GENETIC RESOURCE MANAGEMENT-PROBLEMS AND POLICY ISSUES RELATED TO THE DEVELOPMENT OF LARGE SCALE ATLANTIC SALMON RANCHING IN ICELAND.

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I. Introduction

During the last 20 years, there has been a great increase in the culture of Atlantic salmon in various parts of the world. Most notable is the development of Atlantic salmon mariculture in Norway and Scotland where 115 and 30 thousand metric tons were produced in 1989, respectively. Similar increases have occurred in other European countries.

Inevitably, some of the salmon escape from sea-pens and it has been estimated that over 1,000 metric tons escaped from Norwegian sea cages in 1989 (Hindar et al., 1991). Considerable numbers of reared salmon have been observed in Norwegian salmon streams and similar observations have been made in some Icelandic streams (Gudjonsson 1991) and those of various other countries. These observations have raised concerns regarding the genetic integrity of wild stocks in the rivers in question, which presumably have adapted to those streams for thousands of years.

There has also been a great increase in ocean ranching of salmon in some countries. Atlantic salmon ranching has increased considerably in Iceland, where over 75% of the salmon landed in 1991 were ranched. Phenomenal increases have also occurred in ocean ranching of Pacific salmon - especially in Alaska and the Far East. Strays from some of those releases into wild salmon populations have also caused apprehension.

It has been accepted for a long time that each salmon stream is inhabited by at least one distinct stock and each stock should preferably be managed as a separate unit (Ricker 1972). A stock is often defined as a subpopulation that has become genetically distinct and is optimally adapted for survival and reproduction in its environment (Lannan et al. 1989). Ideally each one of those stocks should be separately managed -- an unrealistic goal under many contemporary management systems.

Iceland has been able to manage its salmon resources on stock basis to the extent that such measures are under the jurisdiction of Icelandic authorities. Salmon fishing in the sea within territorial limits has been prohibited since the early 1930's, at which time no sizeable sea fisheries had developed. Net fisheries occurring in some mainstem streams are rigorously controlled allowing satisfactory escapement to its tributaries. Icelandic authorities, on the other hand, exert no control over the exploitation of its stocks in mixed-stock oceanic fisheries off West Greenland and the Faroes, where two-sea-winter Icelandic salmon are known to occur. No genetic effects, however, from those fisheries have been possible to demonstrate (Scarnecchia et al. 1989, 1991).

For the most part, enhancement of Icelandic salmon stocks has been limited to relatively unproductive streams, where considerable success has in some cases been noted. In major salmon streams, releases have been irregular and small compared to natural production, often confined to inaccessible reaches of the streams, and in recent years derived from natal salmon stocks. Considering that the adverse effects of air and water pollution have only been minor in Icelandic salmon streams the salmon stocks, with a few exceptions, must be considered in a relatively pristine state.

It is thus safe to say that the effects from increased rearing and ranching impose a new perspective in Icelandic salmon management, which demands immediate attention and implementation of a constructive and realistic policy. The policy must consider the long term ecological well being of the wild salmon stocks as well as a proper framework for economic development of salmon rearing and ranching. A preliminary policy was enacted in 1988 (Isaksson 1988), but a more extensive policy which considers long term development should be implemented.

The purpose of this paper is to review current thinking in the field of genetic resource management with emphasis on current policies in various countries regarding genetic interactions of wild stocks on one hand and enhanced as well as reared stocks on the other, with the aim of evaluating an existing policy for the Icelandic situation.

Managers have, in the past, been accused of a rather indifferent attitude towards genetic resource management. This is to some extent due to the rapid accumulation of genetic knowledge and its inaccessibility to those engaged in planning and management activities (Riggs 1990). The managers do not have time to read and evaluate original papers written for specialists in various disciplines of genetic science. Furthermore, much of the information and technology relevant to these problems is transmitted through the "grey literature" or by word of mouth. With mounting evidence, however, many managers chose to take a conservative approach, appreciating the fact that lost genetic diversity can not be recovered.

II. Factors Affecting Genetic Resources

All environmental changes as well as developmental and management activities affect genetic resources of salmon. It is well known that acid rain has wiped out numerous populations of salmonids in North America and Europe. Numerous dams on the Columbia river have eliminated several populations of salmon and certainly affected genetic diversity of many others by exposing the populations to entirely new sets of environmental conditions (Riggs 1990).

Small stocks being harvested in a mixed stock fisheries are often in danger of being overexploited with the risk of losing genetic diversity. Similarly, all stocks in such fisheries can be genetically affected by selective fishing practices such as removal of larger fish through regulated mesh sizes or removal of a certain run component through regulated fishing periods. This has been a major problem in many salmon fisheries.

One can theorize that enhancement activities could affect genetic makeup of salmon populations in several ways. Construction of fishways can eliminate a natural barrier, beyond which the native salmon population has not been able to navigate for thousands of years. The river area above the obstruction, especially if it is extensive, may impose entirely new sets of environmental conditions, to which the original stock must adapt. Salmon fry or parr of local origin released in the upper reaches may need somewhat different genetic characteristics in their new habitat than they were adapted to on the lower river. A genetic change would thus be expected to take place over many generations and the stock might in fact be more like a non-indigenous stock from the up-river reaches of another stream.

I put this example forth to demonstrate the complex nature of the problem that we are dealing with in enhancement and it is safe to say that if we want to be absolutely sure that we are not imposing changes in salmon populations we should refrain from enhancement. This , however, is not warranted if we consider the benefit of numerous fish passes built in the last 50 years.

As mentioned previously, salmon culture and ranching activities can affect wild populations through straying in several ways, both through introductions of non-adaptive gene complexes as well as transfer of diseases and parasites. This paper focuses on these problems, especially with respect to possible solutions and avenues to ameliorate the effects from extensive ranching programs.

III. Genetic Principles

Before going into further discussion, it is probably useful to discuss some of the basic principles involved in implementing genetic changes and some terminology used in the field of genetics. Exhaustive review is not intended and further details can be found in various genetic manuals such as" Genetic Guidelines for Fisheries Management"(Kapuscinski and Jacobson 1987).

Genotype vs. Phenotype

The genotype is the set of genetic material in the genes of an organism which determines how it reacts to different environmental conditions. The phenotype, on the other hand, is the expression of the genotype in a particular environmental setting. It can be morphological (e.g. size), biochemical or behavioral.

It appears that fish are, in many cases, more variable in phenotype than other vertebrates as can be seen in the difference in growth rate and body size observed within as well as between populations of the same species (Allendorf et al., 1987). Normal and dwarf populations of arctic char are a good example.

Large phenotypic variation is not necessarily associated with greater genetic variability. In many cases, the heritabilities for body length and weight are fairly low and indicate that these characters respond easily to environmental variability (Bentsen 1989).

Genetic Variability

Salmon populations need to have adequate genetic variability to be able to cope with the various factors affecting their existence. Genetic variability is thus the raw material that allows the populations to adapt to the environment (Davis et al 1989). It has been postulated that loss of genetic variation will result in loss of fitness, which, however, will depend on, whether the genetic characters lost are necessary for survival. Similarly gain in genetic variation may or may not improve fitness.

Natural Selection

Adaptation of the organism to its habitat happens through natural selection. The genetic changes caused by natural selection are estimated in the terms of "fitness" of a certain genotype (Hershberger 1990). This fitness in genetic sense, however, only applies to reproductive success.

In nature, the phenotype expressed (appearance, functions, etc.) is usually a compromise expression of many traits important for maximum survival. These might properly be called "normal" traits which are suitable for the habitat in question (Hershberger 1990). The changes caused by natural selection are very difficult to assess in magnitude (Hershberger 1988). This is in contrast to artificial selection, which usually leads to large changes in relatively few measurable traits (size, fecundity, etc.) in a short time.

Genetic differences between stocks will evolve if there is little or no gene flow between them. The amount of gene flow needed to prevent divergence depends on the strength of the forces shaping differentiation of subpopulations. These forces are natural selection, genetic drift and mutation (Chakraborty and Leimar 1987). Selection pressures from the environment result in adaption to the local conditions. If, however, the environmental conditions are similar, genetic drift may be a leading factor in differentiation if population sizes are small. Mutation, on the other hand, is a relatively rare event and is probably not a major force in intraspecific differentiation (Chakraborty and Leimar 1987).

Accidental reductions of wild populations to a very low level of spawners can result in genetic drift. This means that there is a reduction in genetic variation similar to the one observed during inbreeding. This can only be increased by migration from other populations (Bentsen 1989).

If inbred populations or those which have diverged by genetic drift are crossed, they might be expected to show hybrid vigor (heterosis). This process is common in agricultural crops, but has never been demonstrated in reared or natural fish populations (Hershberger pers. comm).

