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East Coast Salmon Aquaculture Breeding Programs: History and Future

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Abstract

The salmon farming industry of the Maritime Provinces began in the late 1970s when 6 t of Atlantic salmon were produced by a research project located near Deer Island, New Brunswick. In 1998, about 8.6 million smolts for aquaculture were produced by 31 freshwater hatcheries in the Maritimes. In New Brunswick, only St. John River stock salmon are allowed in aquaculture, while in Nova Scotia the industry uses mostly St. John River stock, plus some local stocks. Growout takes place in floating net cages located in protected, nearshore marine sites. Harvested production in the Maritimes in 1997 was estimated at 19,700 t, worth $145 million. Ninety-four percent of this production was from 80 marine sites in southwestern New Brunswick and the remaining 6% was from 11 marine sites in Nova Scotia. In 1998, in response to an outbreak of the viral disease Infectious Salmon Anemia (ISA) in southwestern New Brunswick, several growout sites were completely harvested and fallowed, while some new sites were approved in order to accommodate the 1998 hatchery-produced smolts that were to have been transferred to the fallowed sites. There is a lack of good data on the numbers and causes of escapes from salmon cages. Various federal and provincial laws have relevance to aquaculture, most notably the federal Fisheries and Oceans Acts, the New Brunswick Aquaculture Act, and the Nova Scotia Fisheries and Coastal Resources Act. Memoranda of Understanding on aquaculture development have been signed between Canada and New Brunswick and Nova Scotia. These give these provinces the right to issue and administer licenses and leases for aquaculture operations within their boundaries. The federal government continues its role in monitoring, diagnosis, prevention, and control of fish diseases in cultured and wild stocks.

Résumé

C'est au début des années 1970 que l'industrie salmonicole a débuté dans les Provinces maritimes, lorsque 6 t de saumon de l'Atlantique ont été produites dans le cadre d'un projet de recherche mené aux environs de Dear Island, au Nouveau-Brunswick. En 1998, 31 piscicultures des Maritimes ont produit quelque 8,6 millions de saumoneaux pour l'aquaculture. Au Nouveau-Brunswick, le seul stock de saumon autorisé à cette fin est celui de la rivière St. John. Il constitue également la source principale pour l'industrie salmonicole de la Nouvelle-Écosse, qui a recours, en plus, à des stocks locaux. L'engraissement se déroule dans des cages flottantes en filet, disposées dans des zones marines côtières protégées. La récolte de 1997 pour les Maritimes a été estimée à 19 7000 t, et sa valeur, à 145 M$. De cette production marine, 94 % provenait de 80 élevages au sud-ouest du Nouveau-Brunswick, et l'autre 6 %, de 11 élevages en Nouvelle-Écosse. À la suite d'un accès d'anémie infectieuse du saumon (AIS), qui a frappé plusieurs emplacements aquacoles marins au sud-ouest du Nouveau-Brunswick, une récolte complète a été effectuée suivie de la suspension des activités d'engraissement dans ces lieux. La production de saumoneaux de 1998 qui devait y être acheminée sera accueillie plutôt dans de nouveaux emplacements approuvés à cette fin. Il y a un manque de données fiables sur le nombre et les causes d'évasions de poissons d'élevage. Un

certain nombre de lois fédérales et provinciales régissent l'aquaculture, dont les principales sont les lois du ministère de Pêches et des Océans, la Loi sur l'aquaculture du Nouveau-Brunswick et la Fisheries and Coastal Ressources Act de la Nouvelle-Écosse. De plus, le Canada, le Nouveau-Brunswick et la Nouvelle-Écosse ont signé des protocoles d'entente sur le développement de l'aquaculture. Ceux-ci autorisent les provinces à délivrer et à administrer les permis et les beaux relatifs aux activités aquacoles qui se déroulent à l'intérieur de leurs limites territoriales. Le gouvernement fédéral continue pour sa part d'assumer la responsabilité de surveillance, de diagnostique, de prévention et de la lutte contre les maladies des stocks de poissons d'élevage et sauvages.

Introduction

The NASCO (1996) definition of genetically modified fish includes polyploid, transgenic and monosex (all female or all male) strains but not select strains. However, directed breeding programs are designed to change wild Atlantic salmon stocks genetically. These changes are intended to improve on performance traits for aquaculture. Since selection programs have been in place in New Brunswick and Maine since the early eighties, it is expected and desirable that the genetic integrity of the founding strains change with time to accommodate the industry's demand for economically important traits. These traits can be quite different than the fitness traits important in the original wild populations.

