Salmon Ranching
Possibilities for Selective breeding

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Ísland
Noregur
Færeyjar
Baltic countries

Contents

Preface

Sea ranching is an aquaculture tactic which utilizes the homing habits of anadromous fish. To sea ranch Atlantic salmon *(S. Salar)*, the juvenile, freshwater stages are grown in controlled, hatchery environments. At smolting, the salmon are released where they are able to migrate to sea and forage as wild fish. After one or more years at sea, maturing salmon home to the release site to spawn. The fish returning after one year are usually called grilse (2-4 kg in size) and fish returning later called multi-sea-winter salmon. Upon return, they are methodically harvested, processed and marketed, hence the Term, salmon ranching.

In 1986 a Nordic workinggroup for aquaculture (Nordisk Arbeidsgruppe for Akuakultur) under the Nordic Council of Ministers discussed the prospects of starting a research program to study the possibilities for selective breeding and to estimate genetic variation for economic traits in salmon ranching, such as survival and growth rate in freshwater and growth rate and survival in the sea. A project plan was worked out with the following objectives:

* To study selective breeding as a part of a ranching program
* The possibility of increasing profitability by applying selection to increase return rate and growth rate.
* To develop a breeding plan for sea ranching.

The project was financially supported by Nordic Council of Ministers, Nordic Industry Fond, and the Icelandic and the Faroese governments. A steering committee was appointed with members from each of the Nordic countries:

Dr. Árni Ísaksson, Iceland, chairman
Dr. Trygve Gjedrem, Norway
Dr. Lars-Ove Eriksson, Sweden
Dr. Unto Eskelinen, Finland
Dr. Jens Ole Frier, Denmark
Mr. Andreas Reinert, Faroe Islands and
Dr. Jonas Jonasson, Iceland, project leader and secretary.

Dr. Stefan Adalsteinsson, Iceland and Mr Ingvard Fjallstein, Faro Islands took later part in the steering committee. Lisa Siitonen took part in the last meeting of the steering committee instead of Dr. Unto Eskelinen.

During the project period the steering committee has been meeting once or twice a year. A meeting was held in January 1987 in Copenhagen, Denmark and again in Oslo, Norway in April 1987 to study details of the project and practical application. Meantime each country looked into the possibilities of carrying out the project. The group concluded that the investigation would be of interest both from a scientific and a commercial point of view. It was decided to run the project in Iceland and the Faroe Islands. Dr. Jonas Jonasson had the responsibility of analyzing the data under the supervision of Dr. Trygve Gjedrem in AKVAFORSK in Norway and write up this report with help from other members of the steering committee. Ingvard Fjellstein supplied data from Faroe Islands. Sumarliði Óskarsson at the Institute of Freshwater Fisheries in Iceland helped with preparing the manuscript for printing

In chapter 10 a reference is presented from the last meeting held by the steering committee held in Denmark on 25-26 of February 1994.

Summary

The Nordic project " Salmon Ranching - Possibilities for Selective Breeding" had the aim to investigate if selective breeding should be part of a salmon ranching program. Estimate the increased profitability in salmon ranching by applying selection to increase return rate and mean body weight at return and develop a breeding plan for commercial sea ranching.

The project started in 1987 and in 1989 the first salmon smolts were released to sea from Iceland and the Faroe Islands. In Iceland four yearclasses were released during the project period and final returns were in the summer of 1993. Eight salmon stocks were tested in ranching in Iceland each divided into full- and half-sib families all together 512 families. 247.262 tagged smolts were released in Iceland. In the Faroe Islands 42 families were tested and all together 39.764 tagged smolts were released in ranching.

Results show that there is considerable significant variation in return rate between salmon stocks and even more variation between families within stocks. It is shown that the most important economic trait in ranching is return rate and that mean body weight at return shows genetic variation. It is concluded that one can improve profitability through selective breeding in a ranching system.

Predictions are presented for increasing profitability by using selective breeding in ranching.

Results are presented where realized response is observed after one generation of selection. In the fall of 1990 6 males from families with average return rate of 1.74% were used to fertilize eggs of 28 randomly selected females. The average of all families that year was 0.51%. As a control 16 males were randomly sampled and paired with 45 females. Smolts of both groups were released from four different release sites. The return rate of the selected groups was 2.8% compared to 2.2% for the control group. Return rate of the selected groups was highest at all release sites. The difference between two groups was 27%. The expected genetic gain would be have been twice as high if selected females would have been available.

Finally a breeding plan for commercial sea ranching of Atlantic salmon is presented.

Sammendrag

Det nordiske prosjektet, "Havbeiting- muligheter i avlsarbeide", hadde som mål å studere om avlsarbeide bør være en del av et havbeiteprogram, estimere genetiske og fenotypiske parametre, studere hvor stor økning en kunne vente i avkastning i form av øket gjenfangst, og vekst og utvikle et avlsprogram for havbeite.

Prosjektet startet i 1987 og i 1989 ble de første smolt satt ut på Island og Færøyene. På Island ble det satt ut fire årsklasser i løpet av prosjekt perioden og den siste gjenfangsten ble registrert i 1993. Åtte laksestammer ble prøvd i havbeiting på Island. Det ble laget full- og halvsøsken av hver stamme tilsammen 512 familier og 251.553 smolt ble satt ut. 42 familier fra to laksestammer ble testet på Færøyene og tilsammen 39.764 smolt ble satt ut.

Resultatene viser at der er signifikant variasjon i gjenfangst prosent mellom laksestammer og at det er enda større variasjon mellom familier innenfor stamme. Det er vist at de viktigste økonomiske egenskapene i havbeiting er gjenfangst % og vekt ved gjenfangst har arvelig variasjon. Det er konkludert med at det er mulig å øke avkastningen i havbeite ved å selektere for høgere gjenfangst.

Beregnet fortjenest ved bruk av seleksjon i et avlsprogram for å øke avkastningen er estimert.

Seleksjon for øket gjenfangst i en generasjon er gjennomført. Høsten 1990 ble 6 hannfisk fra 6 familier med gjennomsnittlig 1,74 % gjenfangst brukt for å befrukte rogn fra 28 tilfeldig utvalgte hunner. Den gjennomsnittlige gjenfangsten for alle familiene det året var 0,51 %. Avkom etter 16 hanner og 45 hunner ble brukt som kontroll. Smolt fra begge gruppene ble sluppet ut fra fire ulike utslippsstasjoner. Gjenfangst av den selekterte gruppa var 2,8 % sammenlignet med 2,2 % i kontrollgruppa. Seleksjons gruppa hadde høgest gjenfangst på alle utslippsstasjonene. Forskjellen mellom de to gruppene var 27 %. Den samla avlsmessige framgangen ville vært dubbelt så stor, siden bare fedrene og ikke mødrene var selektert. Tilslutt er en avlsplan for havbeiting presentert.

Samantekt

Norræna verkefnið "Hafbeit - Möguleikar í kynbótum" hafði það að markmiði að kanna hvort kynbætur eigi að vera hluti af hafbeit á laxi. Auk þess að meta hver mögulegur hagnaður má búast við með því beita úrvalsaðferðum kynbótafræðinnar til að auka endurheimtur og meðalþyngd úr sjó. Í lokin að gera tillögur um kynbótaáætlun fyrir hafbeit.

Verkefnið hófst 1987 og vorið 1989 var fyrstu laxaseiðunum sleppt á Íslandi og í Færeyjum. Fjórum árgöngum var sleppt á Íslandi á meðan á verkefninu stóð og síðustu skráðar endurheimtur voru sumarið 1994. Átta laxastofnar voru prófaðir í hafbeit í verkefninu. Búnar voru til al- og hálfsystkinahópar úr hverjum stofni alls 512 fjölskyldur og 251.553 merktum gönguseiðum var sleppt frá Íslandi. 42 fjölskyldum alls 39.764 gönguseiðum var sleppt frá Færeyjum.

Niðurstöður sýna tölfræðilega marktækan breytileika í endurheimtuhundraðshluta milli laxastofna og enn meiri breytileika milli fjölskyldna innan stofna. Sýnt er fram á að mikilvægustu eiginleikar í hafbeit, s.s. endurheimtuhundraðshluti og meðalþyngd við endurheimtur sýna erfðabreytileika. Sú ályktun er dregin af niðurstöðum að auka megi arðsemi í hafbeit með kynbótum.

Gerð er spá um aukningu í endurheimtum í hafbeit með því að beita úrvalsaðferðum kynbótafræðinnar.

Úrvali var beitt í síðasta árgangi sem prófaður var í hafbeit. Haustið 1990 voru sex laxahængir úr sex laxafjölskyldum valdir til undaneldis. Meðalheimtur þessara 6 fjölskyldna var 1,74%. Svil úr hængunum sex var notað til að frjóvga hrogn úr 28 hrygnum völdum af handahófi úr Kollafjarðarstofninum. Meðalheimtur allra fjölskyldna sumarið 1990 var 0,51%. Svil úr 16 hængum völdum af handahófi úr Kollafjarðarstofni voru notuð til að frjóvga hrogn úr 45 hrygnum sem einnig voru valdar af handahófi. Þessi hópur var notaður sem viðmiðunarhópur. Gönguseiðum úrvalshópsins og viðmiðunarhópsins var sleppt frá fjórum hafbeitarstöðvum vorið 1992. Endurheimtuhundraðshluti úrvalshópsins ári seinna var 2,8% en 2,2% úr viðmiðunarhópnum. Úrvalshópurinn hafði hæstu heimtur á öllum sleppistöðum. Mismunur þessara tveggja hópa er því 27%. Gera má ráð fyrir að framförin hefði verið tvöfalt hærri þar sem einungis voru notaðir hængir úr úrvalsfjölskyldum en ekki hrygnur.

Í lokin er kynbótaáætlun fyrir hafbeit rædd.

Yhteenveto

Pohjoismaisen projektin "Lohen laidunnus - jalostusvalinnan mahdollisuudet" tarkoituksena oli tutkia valinnan mahdollisuuksia parantaa laidunnusohjelmien kannattavuutta. Arvioitavina olivat kalojen kasvu, laidunnuksen jälkeen takaisinpalaavien osuus ja palaavien kalojen paino. Tavoitteena oli myös jalostusohjelman suunnittelu kaupalliseen merilaidunnukseen.

Projekti alkoi vuonna 1987 ja vuonna 1989 vapautettiin mereen ensimmäiset lohismoltit Islannista ja Fär-saarilta. Projektin aikana Islannista vapautettiin kaikkiaan neljä vuosiluokkaa. Viimeinen paluuajankohta oli kesä 1993. Islannissa testattiin kahdeksan kannan laidunnusta. Kannat jakautuivat puoli- ja täyssisarryhmiin. Testattuja täyssisarryhmiä oli kaikkiaan 512 kpl. Islannista vapautettuja merkittyjä smoltteja oli 247.262 kpl. Fär-saarilla testattiin 42 perhettä kahdesta kannasta, kaikkiaan merkittyjä vapautettuja smoltteja oli 39.764 kpl.

Tulokset osoittivat, että lohikantojen paluuosuuksissa oli huomattavaa, tilastollisesti merkitsevää muuntelua ja perheiden välinen muuntelu kantojen sisällä oli vielä suurempaa kuin muuntelu kantojen välillä. Laidunnuksen tärkein taloudellinen ominaisuus oli takaisinpalaavien osuus. Myös palanneiden kalojen painossa oli geneettistä muuntelua. Johtopäätöksenä esitetään, että valinnalla voidaan parantaa laidunnuksen kannattavuutta.

Valinnalla saatavalle laidunnuksen tehokkuuden kasvulle esitetään ennusteita.

Yhdessä sukupolvessa tehdyn valinnan vaikutuksista saatiin tuloksia. Syksyllä 1990 hedelmöitettiin 28 satunnaisesti valitun naaraan mäti 6 koiraan maidilla. Koiraat otettiin perheistä, joissa keskimääräinen takaisinpalaavien osuus oli 1,74 %. Kyseisenä vuonna kokonaispaluufrekvenssi oli 0,51 %. Vertailuryhmänä oli satunnaisesti valittujen 16 koiraan ja 45 naaraan jälkeläistö. Molempien ryhmien smoltit vapautettiin neljästä eri paikasta. Valittujen koiraiden jälkeläistössä paluufrekvenssi oli 2,8 %, vertailuryhmässä 2,2 % eli valittujen koiraiden jälkeläistössä palanneiden osuus oli 27 % kontrollia korkeampi. Valintaryhmässä paluufrekvenssi oli korkeampi riippumatta vapautuspaikasta. Kaksinkertainen geneettinen edistyminen olisi ollut odotettavissa, jos hedelmöityksiin olisi ollut käytettävissä myös valittuja naaraita.Lopputuloksena esitetään jalostussuunnitelma Atlantin lohen kaupallisen laidunnuksen tehostamiseksi.

1 Background of the project

To make salmon ranching profitable production cost of smolts must be low, return rates high, and body weight at return high. Better smolt-rearing methods should be developed in order to produce cheap and high quality smolts. To date, emphasis has been placed on time and size at release and release-techniques to increase return rate (Eriksson and Eriksson, 1985). Little work has been done to study the magnitude of genetic and phenotypic parameters for economic traits in sea ranching, such as return rate and mean body weight at return.

Dr. Lauren Donaldsson did pioneering work in sea ranching when he released chinook smolts of the 1949 brood fish from a small pond on the University of Washington campus in Seattle (Donaldsson 1968). Carlin (1969) and Ryman (1970) reported significant differences in recapture frequency of 17 full-sib families released in Indalselva which migrated into the Baltic Sea. Carlin (1969) recorded differences in return rate ranging from 0.5% to 17% between full-sib families.(Fig .1.1).