Capricious Mortality

It is important to recognize that the environment of salmon populations is very complex and encompasses both freshwater and marine habitat. Both environments go through drastic short and long term environmental variations. Most salmon populations can adapt to a wide variety of environmental conditions. It is accepted that much mortality in salmon populations is related to chance rather than genetic selection. Thus, many juveniles may perish in a flood purely by chance, irrespective of their genetic abilities to survive in the stream, as they happen to be in a certain section of the stream during a flood. This, in general, is true of animals, which produce a great excess of progeny of which only a few live to produce offspring.

Genetic Divergence

It is usually assumed that wild stocks are in genetic equilibrium meaning that the gene frequencies remain relatively stable in relatively isolated salmon populations, which do not interbreed with other populations to any great extent.

If the populations are truly isolated and not interbreeding with other populations, the result will be a great diversity in genetic characters among the salmon stocks, which are adapted to many different types of environments.

It should be pointed out that, in the absence of divergent selection, small amount of migration between stocks can arrest differentiation. It is estimated that one migrant per generation between populations would almost prevent differentiation into subgroups. As migration between neighboring salmon populations frequently exceeds that number, an extensive differentiation among those populations is not to be expected (Gall 1987).

It is usually presumed that the differences between stocks increase with increased geographical distance, which could be used as a guiding stick in stock transplants. This, however, may not be true if the adjacent streams are very different in character, e.g., length or water flow.

Co-adaption of Genes

Many geneticists believe that phenotype is determined by complex gene-gene and gene-environment interactions. If this is true, adaption and fitness potential will also depend on such gene interactions. This system of genetic selection has been called "co-adapted genomes" (Shields 1982).

This theory assumes that different co-adapted genomes can evolve independently in response to similar environmental conditions, if the populations have been spatially and genetically isolated. Transplants between those populations, even if they are living in a similar environment, could thus result in outbreeding depression, i.e., reduced fitness, as the progeny have non-compatible sets of interacting alleles (Gharrett 1990). The intensity of the outbreeding depression would be proportional to the initial difference between the stocks in adaptive traits. It would clearly also be affected by distance between the streams, migration routes and any barriers which might have precluded gene flow over a long time.

If this kind of a system has evolved through natural selection, it can have serious consequences to disturb the complex genetic make-up through hybridization with other stocks, e.g., in salmonids. The resulting population certainly contains all the alleles (gene pairs) of the parent populations, but the probability of the original parental genotype can be extremely low. Thus, although the original genes are present in the hybrid population, the fitness of the parent populations is essentially lost (Hindar et al., 1991).

IV. Separation of stocks

It has been known for a long time that there can be behavioral and physiological differences between salmon stocks in complex river systems, which require that they be managed individually. Brannon (1972) found differential orientation of sockeye smolts migrating through lakes on the Fraser river system which probably were genetically determined. Returning sockeye stocks in the Fraser River system, which had a great variation in migration distance, were found to have innate fat reserves corresponding to the distance that they had to migrate to the spawning grounds (Idler and Clemens 1959). Differences between less complex river systems have been more difficult to demonstrate by quantitative means.

Electrophoresis of various proteins has been developed as a method for stock identification and has demonstrated that some species of salmonids with relatively high proportion of polymorphic loci are organized into discrete stocks (Utter et al. 1987). To be useful in stock separation such markers need to be neutral with respect to survival traits and very constant within the population in question. As a result it is very difficult to interpret observed differences as incompatability of the stocks concerned to live in similar or same habitat.

These methods have proved to be less useful to discriminate between stocks, which are known to be highly specialized than between more homogeneous populations. It has thus been impossible to discriminate clearly on the basis of population genetics data between Asian and American populations of sockeye salmon (O. nerka) a species known to be highly diverse in life history traits (Altukhov et al. 1987). It is also very difficult to differentiate Fraser river sockeye by electrophoretic means (Woodey, pers. comm.). Intrapopulation heterogeneity is, on the other hand, considered to be particularly strong in sockeye salmon, almost parallelling ecological differentiation (Altukhov et al. 1987).

Pink salmon, on the other hand, known to be least specialized and most homogeneous of all the Pacific species, in some cases show a fairly clear electrophoretic difference between continents and geographical areas (Altukhov 1987). Gharrett, et. al (1988) surveying even year runs of pink salmon (O. gorbuscha) electrophoretically found no significant genetic heterogeneity among populations from the Aleutians and areas north of Bristol Bay as well as some Asian populations. Pink salmon from Kodiak island, on the other hand were significantly different. The authors were intrigued by the homogeneity of the Aleutian populations which were sampled over a 1,000 kilometer distance. It was suggested that this homogeneity was primarily maintained by strays over the entire range.

Other authors report that they have been able to differentiate between odd- and even-year runs of pink salmon in the same river but not found differences between geographical areas in the same year (Aspinwall 1974).

Chinook salmon (O. tshawytscha) are routinely separated in mixed stock fisheries on the basis of electrophoretic data (Utter, et. al 1980). These populations have been analyzed over the entire range from California to the Bering sea. Gharrett, et. al (1987), studying genetic relationships of chinooks in Alaska, found that stocks in western Alaska were generally quite similar to each other but quite distinct from the populations in southeastern Alaska. Those populations in turn were intermediate between the populations of western Alaska and those from British Columbia and Washington. Separation of chinooks in the north and the south during the last ice-age was theorized to be the prime reasons for the observed differences.

It has been reported that heterogeneity between neighboring stocks of chinook salmon is greatest in British Columbia and Southeastern Alaska -- areas most recently colonized after the last Pleistocene glaciation. It is noticeable that white-fleshed chinooks only occur in these areas, possibly as a result of "founder effect", when rivers were populated by very small numbers of fish (Hard, et. al 1989). Alternative explanations included adaption during early life history to local freshwater environments.

In most cases, individual stocks can not be separated by electrophoretic means alone. In one case, however, a successfully transplanted stocks of chum salmon could be distinguished, both by electrophoresis and run timing, from an indigenous population (Okazaki 1978), demonstrating the potential of these techniques.

Several authors have reported on genetic separation of Atlantic salmon, although such techniques have not been used for routine separation. In Ireland five reared lines were assayed for six polymorphic enzyme loci. The results showed that all reared lines differed significantly from each other in genetic composition, although four of the lines originated from the same Norwegian source. It was thus postulated that many subgroups of the farmed lines existed and the assays needed to be based on twice as many loci(Cross et al.).

As seen from the above information, the discrimination is rarely at the stock level and the reported differences do not necessarily relate logically to the observed or known differences between salmon populations. This has perplexed many managers, which have found a confusing array of information, which did not necessarily conform to accepted biological principles and knowledge.

These shortcomings have also been of great concern to the quantitative geneticist, who believes that stock differences should express themselves in phenotypic characters and be in some way demonstrable in quantitative, or at least qualitative terms. These differences of opinion have mostly been voiced in relation to the interactions of hatchery and reared stocks with various wild stocks (Bentsen 1989).

In spite of these drawbacks, electrophoresis has so far been the most practical method to detect differences between populations and is widely used. No differences can certainly not be interpreted as an indication of entirely homogenous populations genetically, but observed differences between stocks or groups of stocks can be useful in policy making regarding enhancement and various aquaculture activities.

Procedures for examining the genes directly through sequencing of nucleotides in nuclear genes are being developed and will certainly give more detailed information on genetic variation. Knox and Verspoor used mitochondrial DNA techniques to try to distinguish between farmed Norwegian and wild Atlantic salmon in Scotland. The results suggested that most of the mitochondrial DNA lineages, predominating in Scottish and Norwegian populations, were likely to be shared by the two groups. The authors, however, identified a single genetic variant unique to the Norwegian fish tested, which could have potential as a genetic marker(Knox et al. 1991).

Similarly Davidson et al.(1990) identified a genetic marker that could potentially be used to designate individual Atlantic salmon to either the European or North American continent. This method has high practical implications and is being extended to include salmon over its entire range.

V.Genetic Concerns

There is a great variety of interactions taking place between salmon populations through enhancement and aquaculture activities. Wilkins (1981) designed three categories within aquaculture depending on human intervention in the life cycle of organisms, i.e., precultivation, cultivation and postcultivation phases. The same scheme was adapted for salmonids by Hershberger (1989).

In the first category, "pre-cultivation phase" the organisms concerned are naturally reproducing and being minimally affected by propagation. Most populations being enhanced by habitat improvement would be included in this category. In the cultivation phase, the populations are partly or entirely artificially propagated or even reared. The post-cultivation phase assumes that the animals are entirely in captivity and culture techniques are quite sophisticated, equating those used in agriculture. The following types of interactions with wild stocks can be identified within these main groups:

Precultivation Phase

1. Habitat improvement, management practices

Cultivation Phase

1. Enhancement with wild stocks indigenous or non-indigenous origin

   -Natural broodstock-

2. Enhancement with hatchery stock of indigenous or non-indigenous origin

   -Artificial broodstock-

3. Ocean ranching with special ranched stocks(possibly genetically manipulated)

   -Artificial broodstock-

Postcultivation Phase

1. Reared stocks of local or distant origin (genetically manipulated)
   -Artificial broodstock-

2. Reared stocks of foreign origin (genetically manipulated)
   -Artificial broodstock-

It should be pointed out that these groupings are a simplification of a very complex set of interactions and in many cases there would be an overlap between categories. There is furthermore a progressive alienation from wild stocks as one progresses from one phase to the next. It was considered important to distinguish clearly between enhanced stocks on one hand and reared stocks on the other. Enhanced stocks, normally, live only a part of their life in hatcheries, but must fend for themselves in nature through part of the freshwater and all of the marine cycle. The same is true for ranched stocks. Reared stocks, on the other hand, never leave a rearing facility, are often genetically manipulated and sometimes selected for a number of generations. All the groups, however, may be closely or distantly related to the affected wild stock, making overall genetic effects dependent on relative impacts of genetic manipulation effects versus stock origin.