Areas of New Brunswick and Maine bordering on the Bay of Fundy can be considered one economic region for the purposes of salmon aquaculture. Optimal conditions for the net pen culture of salmon occur only in this relatively small area. In Maine 90% of farmed salmon production occurs within 50 km of the Canadian border (McGonigle et al. 1997). Furthermore, a significant portion of this production is controlled by Canadian business interests. The involvement of Canadian farms in Maine has resulted in a relatively free flow of salmon eggs and smolts between countries. Because of this transfer, the corporate breeding programs in Maine can impact on the New Brunswick industry. Restrictions on transfer of specific strains to New Brunswick does little to restrict gene flow with respect to interaction with wild stock given the proximity of Maine salmon farming operations and the ability of escapees to swim into Canadian waters.

This paper will provide an overview of ongoing breeding programs for performance improvement of *Salmo salar* strains. The assumptions are that these strains are genetically altered and that movement occurs between Maine and New Brunswick. While the emphasis is on the New Brunswick Salmon Broodstock Development Program, comparisons with local corporate breeding programs and similar programs in Maine. The potential role of directed breeding programs in minimizing any impact of select aquaculture strains on wild populations is emphasized.

New Brunswick Breeding Programs

The first program, initiated in 1974 in Chamcook New Brunswick, was designed to evaluate genetic components relating primarily to sea ranching return rate. Secondary freshwater traits such as age at smolting and incidence of precocious parr (Friars et al. 1997, Glebe and Saunders 1986) were also assessed. The program, known as the Salmon Genetics Research Program (SGRP), was originally based on an agricultural breeding model known as a diallel cross. Broodstock from multiple river systems were crossed within and between stocks to create a series of pure and synthesized hybrid strains. Donor river stocks included the Saint John, Rocky Brook (Miramichi), the Big Salmon, Dennis Stream, Digdeguash and the Magaguadavic. Concurrently, a fledgling salmon mariculture industry was developing in the Bay of Fundy along the New Brunswick coast. Access to marine cages permitted the evaluation of two SGRP strains (Saint John and Big Salmon) for growth and grilsing rates, traits important for aquaculture (Saunders et al. 1983). Superior performance of the Saint John stock in these trials and a supply of smolts from the Mactaquac hatchery resulted in its preferred use for local sea pen culture. Provincial regulations eventually specified the Saint John as the only strain that could be grown commercially.

The SGRP's first strain to be evaluated under sea cage culture conditions, designated 85XC was a cross of multiple strains involved in earlier sea ranching trials. This strain was eventually abandoned when the broodstock became clinically infected with BKD. Subsequently, four lines of pure Saint John stock were generated, one in each year of the four year generation period for cultured broodstock. These lines or strains were named for the year the family grouping (generally 50-100) was produced i.e. 84JC, 87JC, 89JC and 90JC. The strain generation dates were not sequential from 84JC due to the elimination of certain year classes by disease. The program replaced these by returning to a Mactaquac Hatchery egg source. Parents were selected from these lines based on length (mass selection). Their progeny were sent as smolts to designated farms as either pedigreed stock (families identified by fin clips and brands) or "multiplier" stock (random mixes of families) intended for harvest only. More recently, a multiple trait selection which included parr length, percent yearling smolt, market size and mature size of two-sea-winter broodfish was used to select gamete donors for generation of the next year class. To date, selection has never been based on individual family performance. Rearing facility constraints did not allow for adequate numbers of families to be maintained to allow for a discard of poor performers.

In 1998, ongoing major capital improvements to the SGRP (now called the Atlantic Salmon Broodstock Development Program, ASBDP) hatchery will allow a shift to a true family breeding program. The installation of 154 industrial scale egg incubation and fry tanks and 80 outdoor smolt tanks will allow for maintenance of additional discrete family units until smoltification and seawater transfer. At seawater harvest, each family will be evaluated for economically important traits, and only representatives from superior families retained as progenitors of the next generation.

Disease has continued to have a major impact on the breeding program with entire strains of broodstock being lost in certain years. This year the ISA virus resulted in the destruction of all pedigreed broodstock at farm sites. Consequently, the ASBDP will generate single pair matings from the only remaining multiplier stock (90JC) and from commercially available broodstock. Currently, 138 of the expected 154 family groups are being incubated.