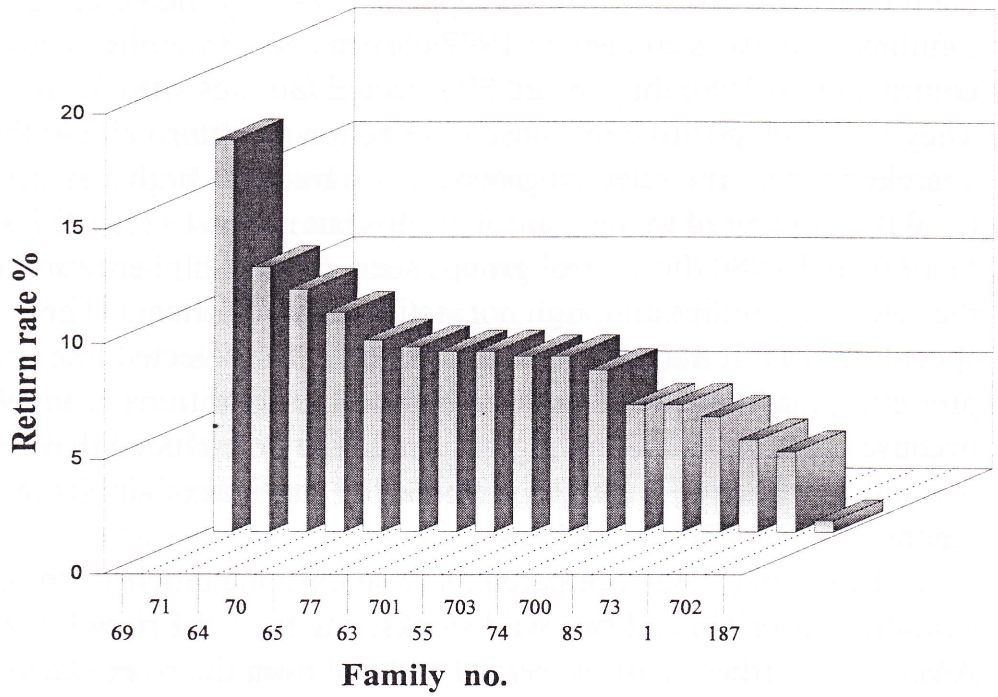

Figure 1.1 Return rates of 17 families released in Indalsälven in Sweden (Carlin, 1969).

A large genetic variation exists in growth rate and age at maturation in farmed Atlantic salmon (Gjerde, 1984; Gjerde and Gjedrem 1984). Gjedrem (1986) discussed the possibilities of genetic improvement in salmon ranching and concluded that more research should be carried out to increase our knowledge in this field. He concluded that the factors of greatest economic importance in ranching, which probably could be improved through selection, were seawater growth, age at maturity and percent return. Saunders and Baily (1980) also list the factors most likely to be of importance in a genetic selection program with Atlantic salmon: fecundity; survival in the hatchery; growth rate in the hatchery; seaward migration; survival in the sea; growth rate in the sea; age at sexual maturation; migratory behaviour; homing; seasonal return pattern; disease resistance; fish appearance and flesh quality, including colour.

Hines (1976) reported increased return rates and fecundity in chinook and coho salmon in a selection program directed by Dr. Lauren Donaldson at the University of Washington in Seattle during the sixties. McIntyre et al. (1988) reported an experiment where 30 families of Coho salmon were tested in sea ranching. They observed differences in return rate ranging from 0.18% to 3.65%, averaging 1.57%. In 1971 they mated the highest returning families and mated all together 30 families with 15 additional families as control groups. In 1974 they mated 22 selected families with 10 as control, in 1977 they mated 10 families with 12 as control and in 1980 they mated 30 selected families with 30 as control. They observed positive response to selection for return rate in the 1974 yearclass where the selected groups had significant higher return rate ($P<0.05$) compared to the control groups but not in 1971, 1977 and 1980. In 1977 and 1980 the control groups seem to have higher return rate than the selected families although not statistically significant. They speculated that if a trend to lower survival in the selected line was present, it may have resulted because oceanic conditions changed or because deleterious inbreeding occurred. They concluded that selection was not an effective method for increasing survival of smolts in salmon ranching at Big Creek Hatchery.

Ísaksson (1982) compared three stocks, one ranched stock of Kollafjörður origin and two wild stocks, one from the river Laxá in Aðaldal in northern part of Iceland and one from the river Dalsá from the southern part of Iceland. He found significant differences in return rate between stocks when using one year old smolts reared at Kollafjörður Experimental Fish Farm in Iceland. The return rate was highest, 9,9%, for the Dalsá stock and lowest, 5,2%, for the Kollafjörður stock. He found differences between these three stocks in age at maturation, where differences in grilse percentages ranged from 38% for Dalsá stock and 80% for the Kollafjörður stock. When he compared biomass of the returning fish (grilse and two-sea winter salmon) per 1000 smolts released, he found differences between stocks ranging from 153 kg for the Kollafjörður stock to 337 kg for the Dalsá stock per 1000 smolts released.

Baily and Saunders (1984) also found significant differences between Atlantic salmon strains in return rate in Canada. However, the return rate varied considerably between years. During an eight year period from 1974-1981 the mean return rate was 0.69% varying from the lowest 0.08% to the highest 2.15% between years.(Baily, J., 1987).

Hansen and Jonsson (1989) report that the proportion of salmon caught in the long-line fishery at the Faroe Islands and in northern Norwegian Sea differed between grilse, intermediate- and multi-sea-winter salmon stocks. Grilse stocks were hardly caught at all, whereas a high proportion of the total yield of multi-sea-winter stocks was harvested in the long line fishery. Concerning return rate to the river they concluded that in general grilse stocks gave higher return than did intermediate- and multi-sea-winter stocks. But due to high variation between stocks and years, these differences were not significant.

Ísaksson and Óskarsson (1986) compared return rate of the Kollafjörður salmon ranching stock at three release sites in Iceland. They transported the smolts one month before release to two ranching sites in addition to control released at Kollafjörður Experimental Fish Farm, where the smolts were produced. This was repeated over three years. They concluded that smolts reared at the same facility and released at various sites have a strong impulse to return to the site of release. Two of the release sites had similar results. At the Kollafjörður Experimental Fish Farm the return rates averaged 8.5% and 280 kg of salmon per 1000 smolts released whereas the return rates at Lárós release site were 10% and 300 kg of salmon per 1000 smolts released. The third site Sugandafjordur is located in a colder and different climatic zone and got only 2.8% return rate corresponding to 100 kg. of salmon per 1000 smolts released. The grilse ratio to total return varied between sites and was lowest at Súgandafjörður. The conclusion was that colder environment resulted in lower returns and the salmon tended to mature a year later.

This information was used to plan the project. Different salmon strains and families were included and tested for survival and growth rate in freshwater and in sea ranching, to estimate genetic variation of the traits of interest. Salmon strains and families were tagged at Kollafjörður Experimental Fishfarm and released at different locations to be able to estimate genotype-environment interaction to answer the question if one could concentrate the breeding work on one salmon stock for the whole industry.

In artificial production of smolts of Atlantic salmon for sea ranching there is some danger that natural selection will result in a stock that is well adapted to hatchery conditions, and has low survival during the sea period. It is therefore of vital importance to estimate genetic variation in freshwater- and seawater phases to study the correlations between these traits.

The project was planned for traditional sea ranching with terminal harvest of the returning fish in the river mouth. The Steering committee also discussed the possibility of studying genetic variation in sea ranching traits under the sea ranching system practised in the Baltic sea, where the majority of the salmon are caught in open sea. However, this was not possible because of limited budget.

2 Salmon Ranching in the Nordic Countries

2.1 Iceland

Salmon ranching started in Iceland in the early 1960´s at the Kollafjörður Experimental Fish Farm. The farm was established in 1961 and started to release smolts in 1963 at a location which had no previous salmon runs. Isaksson (1987) gave an overview of returns from total releases of tagged and untagged smolts at the Kollafjörður Experimental Fish Farm which are shown in Figure 2.1

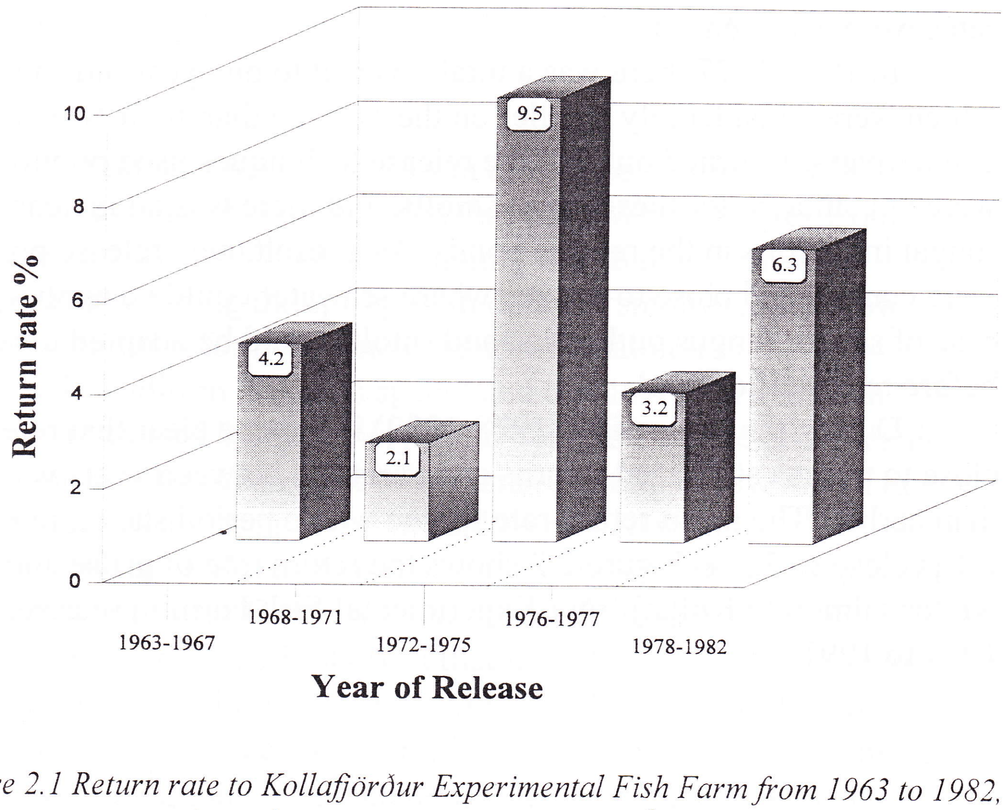

Figure 2.1 Return rate to Kollafjörður Experimental Fish Farm from 1963 to 1982, combining years with similar rearing practices and release techniques (Isaksson, 1987)

The return rates are expressed in percent as well as biomass per 1000 smolts released. Years with similar rearing and release techniques are grouped together. As seen in Figure 2.1 different periods can be identified. From 1963 to 1967 the pioneering experiments were performed with relatively small numbers of smolts. During those years some good return rates were achieved using two year old smolts. In 1968 the first batch of one year old smolts was released as a result of the use of geothermal heat to warm the rearing water. Although growth rates were greatly improved, the general rearing routine was unsuitable for proper smoltification. Large scale releases of one year old smolts from 1968 through 1971 resulted in poor return rates.

During the period 1972-1975 there was a reversal to two year old smolts with some selected groups of one year old smolts. These had been exposed to special photoperiod treatments for proper smoltification (Ísaksson, et al., 1986). In 1974 microtagging was adopted for tagging of smolts which considerably increased the survival of tagged smolts, especially small ones (Ísaksson and Bergman, 1978). Since oceanic conditions were very favourable in those years, some very high return rates were experienced.

In 1976-1977 there was a total reversal to one year old smolts which were considerably smaller on the average than their two year counterparts. It turned out that the release techniques used previously were not suitable for these small smolts, and there was an increase in fungal infections in the release ponds. As a result, new release ponds were constructed close to the sea where seawater could be applied in the case of severe fungus outbreaks, and smolts could be adapted to seawater before release if desired.

During the last period (1978-1982) it became clear that releases close to the sea stabilized returns and variation between years was lower than earlier. The mean return rate for the whole period shown in Figure 2.1 is close to 5.3%. Figure 2.2 shows the return rate of grilse and two-sea winter salmon to Kollafjörður Experimental Fish Farm in releases from 1983 to 1991.

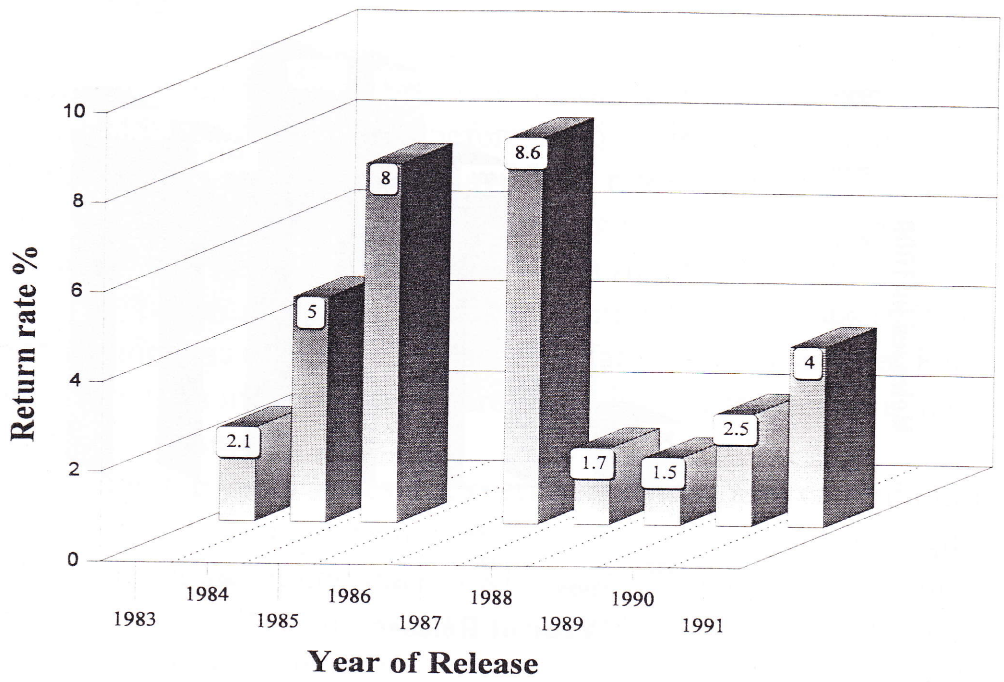

Figure 2.2 Return rate to Kollafjörður Experimental Fishfarm from releases in year 1983 to 1991.