Each one of those interactions will now be discussed highlighting areas, where the respective interactions are considered to be of great concern and some evidence from the literature on possible effects. An exhaustive review of the literature, however, is not intended.

A. Precultivation Phase (no juvenile releases)

This category only includes management and enhancement practices, such as habitat improvement, fishway construction and fishery regulations and do not involve juvenile releases. It is clear that some of those practices can affect genetics of salmon populations but are largely beyond the scope of this paper.

B. Cultivation Phase (enhancement with smolt and fry/ranching)

1. Non-indigenous and indigenous wild stocks

Enhancement efforts have in the past often been conducted with eggs fry or smolts of wild parentage, irrespective of origin. It was, in other words, assumed that each wild salmon stock would have the capabilities to adapt to most other salmon streams within a certain area or country. With increased knowledge on fish genetics and disease transmissions, many managers have started using local stocks for enhancement. This is, however, only possible, where wild stocks are in a fairly healthy state allowing a considerable surplus for egg take. The salmon enhancement in Iceland is a prime example of this.

Artificial spawning of surplus wild salmon has been practiced in Iceland up to the present time, both for enhancement and rearing. Reared broodstock have only recently become available in great quantities. Although non-indigenous stocks were planted into many Icelandic streams until the early 1980's, there is no evidence of harmful effects and some releases into streams with small salmon populations have been a substantial success. As previously noted, it seems unlikely that these enhancement efforts resulted in a major genetic change in the wild populations as they were not very massive and not carried out on a regular basis in most salmon streams.

In Iceland, there are a number of enhancement projects using hatchery reared fry and smolts of indigenous origin from wild parents. Most of the fry are released in barren areas above impassable waterfalls, thus enlarging the rearing area of the streams. Due to the simple structure of the Icelandic salmon fisheries (absence of sea fisheries), results from these plantings have been relatively easy to document. Considerable contributions to the local river fishery have been noted and these activities have in some cases provided a considerable safety margin in years of low salmon abundance. In other instances, hatchery fry from the local wild stock have been planted into the main section of the streams, if electric fishing surveys on the streams have indicated a serious lack of naturally produced fry. Considerable benefit has sometimes accrued, although numerous failures have also been documented from unknown causes. Smolt releases from wild indigenous parent have also been practiced with variable results. The Icelandic experience has shown great differences in survival of fry and smolts depending on the quality of the fish and the hatchery of origin, casting serious doubts on some of the current hatching and rearing practices.

In 1988, a regulatory measure was enacted in Iceland which made it mandatory to use local salmon stocks for enhancement. It also contained provisions regarding the proximity of salmon pens to major salmon streams. Salmon from these pens have escaped in large numbers and migrated into nearby streams (Gudjonsson 1990). The origin of those stocks has been poorly documented. They have all been of Icelandic origin but from various salmon streams. Interactions are being documented.

What are the effects of mixing two wild salmon populations adapted to different habitats. Hindar et al(1991) consider the theoretical outcome when two wild salmon populations, each fixed for different gene combinations at ten loci (locations on a chromosome), interbreed. They concluded that although the hybrid population contained all the gene combinations of the parent populations, the exact parental genotypes would be occurring with less than 0.001 probability. Thus the individuality of the parent populations would essentially be lost. This case, of course, assumes that the stocks were entirely separated and had evolved separate co-adapted gene complexes.

There seem to be instances, where introductions of non-indigenous stocks have displaced the original population, such as in the case of the introductions of chum salmon from the Kalinka to the Naiba River on Sakhalin Island, which drastically reduced the total returns to the Naiba river over a 12 year period (Altukhov 1981). Other examples of displacement are not well documented, whereas the literature abounds with examples of unsuccessful transplants and introductions of exotic species.

From the above, one must conclude that wild populations should, whenever possible, be enhanced with the local stock, taking eggs from non-selected wild parents. If wild stocks are not available, one is faced with the decision whether to use a hatchery stock originating from the same stream or a wild population from a nearby stream. Very little information is available regarding this subject which must be based on the genetic likeness of the stocks in question. It seems likely that a properly managed hatchery stock of indigenous origin would be more suitable than a non-indigenous wild stock (Hershberger personal communication).

2. Hatchery stocks of indigenous or non-indigenous origin

It seems likely that enhancement efforts with non-indigenous progeny of wild stocks have been carried out in various salmon producing countries in the past, but the state of wild populations in the last few decades have not permitted egg take on the spawning grounds. Most agencies have thus relied on egg take from hatchery populations, which is discussed in this section.

The interaction of wild stocks with hatchery (enhanced) stocks of indigenous origin is probably the most common interaction in modern salmon culture. Numerous stocks of Pacific and Atlantic salmon are enhanced by the use of hatcheries and smolt stations which use returning hatchery fish as brood stock. These are therefore ranched populations of salmon which spend all of their freshwater life in rearing facilities. Most of the salmon return to the hatchery which usually is located within the watershed being enhanced, but numerous salmon stray to the spawning grounds and interbreed with the wild population. Numerous chinook and coho hatcheries on the Columbia river fall in this category. The first part of the discussion deals primarily with enhancement using hatchery stocks from the same watershed (indigenous).

Releases of indigenous hatchery stocks have been under great scrutiny and criticism in the Columbia river basin where 79 hatcheries are currently releasing over 200 million smolts per year and contributing over 50% of the annual harvest from the river (Hershberger 1990). Looking at those figures, it is difficult to imagine a sizeable fishery on that stream without hatchery contributions. It has been estimated that an unknown portion of the genetic resources on the Columbia river have been lost due to variety of causes. The total number of stocks contributing to production have been reduced by over-fishing, passage restrictions and habitat loss (Riggs 1990). Over-fishing and enhancement efforts may also have led to loss of genetic diversity by the use of relatively few fish for broodstock. Hatchery practices may have shifted within population diversities e.g., for run-timing and age at maturation in some of the species (Riggs 1990).

There is ample literature demonstrating the hazards of a large hatchery system for small natural populations. These are only partly of genetic origin. The main interactions are the following (Reisenbichler and McIntyre 1986):

1. Competition between hatchery and wild fish (during seaward migration).

2. Predation by hatchery fish on wild fish.

3. Harvest of both types in a mixed stock fishery.

4. Interbreeding of the two groups in natural spawning areas

5. Transmission of diseases from hatchery to wild fish.

It is well documented that artificial selection for early spawning occurs at many hatcheries in the Pacific Northwest. Very often eggs are not taken from salmon that mature late, as the capacity of the hatchery has already been reached. Inbreeding can also be a problem if too few spawners are used for broodstock (Reisenbichler and McIntyre 1986).

A number of studies have shown hatchery salmon to be less competent in the natural environment although they often outnumber wild spawners. Chilcote et. al (1986) thus showed hatchery steelhead to be only 30% as effective in producing smolt offspring as wild parents. Reisenbichler and McIntyre (1977) showed that hatchery steelhead fry had inferior survival and growth rate in the stream environment than the progeny of pure wild parents. The hatchery fish were only two generations removed from the wild population. Reisenbichler (1983) suggests that planting of fry from hatchery stocks into streams affects the naturally spawning population by increasing density dependent mortality and by causing undesirable genetic changes. He suggests that outplanting (stocking) should be avoided or at least used conservatively by restricting the number of fry planted and ensuring that the hatchery fish are genetically similar to the wild population, presumably by using indigenous wild stock.

In Ireland, Browne (1988) questions the benefit of restocking programs on various salmon rivers -- some of which were from indigenous stocks. He agrees that it is possible to start and maintain a run of salmon from a hatchery as long as you keep releasing smolts (ranching program), but the benefit to the total productivity of the river in question remains in doubt.

Much of the previous discussion holds also for the enhancement activity, where hatchery stocks of distant origin are being used with the added assumption that a hatchery stock of distant origin is genetically further removed from the wild population in question and thus less desirable in an enhancement project. Some consideration must, however, be given to the genetic aspects of each stock, such as genetic variation, population diversities and possible inbreeding depression, which in some cases might override the question of origin.

