C. batrachus* hybrid with the preferred female being the Thai catfish, *Clarius macrocephalus*, (Mr Sujin, National Inland Fisheries Institute, Bangkok, pers. comm.).

Many aquatic hybrids are fertile and may be bred together or backcrossed to parental lines. Hybrid red tilapia (Red Florida tilapia x *Oreochromis urolopis honorum*) are being backcrossed to ancestral lines in efforts to improve growth and body shape (FAO unpub. report) in Venezuela.

Manipulation of chromosome-sets (polyploidization) has been accomplished for many aquatic species through thermal and chemical shocks to developing embryos. Triploid organisms are particularly interesting because they should be sterile and therefore be able to put more energy into the growth process rather than into maturation and reproduction. However, this assumption does not hold for all species and triploids demonstrate varying levels of reproductive activity and growth difference from diploids (Mair, 1993; Hussain *et al.*, 1995). The performance in culture of triploids in relation to diploids seems to be species specific (Sugama *et al.*, 1992). Inconsistent performance of triploids within rainbow trout and Atlantic salmon has also been noted; in coho salmon triploids, poorer growth and survival was observed (Withler *et al.*, 1995). In oysters improved growth and marketability resulted from triploidization, and the practice is common in Pacific oyster production in the USA. Guo *et al.* (1996), demonstrated that triploid oysters produced by mating tetraploids with diploids had higher survival and larger size than triploids produced by chemical shock and were larger than diploid controls.

The production of mono-sex groups is another short-term strategy that takes advantage of sexual dimorphism in important traits or when reduced chance of reproduction is desired. For example male tilapia grow faster than females and a single sex population of tilapia would not be prone to reproductive stunting (Mair *et al.*, 1995), whereas female rainbow trout are desirable because of faster growth rate and delayed maturity (Bye and Lincoln, 1986). In species where fish roe is valuable, e.g., caviar from sturgeon, the production of all female groups would be an obvious benefit.

Fish may be directly "sex reversed", by administering androgens or oestrogens to early life history stages, thus producing a group of all one sex (Dunham, 1995). Although the use of hormones early in the culture of aquatic animals is becoming widely accepted due to the fact that no residue remains when the organism reaches market size, certain areas still have restrictions on the consumption of fish that have been treated with hormones. This problem may be solved by the appropriate sex-reversal and breeding of broodstock, such that single-sex progeny are produced without ever coming in direct contact with the hormone (Mair *et al.*, 1995).

## Combining techniques

Several techniques can be combined to take advantage of different kinds of genetic diversity. Gene transfer may be combined with selective breeding because the transferred gene may confer an improvement in only one character and selective breeding may round-out the improvement by increasing the level of domestication. Care should be taken however, to not lose the transgene during the selective breeding phase.

Although many diploid salmonid hybrids are not useful for aquaculture, triploidization of the hybrids may confer increased viability on the hybrids (Gray *et al.*, 1993). Hybridization and polyploidization have been utilized in tandem and have been shown to improve developmental homeostasis in Atlantic salmon x European trout hybrids. Triploidization of Atlantic salmon, *Salmo salar,* x European trout, *S. trutta,* hybrids increased their survival and growth rate to a level comparable to Atlantic salmon (Galbreath and Thorgaard, 1997). Triploid Pacific salmon hybrids had earlier seawater acclimation times (Seeb *et al.*, 1993). Disease resistance was improved by rainbow trout x char triploids and rainbow trout x coho salmon triploid hybrids had increased resistance to IHN, but grew more slowly (Dorson *et al.*, 1991).

Genetic stock identification techniques are being used in fishery management to assess stocking procedures and to determine mixing of aquaculture and wild stocks, as well as to assist in determining the composition of mixed stock fisheries (Brodziak *et al.*, 1992). For example Morán *et al.* (1996) looked at mDNA variation in brown trout and Beaudou *et al.* (1994) examined isozymes to determine that Atlantic populations of brown trout stocked into rivers of the Orb River basin draining into the Mediterranean in southern France were not interbreeding with natural stocks possibly because the Atlantic populations (stocked from hatcheries) were not maturing.