The return rates are low from releases of smolts in 1983, and 1988-1991. Ísaksson (1991) concluded that the low return rates from the releases in 1983 and 1988 were mainly due to low freshwater temperatures during the spring with delay in smoltification, low survival and growth rates for both ranched and wild salmon in the 1984 and 1989 returns. In addition Ísaksson speculated that low return rates in 1984 and 1989 were caused by extremely unfavourable climatic and oceanic conditions in the ocean west of Iceland resulting in low return rate and growth rate in the ocean. This would be related to unusual strong polar current towards Iceland from East Greenland and corresponding decrease in the flow of warm Gulf stream water around the north coast of Iceland.

Stefansson (1993) showed that there has been a rapid increase in total releases of salmon ranching from 1987 in Iceland. Figure 2.3 shows that from 1989 between 4 to 6 million smolts were released annually. Total returns in tonnes in Iceland the last few years is shown in Figure 2.4.

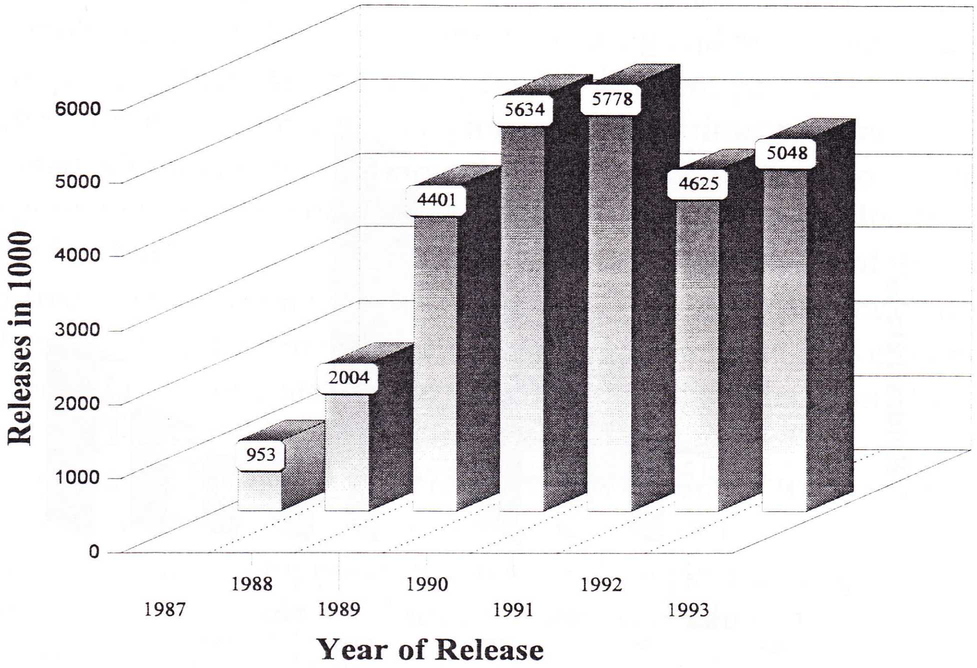

Figure 2.3 Total releases of salmon smolts for ranching in Iceland from 1987 to 1993.

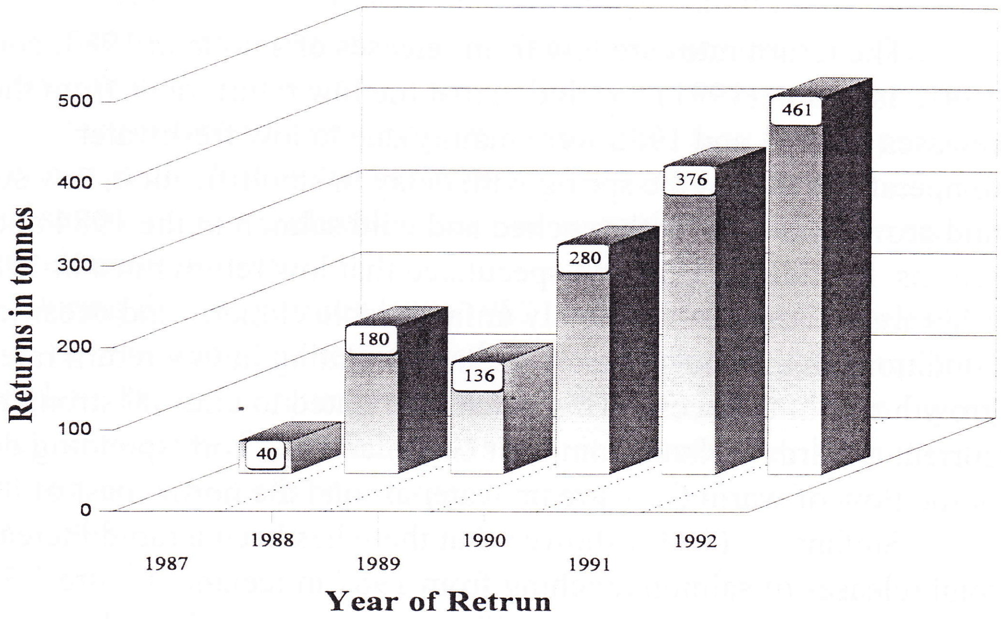

Figure 2.4 Returns in tonnes of ranched salmon from 1987 to 1992 in Iceland.

2.2 Norway

Artificial hatching of Atlantic salmon in Norway started in 1855. No feeding of alevins was practised before 1895. Releases of smolts started about 1950 and since than smolts have been released particularly by hydroelectric companies in several of the regulated rivers in order to compensate for damage to natural stocks. During the last 20 years releases have been in the order of 400 000 smolts per year. In 1978 a new research station was completed, Research Station for Freshwater Fish at Ims and since then most of the research activities in sea ranching has been carried out there.

Through the years series of experiments have been carried out in order to study how to increase the return rate by improving smolt quality and release methods. Gunnerød and Klemetsen (1976) reported a higher return rate from smolts transported by boat 100 km from the river mouth out in to the open sea compared with smolts released in the fjord and in the river mouth. Lowest return rates were found among smolts released in the river mouth. However, when they looked at the frequency of straying it was highest among smolts released in the open sea and lowest in the river mouth.

Both effect of age and size of smolts at release on return rate has been studied. Hansen and Lea (1982) found higher return rate for two year old smolts compared with one year old. Strand et al (1993) found no effect of size of smolts at release on return rate.

Hansen and Jonsson (1991) found a significant difference between salmon strains in time of return to the river where they were released.

Norway has through international agreements reduced fishing of salmon in the sea. This has increased interest in ranching in the rivers in Norway to make ranching a profitable coast industry. It is also of a political interest to increase labour a long the Norwegian coast. In this connection a large national research program was launched called PUSH (program for utvikling og stimulering av havbeite). The goal of the program is to do research in ranching and evaluate the ecological and juridical changes needed for making ranching an industry on the Norwegian coast.

2.3 Faroe Islands

There is no historical evidence that Atlantic salmon (S. salar) have been in the rivers of the Faroe Islands in historical time. Local river names, however, indicate that Atlantic salmon may have been on Faroe Islands, although Norwegian settlers may have taken these names with them from their domicile.

Salmon of Icelandic origin
In the forties, the interest for sport fishing increased and in the 1947 though 1951 period the Faroese Trout Fishing Organisation (FTFO) imported 20.000 newly hatched salmon fry from River Elliðaá on the westcoast of Iceland. These fry were released in River Saksunara and River Fjardara. In the late fifties sack fries were imported again and in the late sixties eyed eggs were imported from the Kollafjörður stock. The fry from these egg imports were released in a new area, the Leynar River system (Reinert 1968, Reinert 1982). Later on these stocks were referred to as the Faroese salmon stock.

FTFO has since 1964 released a variable number of sack fry and in later years also smolts of Icelandic stock origin in these rivers, especially in the Leynar river system.

Salmon of Norwegian origin
In the late seventies other groups got interested in Atlantic salmon for salmon farming. Some farming trials were done with salmon of the Icelandic stock, but the results were not good enough for farming purposes especially because of early maturation. Then eyed ova of Atlantic salmon were imported from the Institute of Aquaculture Research, Sunndalsora in the years 1978 to 1984 (Reinert, 1982).

Releases of microtagged Atlantic salmon
In 1984 the Fisheries Laboratory started tagging Atlantic salmon with coded wire micro tags. The number tagged has varied between 12.000 and 47.000 each year except for 1987, when no salmon were tagged. The returns from the releases from 1984 to 1988 have been between 0 and 11 %. The returns of salmon of Norwegian origin are mostly between 0 and 3%, but there are examples with returns of 5% (Fjallstein, 1989). No activities are at the moment in salmon ranching.

2.4 The Baltic Countries

Eriksson and Eriksson (1993) reviewed the activities of releases in the Baltic.

The Baltic is a large brackish-water basin covering about 400.000 km^2 and extending from 54 to 66° and from 10 to 28°E. Seawater, with a higher salinity (17-20‰), enters the basin in the south, and freshwater is mainly supplied through the large rivers in the north. The salinity is low, varying from 0.2‰ in the north parts to 6-8‰ in the surface water of the Baltic proper in the southern part of the Baltic Sea.

The main salmon rivers of the Baltic drain into the Gulf of Bothnia (Figure 2.5).

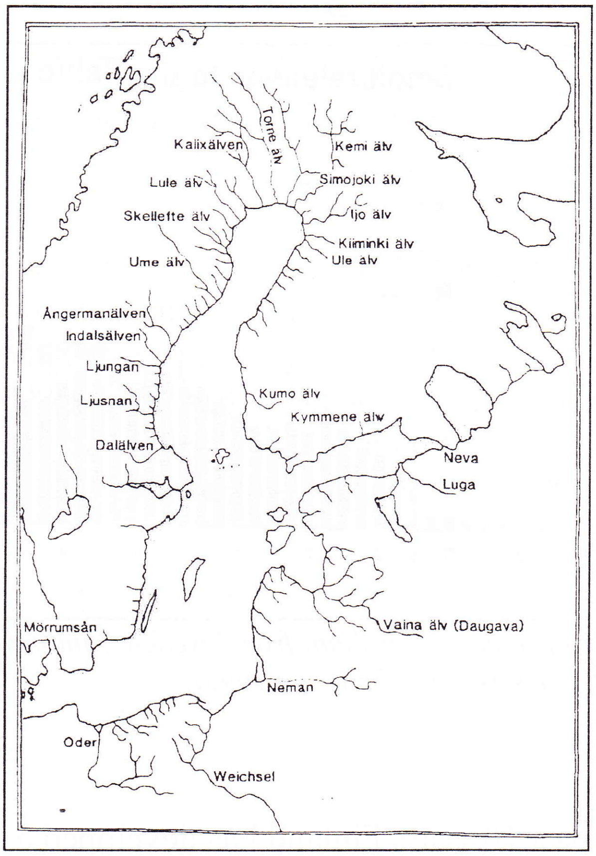

Figure 2.5 Map of the Baltic Sea, showing the main rivers entering the system. (Eriksson and Eriksson 1993).

Adult salmon enter the rivers, normally throughout the summer to spawn in late autumn. Alevins hatch during early summer. After 1-4 years in freshwater, the majority of the juveniles leave their riverine environment and migrate to their feeding areas in the central Baltic proper where they remain for 1-4 years. The smolts leave during springtime at a size of 14-20 cm. During the past 100 years the number and size of natural spawning runs have decreased, owing to man-made changes. Hydropower production has been the major source of disturbance and drainage, logging and pollution have contributed to a lesser extent. Thus today, only about 20 out of over 70 rivers are accessible for natural spawning runs in the Baltic. To compensate for the damage to salmon stocks caused by damming, artificial salmon smolt production techniques were developed by the power companies and releases of smolts started in Sweden during the 1950s. The number of released smolts of Swedish origin increased gradually to about 2-2.5 million mainly two-year-old smolts by the middle of the 1980s (Figure 2.6).

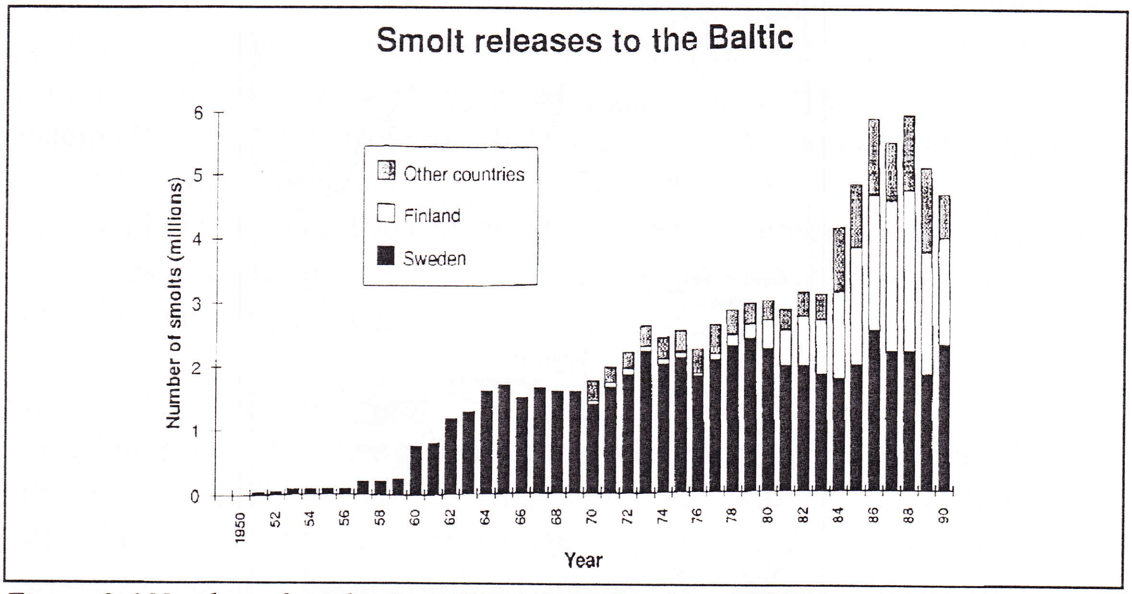

Figure 2.6 Number of smolts (in million) from Sweden. Finland and other countries during 1950-1990. (Eriksson and Eriksson 1993).