Corporate breeding programs have been developed in parallel with the SGRP. Since the early 1980's, major salmon farming companies have been selecting the largest individuals from their market fish for retention as broodstock. This form of mass selection for seawater growth has definitely improved stock performance in the ensuing 3-4 generations. To date, there has been no anecdotal evidence of inbreeding using this form of selection. Most companies initiated their programs with relatively diverse Saint John stock from the SGRP multiplier smolt component. However, in the future genetic progress may be retarded unless inbreeding accumulation is managed by use of pedigreed stock. To accomplish this, seven farming companies have partnered in the ASBDP to sustain genetic diversity in their breeding programs by receiving pedigreed smolts. In addition, they will receive multiplier smolts which should provide superior seawater production performance.

Maine Breeding Programs

Most Maine companies acknowledge that if genetic gains in farmed salmon are not realized, industrial competitiveness will eventually be reduced. Consequently, most have there own mass selection and strain evaluation programs. Maine farms have had greater access to non-local stocks on which to base their breeding programs than their New Brunswick counterparts. In the early 1980's, over several years, large numbers of Saint John stock eggs were imported from a few New Brunswick producers. These imported eggs were used in conjunction with Penobscot River stock at all farm sites. Concurrently, smaller numbers of European origin eggs were also being imported from Scotland, Iceland and Finland. Scottish imports were Norwegian Mowi strain from a company called Landcatch. A one time importation of Icelandic Eldi and Isno River stock and Finnish Moorum River stock also occurred. Subsequent broodstock development from imported eggs resulted in a significant contribution by their progeny to the 4.8 million smolts transferred to sea cages in 1997. The strain composition was approximately 35% Penobscot, 52% Saint John, 13% Landcatch (including hybrids with Penobscot and Saint John). No pure stocks from the other imported strains appear to have been maintain. By comparison, 7 million smolts of Saint John origin were transferred in New Brunswick in 1997. Most recently (1997) sperm from the Norwegian Mowi and Bolaks strain was imported from Iceland and crossed with the Landcatch strain to increase genetic diversity. Anecdotal reports indicate evidence of heterosis (hybrid vigor) when the Landcatch is crossed with Penobscot and Saint John stock. This also suggests inbreeding in the Landcatch stock and the need for increased diversity.

Management Considerations

The goal of any breeding program is to apply controlled selection and mating systems to effect favourable genetic change. These genetic changes must have economic benefits to enhance industrial competitiveness. There is no doubt that this genetic change will result in strains quite different from the wild stocks from which they were originally derived. The ASBDP has a significant role to play in minimizing any impact of interaction between wild stocks and aquaculture strains, both local and non-local.

Genetic Diversity and Outbreeding Depression

Breeding programs essentially promote variable combinations among gene loci and minimize inbreeding. The ASBDP will accomplish this by a true family selection program. With time, the genetic divergence between select and the founding wild population will grow. However, continued maintenance of genetic diversity should not result in a loss of adaptive fitness in wild stocks should introgressive hybridization with aquaculture strains occur. A recent study in Maine showed hatchery and local wild stocks to have similar genetic diversity (T. King, personal communication) possibly indicating that the impact of hatchery escapement on the fitness of the local stocks may be minimal. Moreover, the significant escapement of aquaculture fish is a discontinuous event. A genetically diverse aquaculture population would allow for rapid reversion to original wild genotypes by local adaptation.

Corporate breeding programs may develop strains which would have a more deleterious effect on local populations should escapement occur. First, these programs cannot logistically maintain pedigrees and inbreeding may occur. Second, the mass selection techniques practiced may result in a loss of genetic diversity if the founding stock lacked diversity. An example may be the Landcatch strain in Maine. The original egg imports came from very few parents creating a genetic bottleneck. Relatively higher mortality during the early developmental stages in the progeny from these imports is suggestive of significant inbreeding. In this instance, interbreeding with a local wild population may result in a loss of fitness (outbreeding depression). An infusion of new genetic material such as occurred with the importation of sperm in 1997 (also scheduled for 1998) should reduce the risk of fitness loss if an escapement and interbreeding with a local stock were to occur. In general, the actual diversity of aquaculture stocks may be more significant to any interaction with wild strains than the origin (European or local).

Evaluation of Non-local Stocks for Aquaculture

Salmon farmers are very well informed concerning the global development of aquaculture strains. As a result of genetic improvement and more favourable winter rearing environment in some other farming regions, salmon are known to come to market months before Bay of Fundy salmon. Not wanting to be disadvantaged, farmers understandably want to determine the performance of the competitors stock under local rearing environments. This was the impetus to import Mowi stock into Maine. More recently three commercial hatcheries in New Brunswick ran performance trials using Maine Mowi stock and Saint John stock. However, trials in production hatcheries tend to be inconclusive because of a lack of scientific method (Salmon Genetics Research Program Newsletter 1994). At two of the New Brunswick hatcheries the Mowi produced a greater percentage of S1 smolts. However, egg fertility and fry survival was poor at all locations. Evaluation of seawater performance was not possible. Trials of this nature could be more adequately controlled at the ASBDP facility and the results more empirical when individual families are compared to families of local stock origin.