Although marine ranching is an area where little direct genetic improvement has been attempted, Atlantic salmon ranching in Iceland has been selecting for growth and return rates and different strains for release are being evaluated (Jonasson, 1996).

## Genetic technologies and conservation

As in other agricultural sectors, the expansion of aquaculture has not been without controversy and cost. Several groups have identified aquaculture as a significant threat to natural environments and to aquatic biological diversity through the release of pollutants (feeds, drugs, etc.) and the interaction, e.g., interbreeding, of farmed species with native species. Specific genetic technologies have also been identified as being potentially dangerous, e.g., trans-genics.The danger in the production of transgenics is not the technology per se, but the fact that so much uncertainty may surround the functioning the new gene construct in a new host and whether or not the new gene can be passed on to other organisms. There is also uncertainty as to the reproductive potential of many hybrids and triploid organisms, as well as uncertainty on the viability of selectively bred fish in nature, but the use of these genetically manipulated organisms has not generated the controversy that transgenics have.

Genetic technologies can be used in aquaculture situations to address some conservation concerns (Table 2). A major issue in the salmonid aquaculture industry is the interbreeding of wild and hatchery stocks. Although some reviews have indicated that this interaction is usually to the detriment of the native stocks (Hindar *et al.*, 1991), Campton (1995) pointed out that direct genetic effects on wild stocks are difficult to document and many of the effects come from inappropriate management of the fishery or inappropriate mitigation measures.

Exactly what a hatchery is or how different they are from their "wild relatives" apparently is unclear: "Most aquaculture strains are essentially wild or only recently removed from the wild" (Herbinger *et al.*, 1995, p. 245), versus, "A general perception has arisen in recent years that hatcheries and hatchery fish may negatively affect the genetic constitution of wild populations" (Campton, 1995, p. 337). None-the-less, production of non-reproducing animals can minimize the chances of aquaculture stocks breeding with native stocks, thus responding to the demands coming from different bodies with implications in the sector from the developed world. Mono-sex, hybrids, or triploid animals are examples of non-reproducing groups. However, mono-sex groups would only be non-reproducing if they were 100 % single sex and the other sex was not present in the wild; hybrids and triploids may not be completely sterile and any non-reproducing group would still have the potential to interact ecologically with native organisms at least over the short-term.

An active area of debate, especially in the plant sector, is on the level of regulations associated with the release of transgenic organisms. Until recently, advocates of minimal regulation of the use of transgenic plants, i.e., large-scale and commercial field use, maintained that sufficient testing indicated that most transgenic crops posed a non-significant threat to the environment (Miller, 1994). However, now industry and others admit that these "tests" did not accurately duplicate large-scale uses and often the tests did not address ecological concerns (personal observation - Meeting of experts on Biosafety, CBD; Snow and Palma, 1997; Williamson, 1996). Aquaculturists should consider an ecosystem and ecological approach to risk assessment, and also be aware of the inherent problems in laboratory or small scale models for evaluating the risks of large scale releases of genetically modified or manipulated organisms into the wild.

Table 2. Genetic technologies to assist in the conservation of aquatic biological diversity

| Desired result | Genetic manipulation |
|---|---|
| Non-reproductive animals to reduce chance of aquaculture x wild stock interbreeding | Triploidization to produce sterile animals; Interspecific hybridization to produce sterile animals; Monosex production to reduce chance of reproduction |
| Reconstruction of the genome of threatened or rare species | Gynogenesis and androgenesis using one gamete from related species; process may be facilitated by cryopreservation |
| Reduced survival of aquaculture stocks in the wild | Selective breeding or genetic engineering to produce animals unfit for survival in the wild; Genetic engineering to incorporate dependence on essential nutrient not found in the wild, or as a block to reproduction |
| Economic rational for conservation wild genetic diversity | Gene transfer enables useful genes from non-commercial species to be incorporated into commercially valuable species |

Because of the potential for a diverse gene pool to provide desirable characteristics for farmed species, gene technology has created a new, economically based incentive to preserve biodiversity in both plants and animals (Gene Technology Information Unit, 1995). The Arctic flounder was not a very commercially important species, but its anti-freeze protein gene that can be transferred to other fish and even to plants to increase cold resistance could be very commercial.