Over the past 10 years Finland has developed a smolt release program. At present, the Finns are releasing about 3 million 2-year-old smolts annually.

Before the Second World War, the Baltic salmon harvest, was largely accounted for by the coastal and river fisheries on spawners ascending the rivers. During the years 1915-1945 the total catch in the Baltic amounted to around 1000 tonnes annually (Figure 2.7).

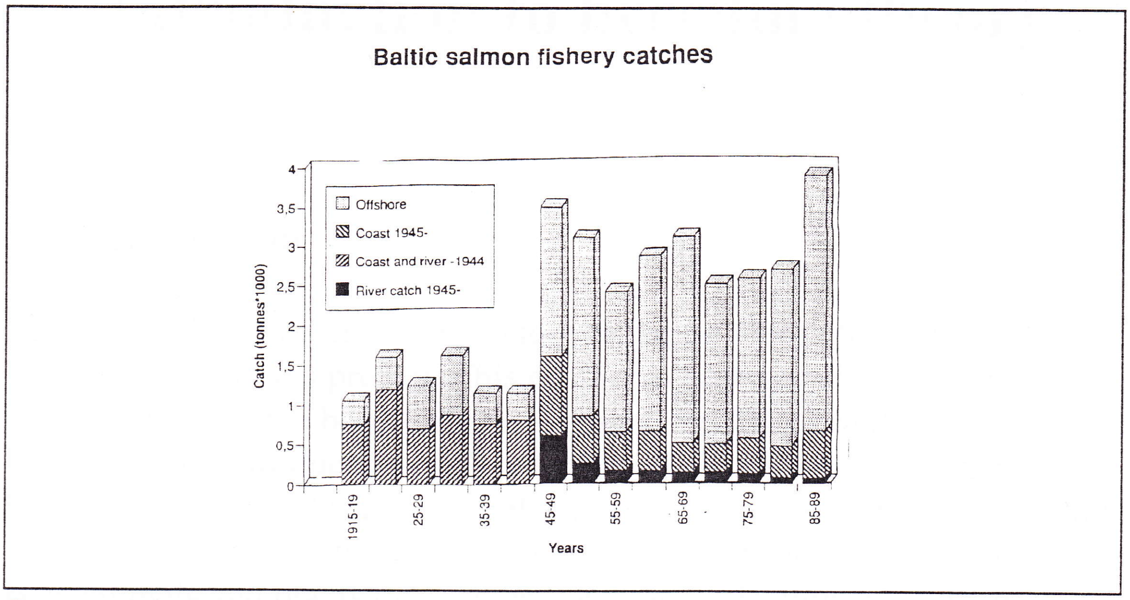

Figure 2.7 Baltic salmon catches (in thousand tonnes) in the fishery. 1915-1990. Catches have been divided into offshore, coastal and river components. (Eriksson and Eriksson 1993).

After the war the intensity of a developing offshore drift gillnet fishery, run by several Baltic countries, increased considerably, resulting in catches of 2500-3000 t annually. From 1984 and onwards the catches have varied between 3200 and 3800t according to official catch statistics. The proportion of the total catch accounted for by the offshore fishery has gradually increased, and is at present well above 80%.

3 Introduction to breeding theory

3.1 Introduction

The aim of this chapter is to introduce breeding theory to the reader since it is the basis for this project. This chapter is based on literature from Gjerde (1993) in the book Salmon Aquaculture (Blackwell Scientific Publication), Introduction to Quantitative Genetics a much used book by Falconer (1989) and some examples from ranching operations in Iceland.

There is a long tradition in increasing yield and product quality of farm animals and plants through breeding and selection. The rate of change has been rapid in the last 2-3 decades and today one cannot really imagine animal husbandry and plant production without selection programs. In aquaculture, efficient breeding and selection programs have recently been started. The first national breeding program in fish was started in Norway in 1975 with Atlantic salmon and rainbow trout (Refstie T. 1990 and Gjedrem T. 1992), and recently another national breeding program was started in the Philippines with farmed tilapia (Eknath A.E. et al. 1993).

To be able to increase yield and product quality by selection one must be able to perform artificial reproduction of the fish species under selection. This has been difficult to perform, because hatching and feeding of larvae or fry has not been possible or has been difficult in most species. Compared with farm animals most aquaculture species have the advantage of high reproductive capacity. This together with the species external fertilization permit the design of more efficient breeding programmes than in farm animals. High fertility also makes the expense of maintaining broodstock very low.

3.2 Main objective in breeding program

The main objective for a breeding program is to change the economic important characters or traits of the animals in the desired direction. In order to start a selection program to improve economic traits one must:

* Define the traits to be improved
* Evaluate the overall genetic capacity of the population to be

improved

* Develop a breeding program

At first it is necessary to introduce some key words and expressions often used in animal breeding terminology.

3.3 Key words in animal breeding terminology

3.3.1 Variation around the mean

In all animal populations one finds large differences among individuals

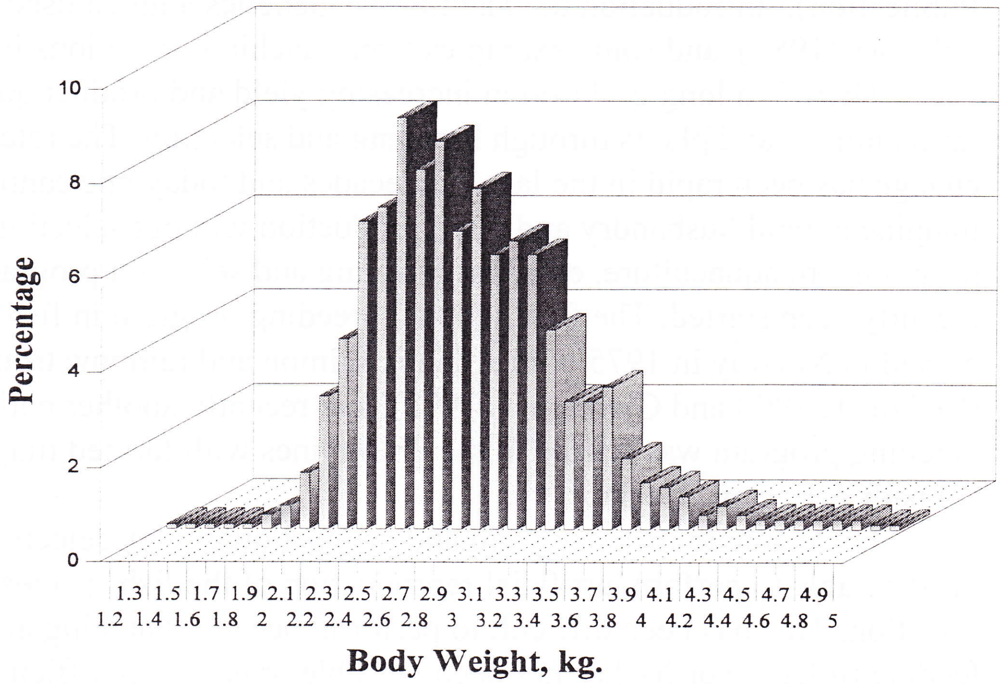

Figure 3.1 The body weight frequency distribution of 1853 Atlantic salmon grilse.

for many characters, like for instance body weight and length. In animal breeding the existence of differences or variation among individuals within a population, play an important role and are a prerequisite for genetic improvement of a trait.

Figure 3.1 shows an example of observed differences between individuals in body weight frequency distribution of 1853 Atlantic salmon returning after one year growth in the sea to Kollafjörður Experimental Fish Farm in Iceland in 1988.

Average body weight for this population of salmon was 2.74 kg and standard deviation 0.51 kg. The smallest fish was 1.2 kg and the largest 5.0 kg which shows that this trait has a large phenotypic variation. The distribution was made by grouping the fish into classes, the difference between the adjacent classes taken as 0.1 kg and each class represented by the vertical bars in the figure. Most of the fish in Figure 3.1 are distributed around the mean value, while the number of fish per class decrease as approaching high or low body weights. Such a character is said to be *normally distributed.* A theoretical normal distribution is shown in Figure 3.2 where sixty-eight percent of the population is $\pm 1\sigma$ (1 standard deviation) from the mean and 99.7% of the population is $\pm 3\sigma$ from the mean. From the example in Figure 3.1 the mean is 2.74 kg and 1σ was 0.51 kg. This means that 68% of the population is 2.74 kg. ±0.51 kg or in the range of 2.23 to 3.25 kg.
Some of the characters one wants to improve by selection are normally distributed. However, for some traits the observation fall into two or a few distinct classes. Such traits are termed either/or traits or categorical traits. Example of such traits is survival (two classes). Categorical traits will be more fully explained later as survival is one of the traits studied in this project.

The traits discussed so far are called *quantitative traits*. This group of traits is characterized by:

(1) Having a normal or underlying distribution

(2) Being influenced by a large number of genes and thus having a quite complicated mode of inheritance

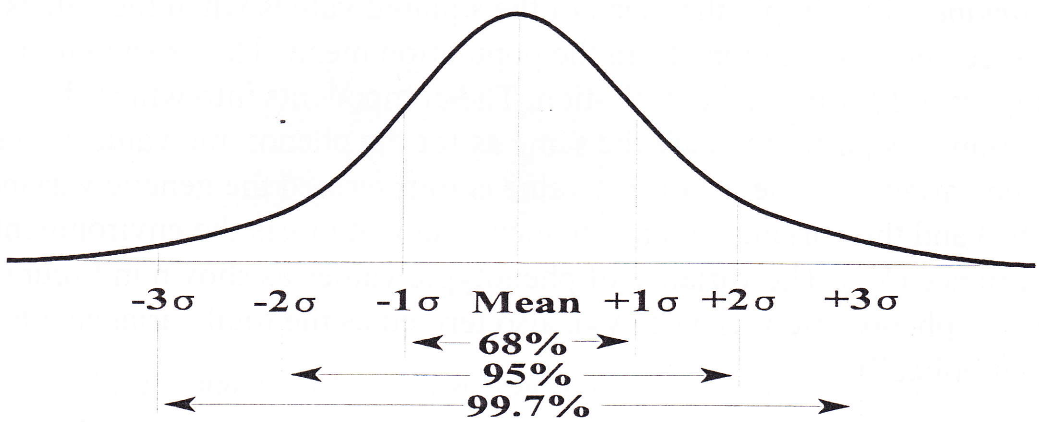

Figure 3.2 A theoretical normal distribution.

(3) To a large extent being influenced by environmental factors. Many of these characters are of great economic importance, like body weight and return rate.

Another group of traits is called *qualitative traits*. These traits are characterized by:

(1) Being determined by few genes with a simple mode of inheritance

(2) Little or not at all influenced by environmental factors

(3) Observations falling into a few distinct classes.

Examples of qualitative traits are eye colour, blood groups and skin colour. In the rainbow trout albino and normal coloured is determined by a single locus with two alleles or genes.

3.3.2 Components of Phenotypic value and variance

The value observed when a character is measured on an individual is called the phenotypic value of that individual. As an example, the distribution in Figure 3.1, is made of phenotypic values of body weight. The phenotypic value can be partitioned into two components; one attributable to the influence of *genotype*; i.e. the particular assemblance of genes possessed by the individual, and one attributable to the influence of *environment*, i.e. all non-genetic circumstances that influence the phenotypic value. Or symbolically,

$$P = G + E$$

where P is the phenotypic value, G the genotypic value and E the environmental deviations.

Quantitative genetics of a character centre around the study of its variation. The amount of variation is measured and expressed as the *variance*, i.e. simply the mean of the squared values when the values are expressed as deviations from the population mean. This is shown in Figure 3.2 for normal distribution. The components into which the variance is partitioned are the same as for the phenotypic value above. The variance of the genotypic value is thus termed the genetic variance (V_G) and the variance of environmental deviations is the environmental variance (V_E). The variance of phenotypic values as shown in Figure 3.2, is the phenotypic variance (V_P), also termed as the total variance. Or symbolically,

$$V_P = V_G + V_E = V_A + V_D + V_I + V_{ES} + V_{ER}$$

In the above equation V_G (genetic variance) is further partitioned into three separate components: V_A is the *additive genetic* variance or the variance due to the average (additive) value of the genes, or the variance of the breeding value. Additive variance is of greatest importance as will be shown later for improving traits by selection. V_D is the *dominance genetic* variance or the variance due to the value of the intra-locus interaction among genes. V_I is the *epistatic genetic* variance or the variance due to the value of inter-locus interaction among genes. The sum of V_D and V_I is termed the *non-additive genetic variance*.

The environment or non-genetic component is partioned into two separate components: V_{ES} is the variance due to the value of systematic or recognizable environmental causes. Examples of systematic causes that are at least partly under experimental control in fish farming are nutritional factors; water temperature; age of the fish; tank, cage and pond effects, and sex effects. V_{ER} is the variance due to the value of unknown or random environmental causes which therefore cannot by eliminated by correction.