3. Ranched Stocks

This case is very similar to the interactions of wild and hatchery stocks with the exception that in this case we can assume that the ranched stock is being purposefully domesticated and manipulated during the freshwater phase by the commercial rancher. This would be particularly true for ranching of Atlantic salmon, which have to be reared for a considerable time before release. Such manipulation would be impractical in the massive ranching operations with pink and chum in the Pacific, but in all cases such characteristics as size-at-return and time of return and maturity could be tampered with, on purpose or inadvertently. In Iceland experiments have demonstrated a possibility of selecting ranched stocks for return rates and size at return(Jonasson 1991). Considerable genetic changes could be expected in such stocks although every precaution would be taken to maintain genetic diversity. It seems therefore likely that genetic separation of ranched stocks from wild ancestors would be greater than for most hatchery stocks, at least those of indigenous origin.

At the moment, the concerns regarding the interactions of wild stocks and commercially ranched stocks seem to be limited to Oregon, where commercial ranching of Pacific salmon has been permitted; Alaska, where non-profit ranching is conducted and Iceland, where commercial ranching of Atlantic salmon is growing rapidly. Various European countries are also looking at salmon ranching as a viable production method. Japan has some of the most successful ranching operations in the world, but is facing serious setbacks in its natural salmon populations.

The largest private commercial salmon ranching operation in the world was established by the Weyerhauser Corporation in the State of Oregon in the late 1970's. These operations released large quantities of chum, coho and chinook salmon (Oncorhynchus sp.) in Yaquina and Coos Bays. Several other smaller operations were established.

Salmon ranching in Oregon met considerable opposition, primarily from the salmon fishing industry, which visualized a strong competitor on the salmon markets and feared that once established the ranching operations would try to eliminate mixed stock fisheries (Berg 1981). Some straying of adults and smolts into nearby rivers was observed and some ecological effects documented (ODFW Staff report 1987). In 1988, an assessment was carried out by Mayo Associates of Seattle to provide a history of private salmon ranching in Oregon, discuss issues of special concern and the viability of the industry, with special emphasis on factors that might influence future options for Oregon's private ocean ranching. In the report, the views of the Oregon Department of Fisheries on salmon ranching are summarized as follows (Mayo 1988):

> "Salmon ranching is a complex proposition that affects coastal and fishery resources and may potentially affect commercial and recreational salmon fishing in unknown ways. The number of regulations, which surround ocean ranching, in large measure, reflects public concern about the values and resources, which are potentially affected. These are legitimate and important public concerns".

Most managers working with ocean ranching are probably faced with similar concerns shaped by local politics and management structure. The biological issues surrounding private salmon ranching in Oregon primarily involved river and ocean carrying capacities as well as genetic concerns due to strays. In the assessment, the authors concluded that release strategies had eliminated much of the concerns regarding river carrying capacities of smolts. Concerns regarding ocean carrying capacity were considered small except at maximum levels of release (Mayo 1988).

The assessment concluded that the genetic implications of ranching could only be seen dimly in the short term. There was general agreement that the genetic implications of mixed stock harvest management were more profound than those steming from private or public hatcheries. The general feeling was that genetic interaction with wild stocks would be less from ranched salmon released into the sea than from hatchery salmon released from river-based facilities (Mayo 1988).

In order to exercise a conservative approach, it seems likely that the only way to reduce the effects of large scale ranching operations is to minimize straying of ranched fish to natural river systems. This can be done by spatial separation, i.e., ranching free zones around salmon streams. This means that salmon streams must be ranked in an order of economic, ecological and aesthetic importance. This is probably the most difficult task as some of these terms tend to be differently interpreted by authorities and those utilizing the stream.

Although not directly relevant to this section, it should be pointed out that strays of fish farm escapees into ranching stations can be of real concern to the salmon rancher that wants to work with a relatively pure strain, which he has adapted to the local conditions, possibly over a number of years. This demonstrates the complexity of the issues to be dealt with in a genetic policy.

C. Postcultivation Phase (Salmon rearing)

1. Impacts of Reared Stocks of Common or Distant Origin

The great increase in the mariculture of Atlantic salmon in various European countries has aroused concerns regarding increased incidences of salmon, escaping from cages, in salmon rivers of several countries. These problems are most severe in Norway, which leads in the production of farmed salmon, with 1989 production in excess of 100 thousand metric tons. In 1988, approxi- mately 26% of the spawners in Norwegian rivers were of farmed origin (Moen et. al 1989). This problem has been confounded by intense inshore drift-net fisheries on the Norwegian salmon stocks and the weakening of several stocks through infections from the parasite Gyrodactylus, which probably was introduced with hatchery smolts from the Baltic in the 1970's (Hansen et. al 1989). A great reduction in the drift-net fisheries in 1989 was considered an important step in ameliorating this serious situation.

There are increased incidences of reared fish in other countries with large salmon rearing activities such as Ireland, Iceland and Scotland, although these problems tend to be more local in those countries and a lot less intense than in the Norwegian situation. Due to its extremity, the Norwegian case is being intensively monitored and studied and hotly debated in scientific circles. It is the primus motor for several conferences held in recent years on fish genetics and management. This case, being very instructive, will be briefly reviewed here.

There are subtle differences between hatchery stocks being used in enhancement activities and genetically manipulated stocks of modern salmon farming. Originally various wild stocks were cultured in the Norwegian mariculture programs, mostly local strains, but sometimes imported from other countries such as Scotland, Iceland, Sweden and Finland. These importations have resulted in the introduction of both parasites (Gyrodactylus) and pathogenic bacteria (Furunculosis), but it seems unlikely that these importations were massive or regular enough to impact Norwegian salmon stocks genetically. In the early 1970's, the Norwegian Aquaculture Research Institute (Akvaforsk) started a selective breeding program at the breeding station at Sunndalsöra. Brood fish were collected from over 40 Norwegian salmon streams for 4 years in a row until reared brood fish were available (Bentsen 1989). Genetic selection has now been ongoing for almost 20 years and brood stocks from selectively bred stocks are now kept at the Norwegian Fish Farmers breeding station at Kyrkesæteröra. It is estimated that 90-95% of the Norwegian salmon production stems from those stocks.

From the foregoing, it seems clear that most of the Norwegian wild salmon are exposed to genetic pressures from relatively distant stocks, in terms of local adaption. Most of the reared salmon are, however, of Norwegian origin but molded to fit the purposes of the fish farmers.

The impact of interbreeding with wild stocks must thus depend on the number of irreversible changes that have taken place as a result of the breeding program as well as the genetic diversity of the original 40 stocks used in the breeding program and their progeny's current ability to adapt to the diverse conditions in Norwegian rivers.

Hindar et. al. (1991) are very concerned about the genetic interbreeding of the wild Norwegian populations and the farmed fish. They admit that nothing is known about the genetic characteristics of either population with respect to selective forces acting upon the populations as well as the number of genes, their function and interactions. The data available through electrophoresis largely reflects characteristics, that are not strongly subjected to the forces of natural selection. They, however, theorize that if genetic characteristics of traits affected by selection could be measured, they would demonstrate higher differentiation than the molecular data available today. A valid viewpoint, but certainly not shared by all experts in the field of genetics.

Bentsen (1989) looking at this problem from a quantitative geneticist's viewpoint pointed out that, when the original 40 river stocks used in the Norwegian selection program were reared in the same environment, it turned out that only 4% of the genetic variation in freshwater growth and 8% of the variation in sea-water growth was linked to the stock used. The rest of the variation (90%+) was between individuals within stocks. He also pointed out that crossing of the different wild stocks did not cause hybrid vigor (heterosis), which would indicate that the crosses were similarly heterozygotic as the original wild stocks. He concluded that since the breeding program does not change the genetic variation within the reared population, the effects of interbreeding with wild stocks could not be more severe than the effects of strays from other wild populations. It is also interesting to note that outbreeding depression has never been reported in the progeny of these crosses, indicating that the stocks were not highly diverged. Unfortunately, however, there have been few opportunities to follow this performance through the F2 generation, where problems might also occur.

In addition to genetic effects, reared salmon can have other undesirable effects on wild populations. Experience has shown that great quantities of reared salmon can escape during a short time. During the winter of 1988-89, some 1200 tons of salmon escaped from Norwegian mariculture operations, a quantity comparable to the total Norwegian catch of wild salmon. Although some evidence shows that the survival of those fish is highly dependent on the time of escape (Hansen et al.1991), it has been observed in various countries that large quantities of reared salmon may ascend estuaries and rivers during the spring and summer (Moen et al. 1989, Gudjonsson 1991). Effects of those aggregations may be both of competitive and predatory nature. Introductions of pathogens have already been mentioned, some of which have a clear genetic basis, as the affected populations do not have an innate resistance to the pathogen, which may be relatively harmless to salmon populations in their home environment.

Although there is little concrete information on the genetic effects from interbreeding of reared and wild salmon stocks, it does not seem prudent to wait for solid evidence without taking precautionary measures. A great deal of research is needed; but by the time we have the information in hand, it may be too late to take appropriate steps, as lost vital genetic characteristics are difficult or in some cases impossible to replace.