Genetic resources of endangered or rare species can be conserved through genome reconstruction from cryopreserved sperm and chromosome manipulation. At present it is not feasible to cryopreserve eggs or embryos of most aquatic animals. Through the use of ova from related species that had had its DNA deactivated and androgenesis, an egg with purely paternally derived the nuclear genome could be generated (for normal sex determination mechanisms it would either be XX or YY depending on the sperm used in fertilization). Subsequent breeding of a mixed population would generate normal males (XY). Thus a population of endangered fish could be recovered from only cryopreserved sperm. However, because of the cytoplasmic inheritance of the mitochondria, i.e., the sperm contain only nuclear DNA no mDNA, the mDNA would not be recoverable (McAndrew *et al.*, 1993).

## Towards sustainable aquaculture

As directed selection programmes progress and as domestication selection proceeds by the simple act of raising fish in fish farms, more genetically differentiated strains for aquaculture will be created. One question the industry will have to face is how to manage this new diversity. Will a few species become differentiated into a multitude of races, stocks or varieties, as has happened in agriculture? Or will many different species become domesticated according to local needs? This issue arose with Atlantic salmon and the winter flounder in the north-eastern section of North America. Should selective breeding of or gene transfer of an AFP antifreeze gene be undertaken in order to expand the area where Atlantic salmon could be cultured; or should efforts be made at domesticating the winter flounder that can naturally live in these cold waters? The International Network of Geneticists in Aquaculture discussed some of the concerns on this issue and developed some guiding principles toward the development of a salt-water resistant tilapia that could be applied to other situations as well (Gupta and Acosta, 1996). These principles point out that choices will be based on local situations, opportunities and risk and will include conservation and development issues.

One scenario in the diversification of aquaculture species calls for the exploitation of genotype x environment interaction, i.e., different selective pressures associated with different areas and farming systems, to generate on-farm diversity and the creation of locally adapted strains (Doyle *et al.*, 1991). Genotype x environment interactions have occasionally been stated as being non important in genetic improvement programmes, with a widely cited example being the production of genetically improved tilapia in the Philippines (Eknath *et al.*, 1993). It is important to realize that the interactions depend on the range of environments and the range of genotypes tested. The genetically improved tilapia in the Philippines represented genotypes from *O. niloticus* and freshwater environments; if genotypes from other species and brackish or marine environments would have been included, genotype x environment interactions would have been much more significant. An accurate estimate of the improvement of many breeding programmes is hindered by lack of standardized controls with which to compare test results across a variety of culture systems (FAO, 1993).

The application of genetics to aquaculture industry has been discussed recently in several fora in relation to conservation issues. The Canadian aquaculture industry is under pressure to farm non-reproductive salmonids to reduce the risk of escaped salmon interbreeding with native stocks. The production of triploid salmon is one technique to accomplish this, but these polyploid salmon show reduced survival and are more susceptible to stress and disease (Withler *et al.*, 1995). The industry does not want to farm such fish and has asked for real evidence that the diploid salmon represent a risk to native salmonid populations (Stuart, 1996). The working group on the application of genetics in fisheries and mariculture of the International Council for the Exploration of the Sea (ICES) reported that "simpler technologies" which have been practised for centuries have formed the basis for the genetic improvement of terrestrial plants and animals, and that this is the basis for the present expansion of aquaculture. Certain technologies such as hybridization and chromosome manipulation are common to the farmer, but others, such as transgenic production are still not well known or controversial. The group thought that it would only be a matter of time before more complicated technologies were adopted (Reported by Ackerfors, 1966).