The partitioning of the total phenotypic variance into its different components is illustrated in Figure 3.3.

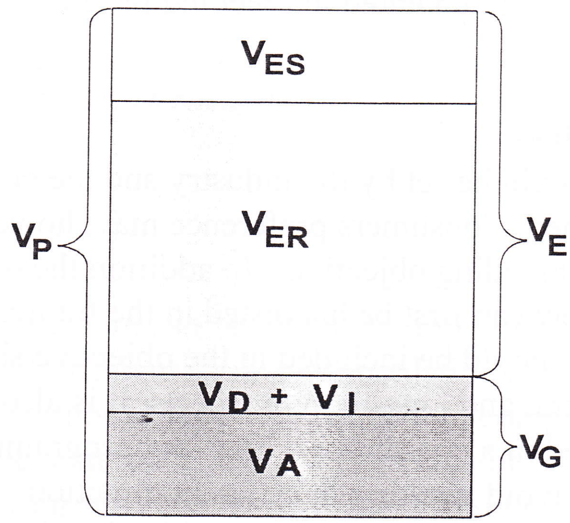

Figure 3.3 Partitioning of the phenotypic variance (V_P) into its genetic (V_G) and environmental (V_E) components.

The partioning of the total variance into its components allows us to estimate the relative importance of the various determinant of the phenotype, in particular the role of heredity versus environment. The ratio V_G/V_P, which expresses the extent to which individual phenotypes are determined by their genotypes, is called the *heritability* in the broad sense. The ratio $V_A/V_{P.}$ the extent to which phenotypes are determined by the genes transmitted from the parents, is called the heritability in the narrow sense, or simply the heritability. The heritability is estimated from the degree of resemblance between relatives.

It follows that the above ratios must have values between zero and one. A high heritability means that the observed variation of a trait to a large extent is determined by additive genetic effects, while a low heritability indicate that the variation is to a larger extent determined by environmental or nongenetic causes. In other words the heritability expresses the reliability of the phenotype as guide to the breeding value, or the degree of correspondence between phenotypic- and breeding value. In the example in Figure 3.1 the heritability is estimated to 0.2 and expresses that 20% of the total variance is attributable to the average effects of genes. The role of heritability will be more fully explained later in connection with response to selection. The non-additive genetic part of the total variance is of vital importance in determining whether crossbreeding should be implemented in breeding programmes or not.

3.3.3 Breeding objectives

Breeding objectives should be set by the industry and the consumers and should be exactly defined. Consumers preference may, however, change over time and thus the breeding objectives. In addition the outcome of selection decisions today can first be harvested in the future. The decision concerning which trait should be included in the objective should therefore involve general and long-term prospects. It is also important that everybody involved in a coordinate a breeding programme agree upon the objectives to avoid working in different directions.

For traits to be included in the breeding objective the following prerequisites must hold:

*The trait must be of economic importance

*It must be possible to measure or judge (score) the trait.

*The heritability of the trait must be greater then zero.

The most important breeding objectives for sea ranching of Atlantic salmon will be: Return rate (survival) and growth rate in sea.

One should also consider freshwater survival and growth rate of parr as well as age at sexual maturity.

3.3.4 Breeding strategies

The main objective of a breeding program is to change the mean value of the trait in the desired direction; or for a trait with discrete classes, increase the frequency of the desired class(es). The change in population mean or class frequencies from one generation to the next is termed genetic gain. This is illustrated in Figure 3.4 for a normally distributed trait.

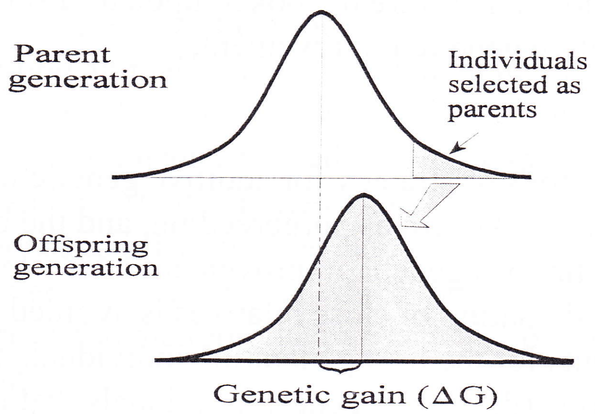

Figure 3.4 Illustration of genetic gain obtained by one generation for selection.

Genetic gain can be obtain by applying different breeding strategies. If different strains or populations are available all breeding programmes should start with collection, comparison and selection of the best genetic material available. The value of testing strains and selecting the best for farming can be equivalent to several years of within strain selection. This will be demonstrated in this project.

3.3.5 Breeding methods and breeding values.

Breeding methods explain the way in which the parents are mated.

Inbreeding - crossbreeding

Inbreeding is mating of relatives. Generally, inbreeding results in reduced performance particularly for fitness traits, the phenomenon known as inbreeding depression. In practical breeding work, inbreeding is only of interest when inbred lines are produced for crossbreeding in order to exploit non- additive genetic variance.

Crossbreeding is mating of animals from different species, breeds or strains or inbred lines. If there is heterosis the offspring surpasses the average of its parents for one or more traits, which is the reverse of inbreeding depression. The cost and time delay in developing and testcrossing inbred lines can only be justified by large heterosis effects. Crossbreeding alone does not produce any additive genetic improvement over time, and should therefore be looked upon as a supplement to a program for additive genetic improvement,

Purebreeding

The breeding methods or strategy for additive genetic improvement within a population is known as purebreeding, and the breeding method of choice for continuous genetic improvement over a long period of time. Using this method mating of close relatives is avoided and one aims at selecting as parents for the next generation individuals that possess a majority of positive (desirable) genes. Individuals that possess a majority of positive genes normally show good production performance. These good genes and properties are transferred to their offspring and are thus being accumulated in the offspring generation.

Breeding value

Individuals that possess a majority of positive genes are said to have a high breeding value.

The breeding value of an individual cannot be measured directly. Neither can it be measured with 100% accuracy. The true breading value will therefore remain unknown and to a greater and lesser extent be masked by systematic and stochastic environmental effects and also by effects caused by interactions among the genes it carries.

The breeding value can only be estimated by recording phenotypic values which are partly the result of the genes. These records may be obtained from the individual itself or from relatives as full- and half-sibs, progeny or parents. Records on relatives can be used because the individual and its relatives share common genes. Information from close relatives is more valuable than information from distant relatives.

Records on full-sibs are thus more valuable than records on half-sibs because the individual shares a larger proportion of common genes with its full-sibs than with its half-sibs. Records on progeny are of particular interest as the breeding value of an individual is strictly defined as the value of an individual judged by the mean value of its progeny.

3.4 Selection methods

Depending on from what individual or relatives we obtain our information to estimate breeding value, one can distinguish between six different methods for the selection of breeding animals. The objective for all methods is to maximize the probability of correct ranking of the potential breeding animals. This is equivalent to maximizing the correlation between the true and estimated breeding value. This correlation (r_{TI}) is frequently termed as the accuracy of the breeding values and is an important parameter, as it is directly proportional to the expected response to selection (see later). What method to choose depends on several factors among which the heritability of the trait(s), the nature of the trait and the reproductive capacity of the species are the most important.

3.4.1 Pedigree selection

This method of selecting breeding animals is based on the breeding value of their parents, grandparents or further ancestors. However, since an individual receives a random sample of half of its chromosomes or genes from each parent, this opens for a vast number of new combinations of chromosomes or genes among the offspring. This segregation of genes in each new generation may result in substantial deviation in the breeding values among offspring. The accuracy of this selection method can therefore not be high. As a result pedigree selection is little used as the only method of selection in modern breeding plan.

3.4.2 Individual selection

Selection based on an individual's own performance or phenotype is called individual selection. This is a well known and widely used method of selection in animal breeding. A prerequisite for using individual selection is that the trait(s) can be measured in the individual itself while being alive. The method is thus difficult to practise for carcass quality traits and is inefficient for disease resistance and age at sexual maturity.

When applying individual selection it is of vital importance that the environmental influences are kept the same throughout the whole life period for all individuals which are compared. By this the probability of correct ranking of the individuals can be kept as high as possible. Differences between individuals or groups of individuals for environmental factors like water temperature and salinity, light condition, and type of food and feeding regimes, may reduce the accuracy of the selection substantially and thus reduce the possibility for genetic improvement. To obtain as equal environmental conditions as possible for fish all individuals that are to be compared should be hatched on the same day or within a few days period and thereafter reared under identical environmental conditions.

3.4.3 Family selection

Whole families are selected or rejected as units according to the mean phenotypic value of the family. The families may be full- or half-sibs and families of more remote relationships may be of little practical significance. The efficiency of family selection depends on the fact that the environmental deviations of the individuals tend to cancel each other out in the mean value of the family. The phenotypic mean of the family comes close to being a measure of its genotypic mean, and the advantage gained is greater, when environmental deviations constitute a large part of the phenotypic variance. Thus, the chief circumstances under which family selection is to be preferred is when the trait selected has a low heritability. On the other hand, environmental variation common to members of a family impairs the efficiency of family selection. If this component is large, it will tend to swamp the genetic differences between families and family selection will correspondingly be ineffective.

To reduce the common environmental component to a minimum, the environment for all groups should be standardized as far as possible in the period when the groups must be kept separate. In addition, individuals from all groups should be tagged as early as possible and thereafter reared together in the same tank, pond or cage. Another important factor affecting the efficiency of family selection is the number of individuals in the families. The larger the family, the closer is the correspondence between mean phenotypic value and the mean genotypic value. The high reproductive capacity in fish thus make family selection important for these species. So the conditions that favour family selection compared to individual selection are low heritability, little variation due

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Another great advantage of family selection is that, based on the values of full-sib and/or half-sibs, one can estimate breeding values for traits that cannot be measured on the individuals which are to be used as parents. Carcass quality traits and disease resistance can therefore be included in the breeding objective by applying family selection. Family selection is also far more affective than individual selection for either/or traits like return rate and age at sexual maturity. In order to keep the rate of inbreeding low and the intensity of selection high, the number of family groups should not be smaller than 100. In the period prior to marking, in which the family groups are to be kept separate, family selection is thus costly of space. If breeding space is limited in this period, the intensity of selection that can be achieved under family selection may be quite small.

3.4.4 Within family selection

The criterion for within family selection is the deviation of each individual from the mean value of the family to which it belongs. This is the reverse of family selection since the family mean is given zero weight. The condition under which this method has an advantage compared with other selection methods is when a large component of environmental variance is common to members of a family. Selection within families would eliminate this large non-genetic component from the variation operated on by selection. Within family selection is frequently combined with family selection applying individual selection within the selected families. An important practical advantage of selection within families, especially in laboratory experiments, is that it economizes breeding space, for the same reason that family selection is costly of space.

3.4.5 Progeny testing

This method of selection is widely applied in breeding programmes of less prolific species, i. e. dairy- and beef cattle, sheep and goats. In prolific species like fish it is of much less advantage since family selection can be applied. In addition progeny testing will usually double the generation interval and is therefore of little interest in fish.

3.4.6 Combined selection

This method combines in an optimal way all available sources of information that can add to our knowledge about the breeding value of an animal; i. e. information recorded on the animal itself, information about full-sibs and/or half-sibs and progenies as well as pedigree information. It represents the general solution for obtaining the maximum rate of genetic gain. It is therefore in principle always the best method.

3.5 Response to selection

The expected genetic gain (ΔG) or response to selection per year is dependent on four parameters. The formula directly applicable for individual selection is, Formula 3.1:

$$\Delta G = \frac{ih^2\sigma_P}{L}$$

where i = the standardized selection differential, also called the intensity of selection. Because of the high fertility in salmonids a very high intensity of selection can be applied. Table 3.1 list the selection differential for different percentage selected. High intensity of selection gives high selection differential.

Table 3.1 Selection differential(i), which is the distance from the mean on the normal scale.

Percent Selected	Selection differential (i)
0.1	3.37
0.5	2.89
1.0	2.66
2.5	2.35
5.0	2.06
10	1.75
50	0.80

h^2 = the heritability of the trait.
σ_P = the phenotypic standard deviation i. e. , the square root of the phenotypic variance (V_P). This parameter is a property of the trait and the population, and it sets the units in which the response is expressed i.e. so many kg, cm, percent units , etc.
L = the generation interval, defined as the average age of the parents at the birth of their selected offspring. It is important to keep the generation

interval short to expedite the selection progress.

As an example for calculation of expected response to selection one can use values in Figure 3.1, where the mean weight was 2.74 kg. and the standard deviation 0.51 kg. If one uses the largest 10% of all the animals in the population they will be more than 3.4 kg and the selection differential will be 1.75, Table 3.1. The heritability was estimated to be 0.2 for body weight and the generation interval is 3 years. Then the response will be from formula 1, 0.06 and calculated as percent of the mean the response will be 2.2 % gain per year. If the selection intensity is 1% (all individuals selected above 4.2 kg) the response would be 3.3 %. A very important factor in the calculations is the generation interval, the shorter it is the higher the response is.

A more general formula, applicable to all methods of selection is, Formula 3.2.

$$\Delta G = \frac{i r_{RT} \sigma_G}{L}$$

where i and L is as described above and r_{TI}= the accuracy of selection i. e the correlation between the true and estimated breeding value. σ_G = the genetic standard deviation i. e. the square root of the additive genetic variance (V_G).

The expected response to selection is therefore directly proportional to the size of the accuracy of selection. The efficiency of different methods of selection can therefore be measured as the ratio between their accuracy of selection. For individual selection discussed before the r_{TI} is the square root of the heritability in the above case 0.45 (square root of 0.2). But for combined selection where one has information on the individual body weight as well as 50 full- and 150 half-sibs the accuracy is 0,71. By using combined selection with the information from relatives (full- and half-sibs) the response is increased to 58%. In the previous example the response from combined selection would be 3.5 % per year when selecting 10% highest ranking animals and 5.3% if selection intensity is 1%.