2. Impacts of Reared Stocks of Foreign Origin

There are numerous instances, where stocks have been transported between continents and countries for aquaculture purposes. Smolt shortage was a chronic problem in the early years of Norwegian salmon culture and smolts were imported from Sweden, Finland, Scotland and Iceland (Isaksson 1991). In the late 1980's smolt production in Norway reached satisfactory levels eliminating imports. Eggs of Norwegian domesticated stocks have, on the other hand, been imported to various countries, including Faroes, Scotland, Ireland, Iceland and western United States and Canada.

It is logical to assume that wild or reared foreign stock are more genetically separated from wild stocks in a country than reared or wild stocks of that country. The amount of difference probably depends primarily on geographical separation. Staahl (1987), summarizing electrophoretic data, reported a great genetic difference between Atlantic salmon stocks from the continents of North America and Europe. Within Europe, he found two separate clusters -- one representing the Baltic and another in the Eastern Atlantic. Even a further breakdown of Eastern Atlantic populations into Boreal (northern) and Celtic (southern) races has been suggested (Payne et al. 1971).

There have been serious incidences connected with transportation of stocks between countries, primarily with respect to disease and parasite resistance, which seem to be largely genetically determined through adaption. The salmon fluke, Gyrodactylus salaris, which probably was imported into Norway with salmon smolts from the Baltic in the 1970's has seriously reduced wild salmon populations in numerous Norwegian salmon streams (Hansen et al. 1989). Similar innate differences in susceptibility between salmon populations have been noted in chinook and coho salmon (Oncorhynchus sp.) with respect to the myxosporean parasite Ceratomixa shasta (Hemmingsen et al. 1986).

These cases are very tangible evidence regarding the adaption of salmon stocks to very specific aspects of their habitat and demonstrate the danger of transporting live material between drastically different ecosystems, whether it be within or between countries and continents. It is interesting to note that in the Norwegian case the Gyrodactylus parasite was transported into a new ecosystem where the salmon stocks could not tolerate it presence. It is, however, safe to assume that Norwegian salmon stocks transplanted into the Baltic regions would similarly have been wiped out by the parasite in its native area. This might partly explain why so many transplants of stocks have been an ecological as well as economic failure.

Many countries have strict laws regarding importation of live material -- in many cases primarily from a disease standpoint. The importation of disinfected salmon eggs is thus in some cases allowed, whereas importation of smolts is in many cases prohibited. As previously pointed out, there have been imports of fry and smolts to various European countries such as Norway and Ireland. Imports of Norwegian salmon eggs have been permitted to most European countries involved in salmon culture. Most of the stocks are in current use in pen-rearing and the countries are thus faced with possible genetic effects from foreign-origin salmon stocks. A recent regulatory measure in Iceland has limited the use of Norwegian stocks to freshwater and land-based rearing.

Atlantic salmon are used as an introduced species for salmon farming in various parts of the world, primarily in British Columbia, Canada, Washington, United States and in Chile. There are concerns regarding ecological interactions of the species with various Pacific salmon. A rather unique situation has evolved in Alaska, which recently enacted a permanent ban on any farming of finfish including salmon (Alaska State Legislature 1990). The reasons cited were concerns regarding the well being of Alaska's natural salmon stocks as well as pollution from farming activity. This excludes fish farming activity from some of the best natural conditions along the west coast of America. Ranching of Pacific salmon is, however, permitted under the new law.

VI. International meetings and recommendations

The potential dangers of transferring organisms between watersheds and countries has been realized by many international bodies for a long time with a primary emphasis on fish diseases. Genetic threats relatively recently gotten attention, primarily due to the phenomenal increase in the rearing of Atlantic salmon, which has created environmental problems in some countries.

The International Council for Exploration of the Sea(ICES) and the European Inland Fisheries Commission(EIFAC) are both concerned with impacts of aquaculture on the environment and have both established Working groups to consider adverse effects of introductions and transfers of aquatic organisms.

Both ICES and EIFAC have adopted codes of practice to reduce the adverse effects arising from the introductions or transfer of freshwater and marine organisms. In addition to these codes, which primarily deal with preventive measures regarding diseases and parasites, ICES has published more detailed procedures to be used to assess apriori possible effects and benefits of an introduction (Turner 1988). There are basically three different categories considered in the report:

1. Introductions or transfers of new species for commercial purposes

2. Introductions of new breeds or stocks of species in current commercial use

3. Introductions solely for scientific studies in research institutions

The protocols dealing with new species are most elaborate and try to deal with ecological as well as genetic consequences of introductions. It is pointed out that ecological consequences of such introductions are almost impossible to predict and, if negative impacts occur, it is practically impossible to eradicate the new species. The protocols make no distinction between introductions intended for release into the wild and those intended for enclosed rearing as escape is assumed inevitable.

The transfer of Atlantic salmon between countries and continents falls, in most cases, under the second heading above. These protocols deal primarily with the disease aspect of introductions and there is limited coverage of ecological and genetic interactions of salmon populations.

In 1988 EIFAC held a technical consultation meeting in London, England on genetic broodstock management and breeding practices. The conclusions ot this meeting are very important as failures of many enhancement and aquaculture programs have been blamed on improper breeding practices. The meeting made a series of recommendations directed at various organizations and interest groups. The main recommendations on broodstock management were as follows (FAO 1988):

1. Maintain and, wherever possible, reinforce local populations in natural ecosystems. Population number and population size must be preserved to safeguard the genetic resources for future needs.

2. Optimize effective populations size, the size of which depends on the production goal, i.e. whether the fish are for enhancement or aquaculture.

3. Whenever possible assess the source and history of a broodstock and keep records of the origin of the stock.

4. When establishing a broodstock, use as many parental fish as possible from practical and economic standpoints.

5. When establishing a brood stock, use random mating of parents and use one male per female. This, in combination with use of many breeding fish, minimizes inbreeding.

6. Monitor the success of the management program by assessing the genetic structure of the broodstock population by employing electrophoretic techniques. For this purpose an initial characterization of the broodstock when it is first created is quite important.

The meeting also made some general recommendation on management of natural populations:

1. When collecting wild broodstock, make sure that progeny are stocked in an environment similar to the one from which the broodstock was derived.

2. When stocking for natural reproduction, use local stock, because in the long run they are likely to be better adapted to the local environment than non-indigenous stocks.

3. If an endangered stock shows loss of fitness, introduce one individual from a nearby stock per generation to mimic natural rate of straying between populations.

4. Natural stocks with a mixed background, which appear balanced from a functional point of view, should be treated as pure stocks.

5. A broodstock used for producing fish for stocking into natural waters and with the principal aim of establishing natural reproduction, should be composed of at least 100 individuals.

6. The minimum value for a hatchery population used for enhancement of wild stocks is 100 individuals.

This discussion has only highlighted the conclusions and recommendations of the technical group, which were discussed in considerable detail in the report of the meeting.

The North Atlantic Salmon Organization(NASCO), having the state of wild Atlantic salmon stocks as its prime responsibility, has discussed the threats to salmon stocks from aquaculture at several of its annual meetings. It has drafted guidelines pertinent to the transfer of salmon stocks and established a data bank on the protocols and regulatory measures in effect in its member countries. In 1989 it sponsored a joint meeting with ICES on the "Genetic Threats to Wild Salmon" in Dublin, Ireland, where experts in various field presented their viewpoints on the possible effects of aquaculture on wild salmon stocks. Views ranged from those of no effect to serious impact (NASCO, CNL(89)19). Evidence was, however, presented that adverse effects were possible. Scientists agreed that there were considerable gaps in the knowledge regarding genetic impact of reared salmon on wild stocks and a great need for experimentation to assess the impact. Development of genetic markers was considered of prime importance to facilitate such research.

In 1990 the Norwegian Government, having increasing ecological problems linked to its soaring aquaculture production of Atlantic salmon, sponsored an international meeting in Loen, Norway to assess the interactions between cultured and wild Atlantic salmon. The meeting summarized knowledge and recommended research regarding occurrence and behaviour of reared salmon, their genetic as well as ecological impacts and methods of identification. It was concluded that there were gaps in the knowlege on the impacts of genetic, disease and environmental interactions between wild and farmed salmon. It was considered very important to do the appropriate research at national and international level, which , however, would be time consuming with no firm evidence for a number of years. The approach, therefore, should be precautionary, where one would assume that salmon culture was a real risk to native salmon until it would be proven that there was little or no risk (NASCO CNL(90)28).

In considering the gentic impacts on wild stocks the meeting concluded(NASCO CNL(90)28):

1. There are variations in various life history parameters between and within river populations, e.g. in morphology, migration patterns and developmental timing. Some of these are genetically controlled and need to be further clarified.