DNA Profiling and Genetic Management of Farmed Salmon Stocks

Variations in repeat units of DNA used as genetic markers make possible the separation of individual broodfish genotypes. By using broodstock known to have sufficient variation at these markers, the genetic variability of subsequent generations could be enhanced. Furthermore, the ability to identify genetic lineages would reduce inbreeding. As discussed earlier, enhancing variability and reducing inbreeding would minimize the risk of fitness loss in any wild/aquaculture interaction. Currently, the ASBDP is collecting tissue samples from all broodstock producing the 1998 families. These samples are being stored for future DNA profiling. Based on studies in Maine, as few a six markers could be used to differentiate the broodstock and their progeny (T. King, personal communication).

River Specific Stocking

In both Maine and New Brunswick, aquaculture companies have been rearing wild stock in their production facilities for release into donor rivers. In Maine, stocks being maintained include the Dennys, Machies, Pleasant and Narraguagas. New Brunswick commercial hatcheries are maintaining Magaguadavic, Hammond and local landlocked populations. The benefits to the wild populations are twofold. Sufficient releases of river specific strains can dilute any genetic contribution by aquaculture escapees. Also, by applying genetic principles to propagation of river specific stocks, the genetic diversity of local populations may be enhanced. For example, the ASBDP could provide advice as to the most appropriate breeding models. Genetic considerations are most important where hatchery stock is being released into rivers with critically low populations. In addition, genetic techniques such as DNA profiling could be applied to assess the genetic status of specific wild populations.

Local anglers associations are becoming more involved in driving river specific stocking programs. They are cooperating with both government agencies and aquaculture companies to rear their stocks. For them, the newer aquaculture technologies are another option for enhancement and the ASBDP is a source of advice on the optimal use of local genetic resources.

CRYOPRESERVATION OF SALMON SPERM

Disease has resulted in the destruction of several SGRP breeding lines and the years of genetic improvement invested in them. To protect against future losses the ASBDP is proposing to cryopreserve sperm from existing and future lines. In the event of catastrophic disease loss, the male genetic component can be preserved and crossed with new introgressed genetic material. Freezing technology for salmonid sperm in aquaculture applications is well established (Stoss et al. 1981). The benefits to wild stock genetic integrity is obvious especially for populations at critically low levels. River specific sperm from a "gene bank" could be used to cross between multiple generations increasing genetic diversity. In the event of a population extinction, a cross could be made with an adjacent river stock to preserve at least the adaptive male genetic component. Recently, trials involving cryopreservation of sperm from wild Magaguadavic River stock were initiated at the ASBDP facility. The intent was twofold – to preserve genetic material from a stock in decline and to refine the freezing technique to store genetic material from aquaculture lines for future use. Long term storage is possible at an agricultural animal breeding center.

Summary

In New Brunswick, an cooperative industry driven breeding program would have benefits to wild populations. Industry would abandon corporate broodstock programs (which may result in inbreeding) in favour of a single, genetically diverse, superior strain. A good example is the importation to Maine of Saint John stock over many years. Broodstock development from this SGRP multiplier strain has resulted in a 52% contribution to aquaculture smolt placement in 1997. DNA profiling has indicated a genetic diversity comparable to local wild stock. A cooperative breeding program would allow for a controlled evaluation of non-local strains to assure the industry that the use of a locally developed strain will not place them at a disadvantage. Conversely, if the non-local stocks have some positive traits then how best to incorporate them in a production stock to minimize the risk to local wild stocks. For example, the Landcatch stock has both favourable and unfavourable traits by industry standards. Egg and fry survival is poor but the stock produces few grilse. Could this late maturation trait be incorporated by introgressive hybridization to a local aquaculture stock without compromising genetic diversity? In this regard, DNA profiling is most appropriate tool for assessing genetic change and diversity. River specific stocking by aquaculture companies is a method of protecting a genetic resource from extinction if a wild population is critically low and to minimize risk of interaction with aquaculture escapees. A river specific program requires cooperation between government, industry and local interest groups. Sperm cryopreservation would also preserve locally adapted gene combinations in the event of critically low wild breeding populations.

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