3.6 Correlated characters

Until now selection has been discussed for one trait, i.e. body weight. But usually the breeder is interested to improve two or more traits in the population. In sea ranching it is of interest to increase return rate as well as mean body weight. This draws our attention to how two or more traits change under selection. It is important to know how improvement of one character will effect simultaneous changes in another. This is done by looking at the relationship between two metric characters whose values are correlated - either positively or negatively.

It is important to distinguish between *phenotypic correlation* and *genetic correlation:*

Phenotypic correlation is the association between two characters observed as correlations between their phenotypic values. This is easy to calculate as it is simple correlation. But suppose that phenotypic values as well as genetic values are known and their environmental deviations for both characters. One would then compute *genetic correlations* as defined as correlations between additive genetic values (breeding values) of the two traits and the *environmental correlations* as the correlations between environmental deviations together with non-additive genetic deviations. The genetic- and environmental correlations thus correspond to the partioning of the covariance into additive component versus all the rest.

In general response to selection will be reduced per trait as number of traits increases in the breeding goal. However, if the genetic correlation is positive and high the response to selection is not much reduced per trait. On the other hand if the genetic correlation is negative and high the response per trait will be much less than when selecting each trait separately.

3.7 Genotype-environmental interaction

The existence of genotype-environmental interactions means that the genotype in one environment is not the best in another environment. What is wanted in practice is often not necessarily good performance in a specific environment but good performance in a range of environments. Individuals cannot usually be measured in more than one environment, so selection for average performance has to be family selection with families divided into several environments. This is usually easy to practise with fish since family sizes can be large and can be divided and tested in different environments. If there is no genotype-environment interaction one can base selection on one breed rather than having many breeds. On the other hand, if significant genotype-environment interaction is significant and account for a large part of the variation, one breed should be kept in each environment.

4 Material and Methods

4.1 Release and recapture sites used in the project for salmon ranching in Iceland and the Faroe Islands

4.1.1 Iceland

Five ranching stations were used in the project as release sites of salmon smolts from different stocks and families. Following is an overview of all the ranching sites shown in Figure 4.1.

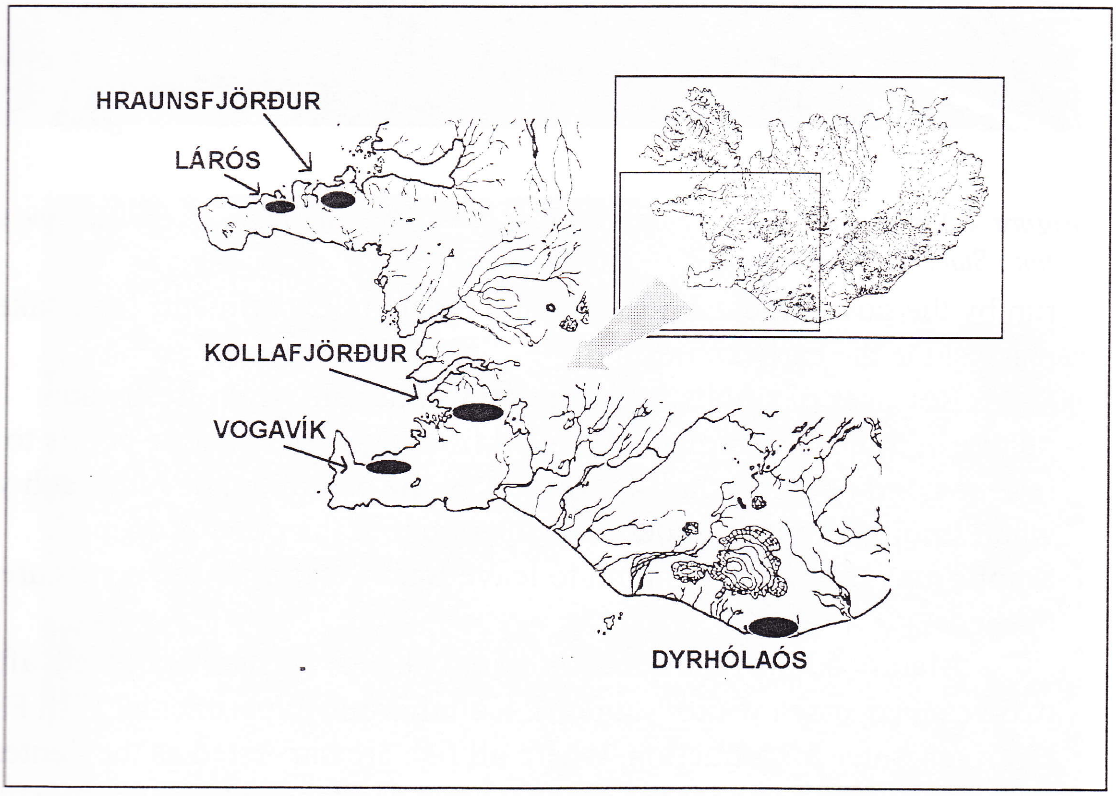

Figure 4.1 Location of all the release sites used in the project.

Kollafjörður Ranching station

Figure 4.2 shows an overview of Kollafjörður Experimental Fish Farm

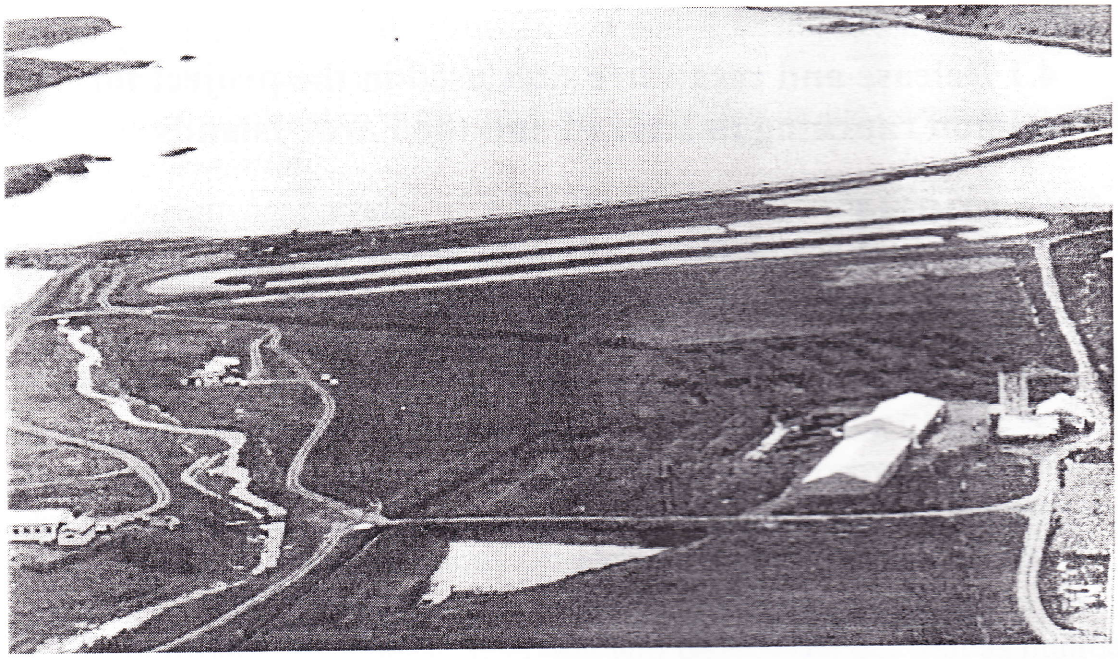

Figure 4.2 Kollafjörður Experimental Fish Farm. Rearing units and release ponds (photo Sumarliði Óskarsson).

run by the government, where salmon ranching experiments have taken place since the early sixties.

Releases of smolts to sea are conventionally from freshwater ponds. In mid May smolts are moved from outdoor concrete ponds to the release pond near the sea (Figure 4.3) In the beginning of June each year when smoltification is under way, the outlet of the pond is opened. Smolts may take up to a month to leave freshwater after the ponds are opened.

Mature adults return mostly after one year (grilse) but partly after two years (two-sea winter salmon). Kollafjörður Experimental Fish Farm has river water for attraction, where all fish are harvested as they enter a riverine salmon trap near the sea (Figure 4.4) .Ranched fish are mostly harvested in June through August with a peak run in July. .

Figure 4.3 Release pond at Kollafjörður Experimental Fishfarm (photo Jónas Jónasson).

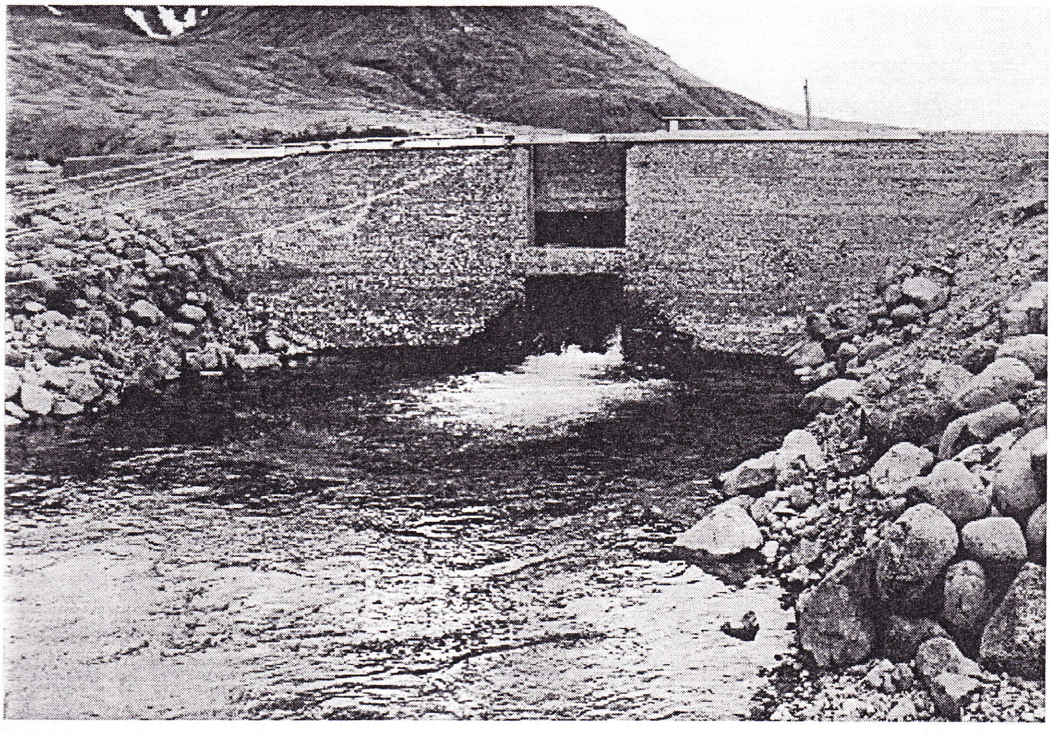

Figure 4.4 Outflow of riverine trap in Kollafjörður Experimental Fishfarm where mature salmon are captured (photo Jónas Jónasson)

Vogavík ranching station

Vogavík ranching station (Figure 4.5) was established as an experimental facility in 1982 on the outer part of Reykjanes in southwestern Iceland. It is a combined smolt rearing and ranching facility.

Figure 4.5 Vogavík ranching station. Second largest ranching station in Iceland.

The surrounding lava has ample warm and cold ground water resources for smolt production but the area is flat and volcanic with no natural river. Attraction water for the returning fish is thus entirely created by the station outflow.

Due to the porosity of the surrounding lava bed, saltwater is easily accessible from bore-holes, which is utilized to acclimatize smolts to sea water in landbased tanks prior to release. Smolts are then released directly from the tanks into the sea. Figure 4.5 show the recapture facility at Vogavík. Initially returning fish were expected to enter a fish ladder containing the runoff from the facility. It soon became apparent that the fish would not enter the fish-ladder in any number, partly due to the fact, that the outflow was entirely unaffected by surface runoff during rainy periods, which always stimulates freshwater migration of

Atlantic salmon. The returning fish were congregating outside the facility, getting discoloured and starting to stray to other areas.

After observing the migratory behaviour of the fish in the area, the present trapping facility was constructed. The migrating fish swim into the area on high tide and when the tide recedes they are guided by a leader fence into a metal cage. The mechanism has ensured speedy recapture and prime quality of fish.