2. There is evidence that hatchery fish have reduced fitness in the wild. Breeding with wild stocks may thus be detrimental and one solution might be to develop sterile farming lines for cage culture. It is also very important to minimise genetic change in smolt production units, if the fish are intended for release into wild river systems.

3. There is empirical evidence that genetic changes have occurred in wild populations as a result of enhancement activities. Theoretical models suggest that massive intrusion of farmed fish into wild populations could do permanent damage in a few generations. These models, however, need to be tested experimentally, for further verification.

In May of 1990 a workshop was held at Sherkin Island Marine Station, which should look into the ecological and genetic effects of reared and stocked salmon on wild salmon stocks. The workshop identified a number of ecological concerns such as reduced growth in the wild due to releases of excessively high numbers, domination of larger hatchery fish over smaller wild counterparts, transmission of diseases into the wild and increased predation by other species as a response to high stocking numbers.

The workshop also identified the following genetic concerns in relation to rearing and stocking programs (Anon 1991):

1. The introduction(deliberately or accidentally) of new gene complexes into presumably locally adapted populations can alter the genetic composition of the native population in the short and long term until proper genes are reestablished through natural selection.

2. Introduction of hatchery fish, having low genetic variability, may through interbreeding lead to lowering of genetic variability in the wild population.

3. Introduction of selected farmed fish into the wild may through interbreeding have an adverse effect on the productivity and behaviour of the wild population, if the traits in question are genetically determined.

4. Introduction of genetically uniform salmon into differentiated wild populations may lead to undesirable genetic uniformity, with unknown consequences for migration and spawning behaviour.

The workshops general recommendation was that more effort was needed to establish inventories regarding ecological, genetical and production characteristics of wild and farmed strains of salmon. Regarding escaped farmed salmon it was considered advisable to try to trap escapees in rivers to prevent spawning and their use in broodstock collection. The workshop in particular endorsed the establishment of gene banks for storage of endangered stocks and the development of sterile lines of salmon for sea cage culture. Use of local stocks in cage culture was advocated instead of using imported farmed strains and the use of surplus farmed salmon for stocking was discouraged as these will probably be the poorest genetical and ecological match for the wild populations. Ranching of salmon was generally endorsed, if it involved total harvest at return and no mixed stock fisheries.

Although not covered here, there have been recently additional conferences on genetic threats from aquaculture on the west coast of North America, dealing primarily with problems related to Pacific salmon.

VII.National Laws and Policies

The conclusions of the international workshops and meetings confirm that it is of utmost importance for most countries to enact conservative laws and regulatory measures to protect the Atlantic salmon resource from the potential dangers associated with undesirable transfers of salmonids as well as poorly managed aquaculture operations. It has also been advocated that individual countries should establish gene banks, where sperm from endangered wild stocks could be frozen for future use if the stocks in question become extinct. Such gene banks have been in operation in Norway and Iceland for a number of years, partly for storage of endangered stock and partly for storage of prime material in selective breeding experiments.

Various member countries of NASCO

NASCO has compiled and reviewed legislation relating to introductions and transfers of salmonids in its member countries (CNL(89)22) and suggested a code of practice to minimize the threat of aquaculture on wild stocks on salmon(NASCO CNL(89)23). Review of existing legislation shows that most of it is aimed at preventing the introduction of contagious fish diseases and other health related risks. Very few laws take genetic concerns into account, at least not in a comprehensive manner. In 1988 a regulatory measure was enacted in Iceland which was intended to reduce the impact of an expanding rearing and ranching industry on wild stocks. Norway, which has been leading in the cage rearing of salmon has also established aquaculture free zones off the mouths of 121 salmon rivers to minimize the impacts of salmon mariculture on salmon stocks in those rivers(Hutchinson pers. comm.).

In spite of the lack of proper legislation in many countries there has been considerable effort on the part of the scientific community to establish protocols for various countries, states and continents. In this section I will review some of these efforts as an example of comprehensive policies at the national level. The early part of the discussion will deal with Atlantic salmon management but an additional section will highlight genetic policies in Alaska and the Pacific Northwest of North America, where enhancement of Pacific salmon has been carried out since the turn of the century.

It should be borne in mind in the following discussion that national or state policies often reflect the ownership of the salmon resources in various countries. In north America the resources are publicly owned and any policy is entirely up to the politicians, managers and administrators of that state or country. Conservation measures are thus entirely dependent on how the public balances industrial and hydroelectric development against the benefits of a salmon resource. In these areas the aquaculture development has been more hampered by various water use and aesthetic grounds rather than genetical grounds.

In Europe the salmon resources are frequently owned by the river owners and generate considerable income through a net or sports fishery. Any policy formulated by the government must thus be approved by these interest groups, which normally would defend the interests of the salmon vigorously e.g. against industrial or aquaculture development.

North America

In 1986 a Bilateral Scientific Working Group was established within the North American Commission of NASCO. The group, which consisted of members from Canada and the US was requested to review and provide advice on existing and proposed introductions of salmonids to the Atlantic Seaboard of North America, especially with respect to the ICES revised Code of Practice. The group presented its first report in 1987(NAC (87)20), where it came to the conclusion that none of the benefits from transfers of young Atlantic salmon into Canadian waters outweighed the threats to native stocks and a timely definition of a policy was of high priority. The group further recommended that Atlantic salmon from Iceland and Europe should not be tranferred to the East coast of North America. Similarly no more transfers of Pacific salmon should be allowed west of the continental divide. Finally it was recommended that local origin stocks should be used for enhancement and aquaculture activity (NASCO NAC(87)20,Annex 13).

In 1989 the Bilateral Scientific Working group asked the US Fish and Wildlife Service to compile legislation concerning introductions and transfers of salmonids in North America. An exstensive document was presented at the 1990 meeting of NASCO, reviewing legislation in most States and Provinces on the Atlantic Seaboard (NAC(90) 13). In spite of this extensive review it was quite clear that most of the legislation was applicable to an array of species and was primarily concerned with disease regulation and in some cases pollution control. It also applied to individual States or Provinces and a overall genetic policy applicable to the continent or to the US and Canada individually was not available.

In 1989 the the Working group presented an expanded document to the North American Commission of NASCO (NAC(89)13), which elaborated on its previous findings. The document can be considered as a suggested protocol for aquaculture and enhancement activity within the Atlantic Seaboard of North America. The most important points are the following:

1. The eastern seaboard is devided into three zones ranging from pristine rivers in Labrador(Zone 1), minimally affected rivers in New Brunswick and Nova Scotia(Zone 2) to seriously affected rivers with exotic species mostly in the US(Zone 3).

2. Different management strategies are suggested for each zone in the following manner:

a) Rivers in zone 1 are basically protected from any influence of aquaculture and enhancement only permitted with local wild stocks and re-establishment only with genetic material from nearby watersheds with similar habitat. No commercial salmon ranching is permitted.

b) In zone 2 enhancement and aquaculture activities in fresh and salt water are permitted, but only with native(preferably local) species. Non-indigenous(distant) stocks can be reared in land-based facilities having minimal risk of escapement. Commercial salmon ranching is permitted if shown not to affect wild populations.

c) In zone 3 it was suggested that non-indigenous species could be used for enhancement and aquaculture activities and commercial ranching allowed if shown not to affect rehabilitation or enhancement programs aimed at restoring wild salmon stocks.

The working group finally concluded:" The importance for member countries(of the North American Commission) and their cooperating agencies to enact adequate laws to control introductions and transfers cannot be over emphasized. Present laws need to be modified and/or enacted to support implementation of the protocols in this document"(NAC(89)13).

Iceland

A regulatory measure was enacted in 1988, based on provisions in the Icelandic salmon and trout fishing act, No.76, 1970. The regulatory measure deals with the transfer and transport of wild salmon and their eggs and fry for stocking as well as the transport and release of reared and ranched stocks within Iceland. The measure was a compromise solution after considerable negotiations between river-owners, salmon farmers and the Directorate of Freshwater Fisheries. The main provisions were the following:

1. Transport of adult wild salmon was prohibited without the consent of fish disease authorities.

2. Transport of reared stocks between areas was permitted as long as it complied with disease regulations.

3. Enhancement of salmon rivers should be based on indigenous(local) stock, whereas enhancement of non-salmon streams should be based on nearby stocks from similar habitat.

4. Ranching stations were allowed to use recognized ranching stocks or wild stocks of nearby origin.

5. Iceland was devided into two zones, one comprising the south and west coasts and the other encompassing the north and east coasts, taking into account subtle differences in climate and oceanography. Enhancement and ranching efforts within these zones were required to use stocks from the respective zones.

6. Ranching operations were required to microtag 10% of their release, up to a 10 thousand smolt minimum for large releases.

7. Releases of salmon of ranched or reared origin for a put and take fishery were required to use local salmon stocks.

8. Provisions were made for rearing and ranching stations not to be closer than 5 km from salmon streams with an average sport catch in excess of 100 salmon and 15 km from streams with an average sport catch exceeding 500 salmon.