A seabass and seabream workshop organized by the European Aquaculture Society convened a round table discussion on genetics as a research priority and identified the following problems and needs (Anon, 1996):

(i) economic interest in genetically modified fish,
(ii) inbreeding estimation and procedures to avoid depression,
(iii) selection in marine fish,
(iv) sex and maturation control, e.g., monosex, sterile populations and their cost effectiveness.

A Mediterranean network dealing with aquaculture marketing issues (SELAM) has identified marketing strategies to increase profits, some of which are related to genetics and breeding (Pedini, 1996): (i) diversification of species; (ii) stock management to adapt supply to demand; and (iii) improve relationships with capture fisheries sector

Furthermore, the network noted that publicity to enhance the image of aquaculture products should be part of the strategy.

One reason for the expansion of the aquaculture sector is consumer confidence and acceptance of farmed products. The criticism by some conservation groups regarding genetically modified organisms (GMO's) could undermine this confidence and threaten the entire industry. Thus, the promotion of genetic technologies applied to protect consumers and the environment and the avoidance of controversial, poorly known (high degree of uncertainty) or high-risk practices, such as the release of fertile, poorly studied gmo's in areas were wild relatives are important, would enhance the image of the aquaculture sector as a whole.

The aquaculture sector should look to the agriculture biotechnology experience regarding consumer acceptance of gmo's. Currently there is strong opposition from environmentalists and NGOs to the use of genetically modified food products. A recent issue of an agriculture trade journal reported that a German subsidiary of Unilever has refused to sell genetically altered soybeans from the USA; genetically modified corn is also being attacked. Many European countries are demanding that genetically modified products are labelled as to their method of production (this is opposed by the USA and others). However, European Parliament and the EU has not ruled whether the modified foods represent a human or environmental hazard or how they need to be labelled (Elliot, 1996).

Religious and ethical concerns may also affect the application of some genetic technologies in aquaculture. Transferring genes between species may appear to be like "playing God" or "interfering with nature". Some new technology may also be objectionable to animal-rights advocates because of some level of increased suffering in the improved animals, as in the case of arthritic transgenic pigs, or some transgenic coho salmon that may starve due to malformed mandibles (Devlin *et al.*, 1994). Transgenic organisms may also contain new allergens that were not present in the non-transgenic form as in the case of a Brazil nut gene introduced into soybeans. The Pioneer HiBrid seed company developed a transgenic soybean with a gene from the Brazil nut; the protein produced by the transgenic plants elicited an allergic response in people who previously were not allergic to non-transgenic soybeans. The company has decided not to market the transgenic soybean (Nordlee *et al.*, 1996).

Geneticists and industry can help ease many fears about the technology by acknowledging the above concerns and striving to develop a sustainable aquaculture sector. Member countries of the FAO have made a similar commitment by adopting the Code of Conduct for Responsible Fisheries. Article Nine on Aquaculture Development contains recommendations for the conservation of aquatic genetic diversity. Voluntary performance standards have been created by the US Department of Agriculture on how to conduct research on gmo's so that the risk to the environment is minimized (Agriculture Biotechnology Research Advisory Committee, 1995).

In a survey of international attitudes on biotechnology, developed countries expressed a strong desire to utilize aquatic species as bio-reactors (Bartley and Hallerman, 1995). Transgenic rabbits have been produced with a salmon gene that produces calcitonin that helps to control calcium loss in humans. (reported from the Electronic Telegraph March 25, 1997). In Canada, tilapia are being genetically engineered to produce human insulin (MacKenzie, 1996). Although these applications are not directly concerned with food and agriculture, they may become important activities for the aquaculture industry.

The ease at which the genome of some aquatic species can be manipulated, partly because of large eggs, external fertilization, and high fecundity, makes the production of genetically manipulated organisms an attractive proposition for increasing production The aquaculture sector is not limited to the use of conventional breeding techniques nor is it necessary to go through the basic development steps of selection and isolation that lead to the domestication and diversification of livestock and crops over thousands of years. With modern molecular genetic techniques and induced breeding it is possible to create essentially new species immediately. Whether or when the aquaculture industry should forego these basic development steps is still controversial.

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