Silfurlax-Hraunsfjörður ranching station

Figure 4.6 shows an overview of the Hraunsfjörður ranching facility. The station is primarily a release and recapture site. During the project the parr are reared in smolt farms in southern Iceland and transported as

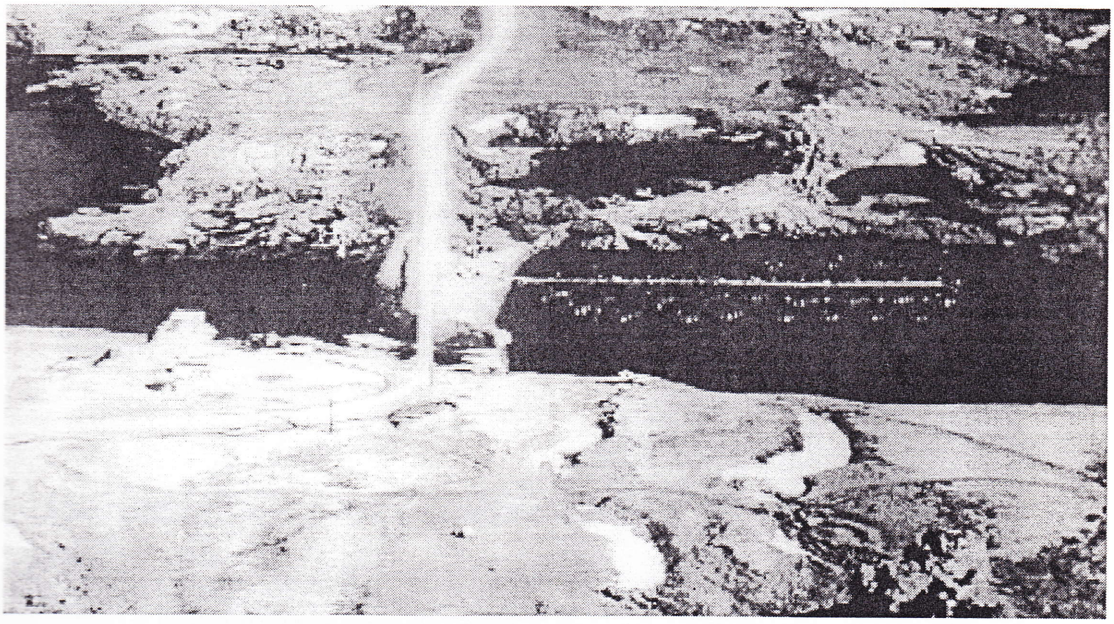

Figure 4.6 Silfurlax-Hraunsfjörður ranching station. The largest ranching station in Iceland (Photo Silfurlax inc).

smolt size parr (>20 grams) throughout the winter and fed in floating pens on a freshwater lake until smoltification.

The smolts are moved into seawater pens in the spring after smoltification, where smolts are adapted for about 1 month prior to release. The company Silfurlax in Hraunsfjörður has been in operation since 1987 and released over 3 million smolts annually in recent years.

Recaptures occur just below the lake outlet through a seining mechanism, which traps the migrating adults on the high tide. The fish are collected into floating pens and slaughtered at the earliest convenience. This method has proven to be efficient and procures bright fish in good condition for export.

Dyrhólalax-Ranching station

Dyrhólalax is located in southern Iceland in a lagoon called Dyrhólaós. The lagoon is a shallow brackwater lagoon where full saline sea-water enters on high tide. Two rivers flow into the lagoon keeping it brackish.

Parr are reared in a smolt farm nearby and at the end of May each year the smolts are moved into pens in the lagoon and adapted to sea-water. After 3-4 weeks of adaptation the pens are moved to the outlet of the lagoon and the smolts released on low tide, from where they migrate directly to sea.

Recaptures occur in the outlet of the lagoon where a fence has been put to gather migrating adults in a riverine trap. (Figure 4.7).

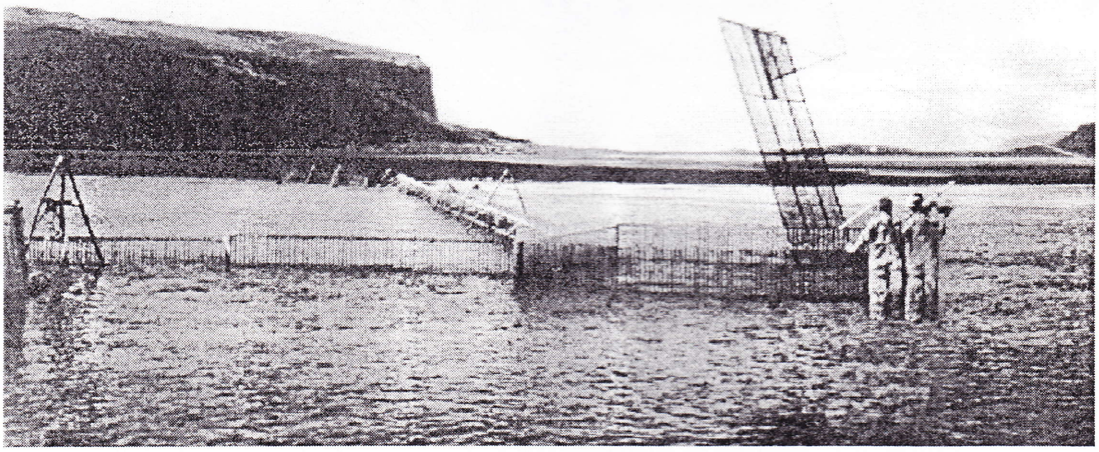

Figure 4.7 Riverine trap at Dyrhólalax south Iceland (photo Jónas Jónasson).

Lárós ranching station
Lárós is located in Western Iceland close to Silfurlax ranching station in Hraunsfjörður. It is only a release and recapture site using a man made lake system. It has been in operation since the late 1960s. (Figure 4.8) .

Parr are reared in smoltfarms and in May each year smolts are

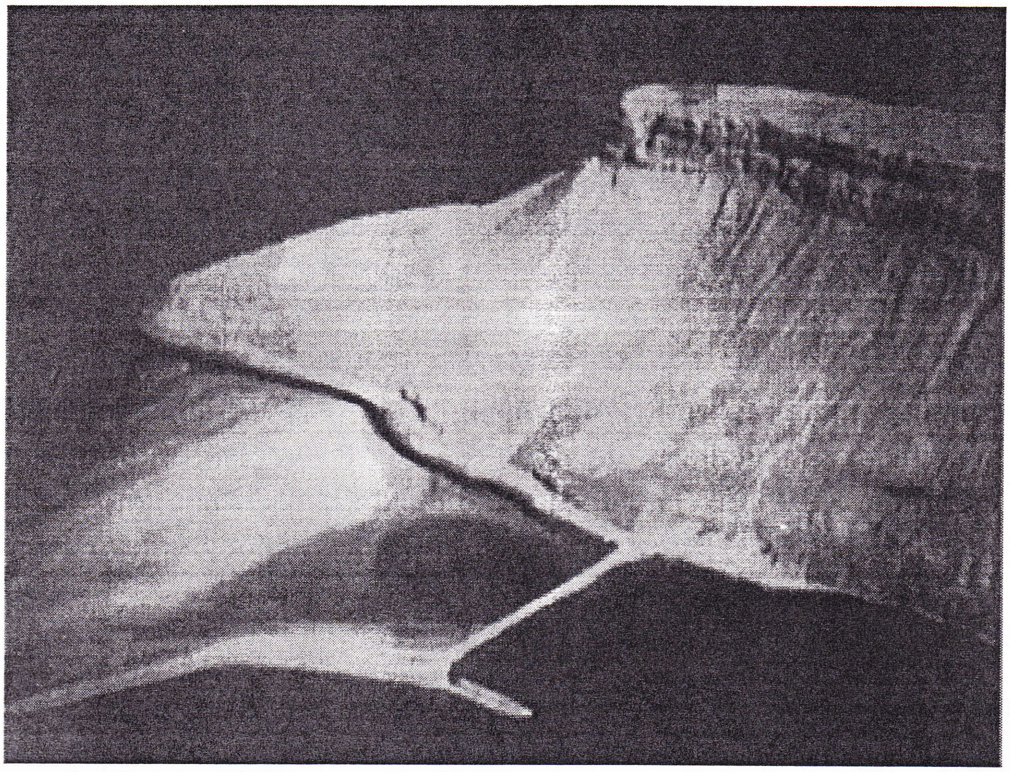

Figure 4.8 Lárós ranching station in West Iceland. One of the oldest operating ranching stations in Iceland.

transported to Lárós and kept in net pens until release, which is in June each year.
Recaptures occur in a riverine trap in the outlet of the lake.

4.1.2 Faroe Islands

On Faroe Island only one release and recapture site was used. It was in the river and lake system in Leynar. Lake Leynarvatn is 63 meter over sea level and the main spawning areas are in rivers and brooks around the lake.

This site has been the main ranching site for the Faroese Trout Fishing Organisation (FTFO) in the later years and here they built a salmon ladder in a section of the river below the lake Leynarvatn. Before the ladders were built, there was no spawning migration between the sea and the lake of the original trout (Salmo trutta) and Arctic charr (Salvelinus alpinus) stocks.

Before the first release in 1988, an agreement was made between the Fishery Laboratory and FTFO about release and recapture of tagged salmon.

4.2 Salmon stocks used in Iceland

Data were recorded from four yearclasses 1988, 1989 1990 and 1991. A yearclass is defined as the year of hatching. Eight different stocks of Atlantic salmon were tested over the years. Figure 4.9 gives an overview of the locations from which the stocks were sampled.

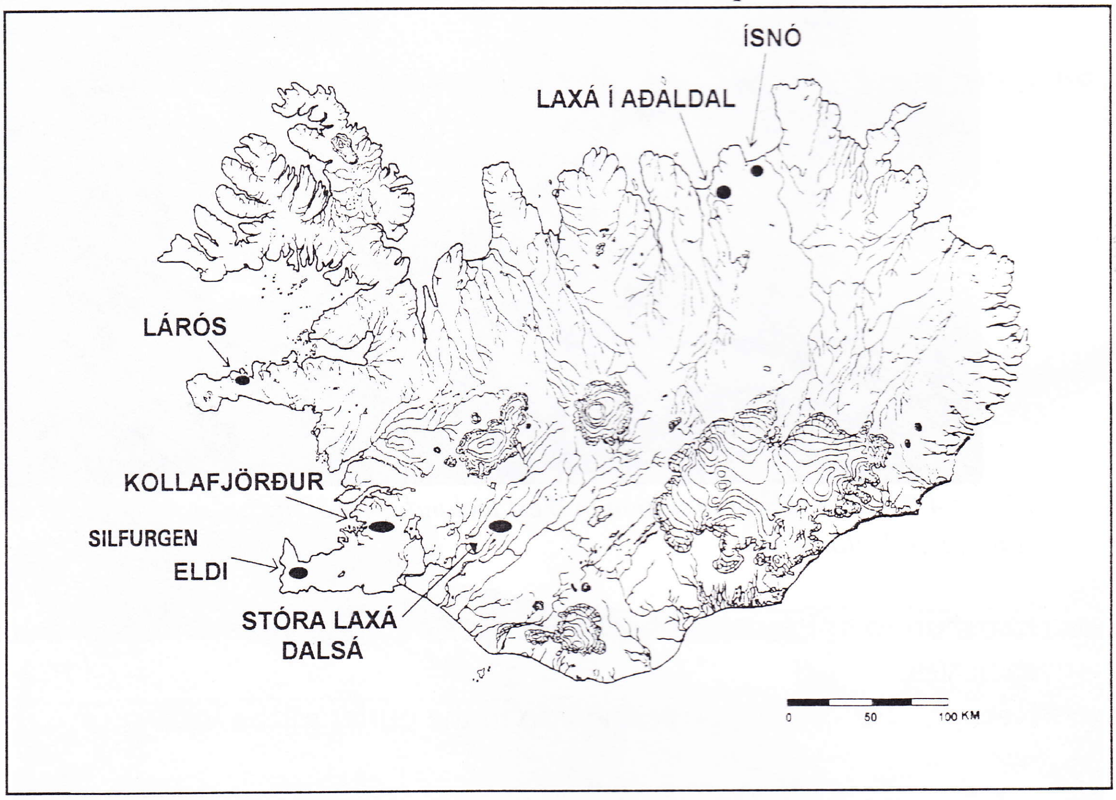

Figure 4.9 Origin of salmon stocks used in the project.

The Kollafjörður stock which originally is a mixture of 14 stocks, has been used as broodstock from the early 1960's (Gudjonsson 1989). For yearclass 1988, only two sea winter fish were used as broodstock, for yearclass 1989 only grilse were used as broodstock for the Kollafjörður stock and yearclass 1990 a mixture of one and two-sea winter fish were used for the Kollafjörður stock and two sea winter fish for the Silfurgen stock. The reason being that this was the only available broodstock for those two yearclasses at Kollafjörður Fish Farm.

Laxá in Adaldal is a wild stock taken from a river in Northeast part of Iceland, Ísnó stock is a stock used for ranching and penrearing at Lón in the same part of Iceland. The Ísnó stock is originally taken from Laxá in Adaldal but has been used for one to two generations at Lón.

Dalsá and Stóra Laxá are wild stocks taken from two different tributaries to Hvítá in the south part of Iceland. Eldi is a stock used in landbased fishfarming in Iceland and Silfurgen stock is a mixture of Stóra Laxá and Dalsá stocks and reared for one generation.

Eldi and Silfurgen stocks were reared in a land based fishfarm called Stofnfiskur in Southwest Iceland. Lárós stock used in yearclass 1991 is a ranching stock used at the Lárós ranching operations.