9. Tranfer of foreign stocks for enhancement or ranching is strictly forbidden and tranfer of such stocks for rearing is subject to approval by the Ministry of Agriculture.

In general one can say that the regulatory measure has provided a useful framework for managing Icelands salmon resources. In some respects a more stringent policy would have been desirable, but considering the various interest groups affected by such laws some compromising was necessary.

Alaska Genetic Policy

It is well known that Alaska is primarily dependent on wild salmon for its salmon production. In the early 1970s a system of public and private non-profit hatcheries was established in order to enhance the wild salmon populations, which had been returning in low numbers (Davis and Burkett 1989). It was never intended to replace wild populations with hatchery fish, but rather augment wild populations and try to reduce fishing pressures on wild systems.

A provisional genetic policy was developed as early as 1975 by the Alaska Department of Fish and Game. It was revised in 1978 and 1985. The background of the policy has been discussed in a recent publication of the Alaska Department of Fish and Game(Davis and Burkett 1989).

The Alaska genetic policy is a comprehensive document, containing both the Policy Statement and its justification. Only the main points can be highlighted here. It should be kept in mind that the statement is primarily a declaration of intent and does not have the power of a law or regulatory measure. It is, however, of considerable use for managers dealing with similar problems in their respective countries. Alaska has relatively pristine salmon populations and thus tends to approach these problems in a very conservative manner.

The Alaska policy statement deals with three main points, transport of stocks, protection of wild stocks and the maintenance of genetic variance. The main points are as follows(Davis et al 1985):

1. <u>Stock transport</u>

a) No imports of live salmonids or their eggs are allowed into Alaska, except for transboundary rivers.
b) Stocks must not be transported between the seven major geographic areas: The Southeast, Kodiak Island, Prince William Sound, Cook Inlet, Bristol bay, AYK and the Interior. It should be borne in mind that geographic areas in Alaska are very large, often matching the size of individual countries in Europe.
c) Transport within geographic areas shall be judged by the suitability of the donor stock to match goals set in a management plan.
d) No distance is set for transplants within a region but the preference of distant over local stocks must be justified in a stocking proposal.

2. <u>Protection of wild stocks</u>

a) Non-indigenous stocks must not be introduced to sites, where they may have significant impact on important or unique wild stocks.
b) Important or unique stocks must be identified on a regional and species basis in order to define non-sensitive areas for stocking.
c) A watershed with an important(significant) wild stock can only be stocked with indigenous stocks.
d) In the above case no more than one generation of separation from the donor stock to planted progeny is allowed.
e) Certain drainages shall be established as wild stock sanctuaries on a regional and species basis. No enhancement activity will be allowed in those areas.
f) Fish releases at sites where no impact on unique or significant wild stocks will occur need not be restricted by genetic concerns.

3. <u>Maintenance of genetic variance</u>

a) A single donor stock cannot be used to establish more than three hatchery stocks.
b) Off-site releases for terminal harvest(ranching) rather than enhancement of stock need not be restricted by the above paragraph, if such release sites are selected as not to impact significant wild stocks, wild stock sanctuaries or other hatchery stocks.
c) A minimum effective population of 400 should be used for broodstock development and maintained in hatchery stocks.
d) To ensure that all segments of the run have the opportunity to spawn, sliding egg take scales for donor stock transplants should not allocate more than 90% of any segment of the run for broodstock.

One interesting aspect of the Alaska Genetic Policy is the fact that salmon stocks must be defined as significant or unique in order to be protected from outside influences. This tends to be a very subjective appraisal as the value judgement varies a great deal between interest groups such as commercial fishermen, native indians and conservationists to mention a few. This appraisal is , however, a fact of life for most managers, which are forced to look at monetary or economic benefits of the resources. The Alaska policy only contains provisions regarding enhancement and ranching as commercial fin fish rearing in the sea, e.g. salmon farming has been banned by the Alaska legislature.

In addition to the genetic policy the State Pathology Review Committee has composed policies and guidelines for health and disease control in Alaska (Mayers et al.1987). These guidelines, which also are designed by the FRED (Fisheries Rehabilitation Enhancement and Development) division of the Alaska Department of Fish and Game, were moulded to fit the genetics policy so both policies work hand in hand.

The Pacific Northwest

The Columbia river

The Columbia river on the west coast of the US has lost an unquantified portion of genetic resources from its salmon populations due to numerous dams in operation on the river. The total number of stocks in the main river and its numerous tributaries has been reduced historically by episodes of overfishing, passage restriction and habitat loss. Diversity within some populations has probably also been reduced by these same factors, in particular due to reduced escapements and relatively small numbers for broodstock in hatchery operations(Riggs 1990).

In 1990 a report was prepared for the Northwest Power Planning Council, which proposed a framework for integrating genetic conservation into the planning of salmon and steelhead enhancement in the Columbia river basin. The report was thoroughly reviewd by bioligical and genetic experts in the area and identified three broad production approaches, which, if used selectively, would satisfy the goal of increasing the productivity of salmon and steelhead populations in the Columbia without sacrificing genetic resources and genetic diversity through management interventions or inactions(Riggs 1990).

The conclusions of the study have no formal policy status in the area but are used as guidelines for enhancement activity on the Columbia. The report identified three major management approaches(Riggs 1990):

1. Establishing a refuge or genetic conservation area.
Status of stocks: Wild salmon dominating.

This measure is intended to conserve a native population without using any kind of enhancement activity. A preferred approach would be to improve habitat, secure proper escapment, provide optimal flows and reduce smolt mortality at dams. These measures were considered suitable in areas where little or no enhancement has been applied and wild fish are still in adequate numbers.

2. Minimize genetic risk in artificial propagation.
Status of stocks: Variable hatchery vs. wild interactions.

In this case enhancement activities can be used to conserve a population to help restore natural spawning capacity in a manner minimizing genetic risks associated with hatchery and release practices. Broodstock for the program should be taken from native or naturalized stock without depleting natural spawning escapement and selection of spawners should follow procedures which minimize changes in genetic characteristics.(Riggs 1990).

Measures should be taken so ensure that the enhancement program is operated in a way that minimizes negative ecological interactions(competition, predation and disease etc.) between the hatchery fish and native populations in the same and neighbouring drainages.

This approach would be preferred in areas where artificially and naturally propagated populations occur together in a system, but can be considered separate stocks with little interbreeding. Segregation of the two populations would be desirable and hatchery fish should, if possible be prevented from entering natural spawning areas.

These methods are also desirable in areas, where hatchery production is dominating and contributing most of the escapement to natural spawning grounds, which are still in good condition. The hatchery stock must thus retain characteristic adaptive in the wild, particularly those necessary for spawning success and survival in the wild.

3. Emphasize artificial propagation.
Status of stocks: Wild stocks mostly lost.

In this scenario the main emphasis is on using genetic considerations and fish culture and management techniques to maximize the productivity of a hatchery stock without undue risk to other populations or stocks in the Columbia river basin through straying. Opportunities exist to improve the hatchery stock via selective breeding manipulation. Little or no attention is paid to restoring natural production.

This approach is recommended in areas, where the potential for natural production is deemed very low due to habitat degradation, restricted passage or other constraints. It would also be suitable in areas , where native stocks have been irreversibly lost and existing introduced stocks are performing poorly. Introductions of new suitable stocks is a viable alternative under this scenario, although it should be carefully monitored with respect to the stocks suitability and compatibility with the existing biological community.

The State of Oregon

In January of 1990 the Oregon Department of Fish and Wildlife presented "Natural Production and Wild Fish Managment Rules" to the Oregon Fish and Wildlife Commission. These proposed rules were aimed at conserving the genetic resources of wild and hatchery populations in Oregon. The rules were adopted by the Commission and effective from January 24th 1990. The rules must be considered more of a working principle for the the ODFW than legislation .

The rules are fairly extensive and dealing with an array of species and various aspects of fisheries management. Only rules dealing with managment of genetic resources of salmon will be highlighted here (ODFW 1990). Thus the wording has been considerably shortened and changed from the original document and some important paragraphs nonrelated to genetic conservation have been omitted. A complete representation of the Oregon rules is thus not conveyed.

1. Wild fish management policy

It is accepted that protection of genetic resources shall be the priority in the management of wild fish to assure optimum economic, commercial, recreational and aesthetic benefits for present and future residents of Oregon.

The protection and enhancement of wild stocks will be given first and highest consideration. Hatchery stocks of fish may be released, where necessary to provide optimum benefits from the resource. Managment options in priority order, harvest strategies and other constraints will be:

a) Management exclusively for wild fish
Harvest will be regulated to maintain production potential, genetic integrity, and genetic diversity of wild fish populations.

b) Management for wild plus hatchery fish
Harvest will be regulated so that added fishing pressure created by the hatchery fish does not reduce future production of wild fish. Native stocks will be utilized for hatchery production, wherever parctical.

c) Management exclusively for hatchery fish
Harvest restrictions will not necessarily be imposed to protect wild fish populations. Benefits from hatchery production will be maximized, except that natural spawning and rearing areas may be protected.

2.Operating principles for wild fish management

It is recognized that operating principles associated with the policy have to be continuously revised as better information becomes available. The following operating principles apply to the managment of wild populations(ODFW 1990):

Interbreeding of hatchery and wild fish
The interbreeding of hatchery and wild fish poses risk to conserving and utilizing the genetic resources of wild populations. These risks will be limited by implementing the following alternatives:

A Eliminate the release of hatchery fish

B Releases hatchery fish that are sterile and do not attempt to spawn.

C Release hatchery fish that are maintained to be genetically similar to the wild populations and limit the number of all naturally spawning hatchery fish to no more than 50% of the total number of naturally spawning hatchery and wild fish. Operating principles for developing and maintaining hatchery fish that are genetically similar to the wild populations are:

a) Use only hatchery fish that originated from wild populations

b) Incorporate naturally produced fish in every generation

c) Avoid random and nonrandom genetic change due to irrepresentative sampling of genes within a population.

d) Release hatchery fish that are reproductively isolated(spatially or temporally) from neighbouring wild populations. In the event of imperfect separation no more than 10% of the naturally spawning fish shall be of hatchery origin. More stringent requirements apply if the hatchery and wild stocks are known to differ substantially in their genetic makeup.

3. Maintenance of genetic variability

Several rules are provided to ensure that genetic variability is maintained in Oregon salmon stocks. The most important are the following:

a) Genetic variability of Oregon salmon stocks shall be maintained in wild and hatchery fish.

b) Species management plans will include list of specific streams, which will be maintained for natural production of salmon without enhancement.

c) Hatchery breeding programs for each salmon stock shall be designed to maintain diversity in characteristics, such as time of migration, time of spawning, age at maturity and age specific size.

d) Streams designated for hatchery only or wild and hatchery productions will be enhanced with stocks designated in a species plan for that river system. Brood stock for hatchery production shall be collected throughout the return of the parent run..

e) Foreign stocks will not be allowed for general release into an Oregon stream or estuary unless available information and experimentation has shown the stock to be comparable or better than local stocks in survivability, contribution to Oregon fisheries and meeting other goals of increasing natural production over current levels.

f) All salmon stocks previously imported to Oregon coastal areas must be out-crossed or replaced with appropriate Oregon stock unless the foreign stock has shown better performance than local stock.

g) Some gametes from acceptable, natural spawning stocks may be incorporated in hatchery programs periodically as required to maintain genetic diversity and inherent vigour of hatchery stocks.

h) Hatchery produced salmon shall be selected, reared and released in such a manner as to achieve the optimum harvest of the hatchery product, while protecting natural production and the genetic resources of wild salmon.

VIII. Summary and Conclusions

The paper reviews the current thinking in genetic resource management, with primary emphasis on the development of genetic policies regarding the interactions of wild, ranched and reared stocks. Genetic principles are briefly reviewed as well as current stock separation techniques. Various enhancement and aquaculture activities are classified according to the intensity of genetic manipulation involved in the rearing process. The paper finally reviews the recommendations of various international meetings on the genetic interactions of wild, ranched and reared stocks and the contents of various genetic policies developed in the major salmon producing countries both in the Atlantic and the Pacific.

The main conclusions are as follows:

1. Stock separation

Electrophoresis of proteins is the most widely used method for identification of salmon stocks. Since the markers used are relatively few and have to be neutral it is rarely possible to relate the observed differences to any characteristics important for survival in the wild.

The technique works better for identifying salmon stocks from different geographical areas than for identifying individual stocks. It has been very useful in distinguishing groups of fairly homogeneous salmon population with relatively high straying rates such as pink salmon. Identification of more differentiated salmon populations with more precise homing and a more variable life history such as the sockeye and Atlantic salmon has been more difficult.

A more recent technique involving the sequencing of nucleotides will certainly give more detail on the genetic variation of salmon stocks. The technique holds promise through genetic markers for identifying Atlantic salmon stocks from different continents and is being extended to cover the whole range of Atlantic salmon distribution.

2. International meetings

Several international meetings have in the last 2 years considered genetic threats to wild stocks, primarily from salmon mariculture. Most have recommended further research into the genetic impacts associated with the interaction of ranched, reared and wild salmon stocks and encouraged caution as information is being gathered.

A meeting in Loen, Norway, in 1990 summarized knowledge and recommended research regarding the occurrence and behaviour of reared salmon, their genetic and ecological impact and methods for identification. It was concluded that there were serious gaps in the knowledge regarding the impacts of genetic, disease and ecological interactions between wild and farmed salmon.

Appropriate research at the national and international level was encouraged but little conclusive information expected for a number of years. A precautionary approach was encouraged, where one would assume that straying escapees from salmon farms were a real risk to native salmon populations until proven that there was little or no risk.

A workshop at Sherkin Island in Ireland in 1990 proposed inventories regarding ecological, genetical and production characteristics of wild and farmed strains of salmon. Gene banks for the storage of milt from endangered stocks were considered a high priority as well as the development of sterile progeny for use in sea cage culture.

Use of surplus farmed salmon for stocking or ranching was discouraged as their genetic characteristics would be a poor match for the wild populations. The genetic and ecological impacts of ranching were considered less harmful than those of salmon mariculture, provided that the salmon were totally harvested at return in a terminal fishery.

3. National laws

An international review revealed that a number of countries have comprehensive legislation dealing with transfers of organisms with respect to disease transmissions. In many cases, however, these legislations reflect local concerns and are implemented by states or provinces rather than federal agencies. Policies for larger areas, such as the continental USA, Canada or Europe are thus lacking. Existing legislation deals only in a limited way with genetic or ecological impacts.

International agencies such as ICES and NASCO have suggested protocols for the transfer of organisms, which have been used as guidelines for policy making in many of the member countries.

Although proper legislation is lacking many countries have evolved genetic guidelines or policies, which are the basis for decision making of management agencies. Alaska has had such a policy for a number of years and the North American Commission of NASCO recommended such protocols for the east coast of North America. Similar protocols have been implemented in the state of Oregon in the Pacific Northwest. The main features of those protocols are reviewed in the paper.

In 1988 Iceland enacted a regulatory measure to deal primarily with genetic concerns regarding salmon culture and ranching. Although some compromising was necessary the measure is fairly conservative, providing aquaculture free zones off major salmon rivers, prohibiting the use of foreign stocks for ranching and mariculture and deviding the country into two major enhancement zones based on climatic and ecolocical characteristics. Enhancement of salmon rivers was furthermore restricted to local stocks.

This regulatory measure seems to comply fairly well with present international concerns but should be upgraded as further information becomes available.

4. Interactions of wild, ranched and reared salmon

The impacts from genetic or ecological interactions of ranched, reared and wild salmon stocks are highly unclear. The following conclusions are thus based on rational conservative viewpoints advocated by the various international fora dealing with the subject.

The impact of human activity on wild salmon stocks is highly variable depending on the activity concerned. Habitat improvement and construction of fishways presumably has a positive impact, if the stream is minimally affected by mixed stock fisheries and habitat deterioration. Enhancement with fry or smolts, if carefully planned, can help to build up reduced stocks and create new salmon runs, provided that the stock used is indigenous and minimally affected by husbandry practices. Wild stocks from nearby rivers would be the second best choice in the absence of local genetic material. Brood stock for such enhancement activity should preferably be of wild origin.

Ranching of salmon unavoidably involves a genetic change in the freshwater phase of the life cycle. Ranching activity should thus be conducted in such a way that wild stocks are minimally affected. The salmon should be harvested in a terminal fishery and a ranching stock should be developed for the area concerned, which probably improves homing and reduces stray. Ranching populations can be genetically manipulated in order to improve return rates and size at return, provided that genetic variation is conserved. Ranching stations with large releases should be situated far from major salmon rivers and release techniques used should minimize straying of returning adults.

Salmon farming in sea-cages is the most common form of rearing and experience has shown that large quantities can be expected to escape. This activity usually involves genetic manipulation of the whole life cycle of the salmon in order to improve growth rates and delay sexual maturity. These stocks can thus be expected to be far removed from wild ancestors. Although information on the effects of genetic interaction between reared stocks and wild populations is scanty it is reasonable to assume that they could be considerable. Genetic interactions should thus be prevented, either by preventing the reared fish from reaching spawning grounds in rivers or using triploid(sterile) populations for salmon farming.

The greatest threat would be expected by using foreign imported stocks for rearing as their original genetic makeup could be different with respect to many survival traits such as homing, migration timing and tolerance to extreme environmental conditions as well as various parasites and diseases. Importation and use of such stocks would thus only be warranted if they had a clear advantage over local stocks with respect to growth rate and survival and carried a minimum risk regarding importation of new fish diseases. In order to safeguard wild salmon populations these stocks should only be used in landbased operations and sterilized for use in sea-cages.

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