4.2.1 Mating system

For each yearclass hierarchical mating system was used where sperm from each male fertilized eggs of three females. All together 512 full-sib families were made over four yearclasses. Broodstock was randomly picked in each stock and random matings were used. Newly fertilized eggs were brought to the hatchery at Kollafjörður Experimental Fish Farm and each full-sib family was incubated in separate trays. At the eyed-egg stage, the diameter was measured by counting number of eggs

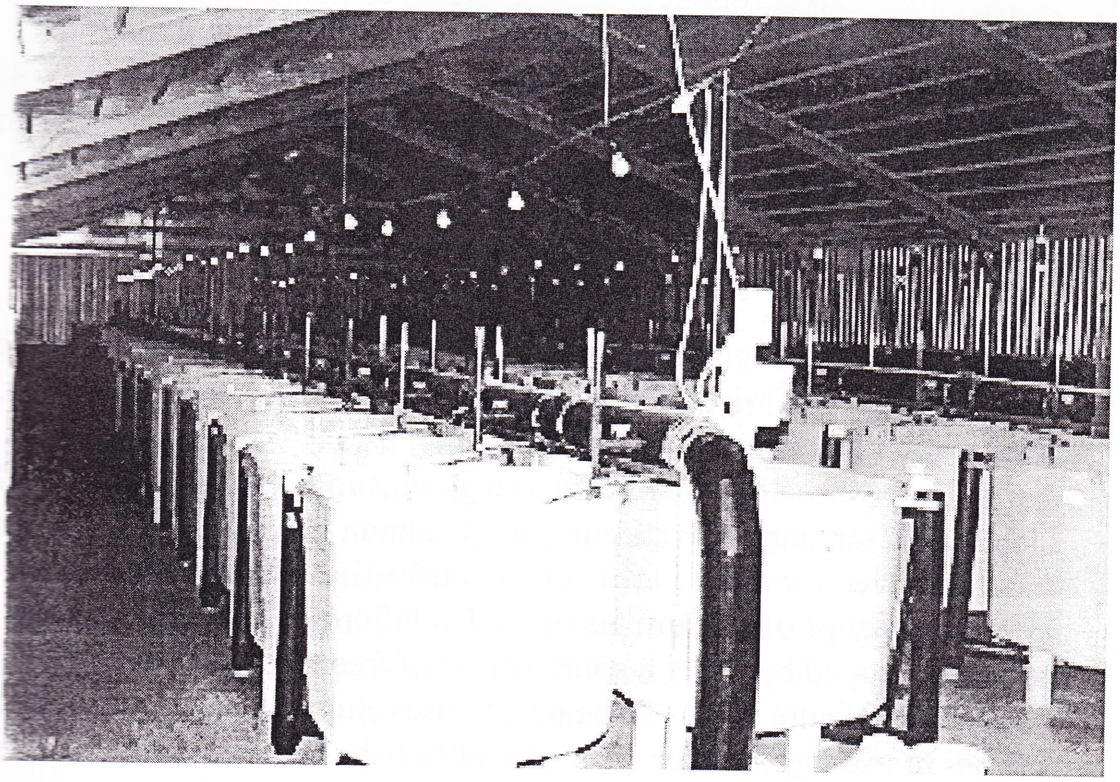

Figure 4.10 Rearing unit for salmon families in Kollafjörður Experimental Fish Farm in Iceland (photo Jónas Jónasson).

on a 25 cm board. Number of eyed-eggs for each full-sib group was standardized to 4000. Each full-sib group was reared separately in indoor 1 m^2 fibreglass tanks during startfeeding and fingerling stage (Figure 4.10).

4.2.2 Rearing routine

The day of startfeeding was recorded when swim-up started in each tank. This was in the time range from march to April. Families were spread randomly in the rearing house, this was done to reduce possible variation caused by differences in environmental conditions within the barn. Survival from eyed-egg stage to 12 weeks after beginning of startfeeding was recorded. All full-sib families were standardized to 2000 parr at the size of 1-2 grams. This was done to reduce variation caused by uneven number of parr per tank. However, some families did not exceed 2000 parr. Thereafter daily mortality from each tank was recorded until body weight was recorded at an age of 190 days from startfeeding.

Fish were given EWOS feed for salmon fingerlings until release in the sea. The parr were reared unsorted in each tank until tagging. Individual weight and length were measured on 50-100 parr from each family at 190 days from beginning of startfeeding. The sampling of fish was done by lowering the water level in the tank and sweep netting around 300-500 par with a dip-net three times into a 50 litre bucket. 50 to 100 parr were sampled from the bucket, weighed to nearest 0.1 gram and length measured to the nearest 0.1 cm. Temperature was recorded each day.

4.2.3 Tagging

All families were microtagged using Binary coded wire tags. Microtags are small pieces of wire (1 mm long) with a binary code (Figure 4.11), which are injected into the snout of salmon parr.

The adipose fin was cut off at tagging and is used as an external indicator of tagging. All returning adult salmon have to be killed and the snout removed for tag retrieval and identification. In the yearclass of 1991 two groups of all families of the Kollafjörður- and Lárós stocks were also tagged by using a combination of freezebranding and finclipping (Figure 4.12). To be able to use returning fish as broodstock one has to use tags that can be read on life fish. This is impossible with microtags. Therefore freezebranding in combination with finclipping is used for all the families released in Kollafjörður. Returning grilse and salmon, which carry freezebrands were sorted and later used as broodstock.

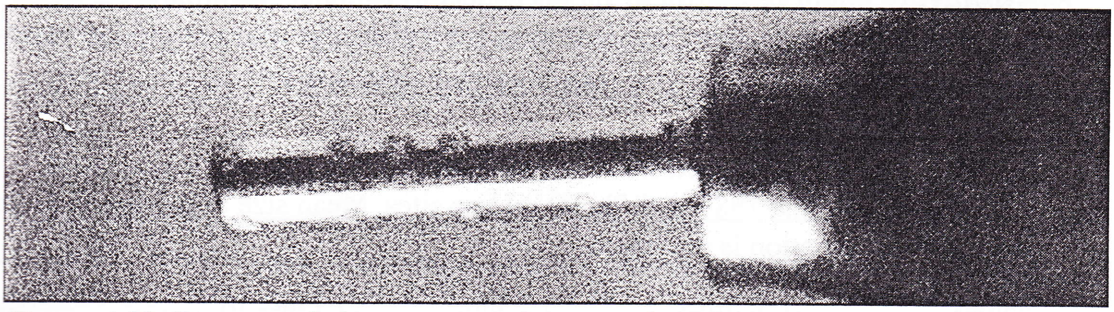

Figure 4.11 Binary coded wire tag used to tag salmon smolts. The tag is 1 mm in size (photo Sumarliði Óskarsson).

One of the freeze branded and finclipped groups was released for ranching from Kollafjörður Experimental Fish Farm (table 4.1) and the second group was reared in the land based broodstock farm Stofnfiskur. This was done to be able to keep broodstock alive at return as tags can be read without killing the fish.

Figure 4.12 Freezebranded and finclipped salmon smolt (photo Ingi R. Jónsson).

Before tagging all families were graded and parr below 10 cm were not marked because they were too small to be tagged. The frequency of parr below 10 cm was detected and was in average 41.19 % for all years. An analysis was made to check if the proportion of parr graded away in each family had any effect on return rate. Results showed no significant effect.

Precocious males at parr stage were detected by observing running milt at tagging, and were not microtagged. The average proportion of premature males was 1.3% in all families.

After tagging all families were put together in an outdoor pond at Kollafjörður Experimental fish farm usually in the period November-December and kept there until transported to the release site in

April/May each year.

Table 1 lists the total releases including the names of the salmon stocks, number of sires and dams and release sites.

Table 4.1 Number of tagged smolts of different salmon stocks released from yearclasses 1988 and 1989 at different release sites. Mean size at tagging in grams and standard deviation is presented.

Stock	Sires N	Dams N	Place of release	Number released
Yearcl. 1988				
Kollafjörður	31	93	Kollafjörður	41.493
Kollafjörður	31	93	Vogavík	14.139
Laxá Adaldal	12	23	Kollafjörður	8.032
Laxá Adaldal	12	19	Vogavík	2.644
Stóra Laxá	7	20	Kollafjörður	6.836
Stóra Laxá	7	15	Vogavík	2.276
Total 1988	50	136		75.420
Yearcl. 1989				
Kollafjörður	37	108	Kollafjörður	33.723
Kollafjörður	37	107	Vogavík	16.612
Kollafjörður	37	108	Silfurlax	17.026
Stóra Laxá	3	9	Kollafjörður	2.834
Stóra Laxá	3	9	Vogavík	1.416
Stóra Laxá	3	9	Silfurlax	1.471
Dalsá	3	5	Kollafjörður	1.545
Dalsá	3	3	Vogavík	418
Dalsá	3	3	Silfurlax	498
Ísnó	7	18	Kollafjörður	5.561
Ísnó	7	14	Vogavík	1.247
Ísnó	7	18	Silfurlax	2.786
Total 1989	50	140		86.037

Table 4.1 continued. Number of tagged smolts of different salmon stocks released from yearclasses 1990 and 1991 at four different release sites. Mean size at tagging in grams and standard deviation is presented.

Stock	Sires N	Dams N	Place of release	Number released
Yearcl. 1990				
Kollafjörður	33	84	Kollafjörður	17.69
Kollafjörður	33	84	Dyrhólalax	7.675
Silfurgen	5	7	Kollafjörður	856
Total 1990	38	91		26.221
Yearcl. 1991				
Kollafjörður	22	73	Kollafjörð 1	14.695
Kollafjörður	22	73	Kollafjörð 2	7.600
Kollafjörður	19	51	Vogavík	5.305
Kollafjörður	20	56	Silfurlax	5.800
Kollafjörður	15	36	Lárós	3.801
Lárós	10	27	Kollafjörð 1	5.374
Lárós	10	26	Kollafjörð 2	2.870
Lárós	9	24	Vogavík	2.459
Lárós	9	22	Silfurlax	2.282
Lárós	9	26	Lárós	2.688
Eldi	17	34	Kollafjörð 1	4.243
Eldi	16	28	Silfurlax	3.697
Ísnó	7	11	Kollafjörð 1	1.534
Ísnó	7	11	Silfurlax	1.527
Total 1991	56	145		63.875
Total all Years	194	512		251.553

4.2.4 Time of release

Table 4.2 presents the release time at each release site for the four yearclasses.

Table 4.2 Date of release at each release site. Records of average body weight at tagging and average body weight and length , taken at latest possible time prior to release with standard deviations (S.D) are also shown.

Yearclass	Release site	Date of release	Body weight at tagging	No of fish sampled	Body weight Mean (S.D)	Body length Mean (S.D)
1988	Kollafjörð	25.05.'89	17.7 (1.8)	134	25.6 (6.4)	13.1 (1.1)
	Vogavík	23.06. '89	17.7 (1.8)	-	-	-
1989	Kollafjörð	25.05.'90	20.5 (2.0)	110	25.3 (5.9)	13.1 (1.0)
	Vogavík	15.06.'90	20.5 (2.0)	-	-	-
	Silfurlax	28.06.'90	20.5 (2.0)	100	30.9 (8.6)	14.6 (1.4)
1990	Kollafjörð	25.05.'91	19.9 (2.0)	176	28.6 (6.4)	13.7 (1.0)
	Dyrh. lax	13.06.'91	19.9 (2.0)	25	36.0 (11)	14.7 (1.6)
1991	Kollafj. 1	26.05.'92	18.6 (2.2)	100	23.5 (5.8)	12.9 (1.3)
	Kollafj. 2	26.05'92	18.6 (2.2)	100	36.4 (9.8)	14.7 (1.2)
	Vogavík	22.07 '92	18.6 (2.2)	-	-	-
	Silfurlax	29.06 '92	18.6 (2.2)	100	21.8 (5.5)	12.8 (1.3)
	Lárós	28.06 '92	18.6 (2.2)	100	27.5 (5.8)	13.3 (1.3)

At Kollafjörður all smolts were released from a freshwater pond from which they started to migrate after mid June each year. Smolts used up to a month to migrate to sea.

At Vogavík smolts were kept in concrete tanks until release. One month prior to release in 1989 and 1990 temperature was increased in the tanks from 4 °C to 10°C. Sea water was also added to one release pond to adapt smolts to sea water before release. Releases were made by letting out all the smolts during one night. In July of 1992 all smolts at Vogavík were released on July 22nd from a concrete tank through a pipe directly to the sea. This was done one month later then for the two previous yearclasses due to difficulties in rasing the temperature in the tank for smoltification.

At Silfurlax in Hraunsfjörður the smolts were transported to the release site in May of 1990 and 1992. In the beginning of June they were moved from the freshwater facility to sea water and kept in net pens for a few weeks longer. All smolts were then released from net pens 28th of June 1990 and 29th of June 1992 by moving the netpens to the mouth of the fjord and opening them.

At Dyrhólalax the smolts were transported from Kollafjörður in mid May 1991. Smolts were brought directly to a net pen in the Dyrhólaós lagoon. After the smolts had smoltified they were released to sea migration by moving the pen to the outlet of the lagoon and released 13th of June 1991.

At Lárós the smolts were transported from Kollafjörður in May 1992 and kept in a net pen on the lake until release on the 28th of June 1992.

4.3 Salmon stocks used in the Faroe Islands

Data were recorded from two yearclasses in the Faroe Islands. Two different salmon stocks were used. One Faroese stock, which originally was imported from Iceland during the period of 1947 to 1965 and introduced to rivers for sports fisheries. The Norwegian stock used was brought to the Faroe Islands from AKVAFORSK Sunndalsøra in 1978 through 1984 as a salmon stock for pen rearing. For yearclasses 1988 and 1989 a broodstock was caught in River Saksunara in September and October. All broodfish taken from the Faroe Islands stocks were grilse which had stayed one year at sea. Broodfish from the Norwegian stock were in both yearclasses taken from the release experiments for ranching at Air Research station, and were all two-sea winter salmon.
The males and females were mated as in Iceland by hierarchal matings where one male was mated to three females. Parr were reared in identical trays and tanks as in Iceland.
Table 4 lists the total releases of all salmon stocks in the Faroe Islands and number of sires and dams used.

Table 4.3 Number of tagged smolts of two yearclasses from different salmon stocks released in the Faroe Islands in 1989 and 1990. Mean size at tagging is presented.

Stock	Sires N	Dams N	Size at Tagging	Number released
Yearclass 1988				
Faroe Islands	5	15	26.7	13.611
Norwegian	5	15	34.3	14.341
Yearclass 1989				
Faro Islands	2	6	26.5	4.476
Norwegian	3	9	29.1	7.336
Total	15	45		39.764

4.3.1 Time of release

The tagged salmon parr were transported to Lake Leynarvatn and reared in netpens for four weeks for acclimatization before release. At release the smolts were moved 1.2 km down the river Leynara during 14th and 15th of June 1989 and the smolts of the 1989 yearclass were released 15th of June 1990. The smolts were released below a closed salmon ladder so that it was impossible to swim up the river again. Guard was at the release site for three days because of seabirds.

Figure 4.13. Fishladder where the smolts were released from in river Leyrar in the Faroe Islands. (photo Ingvard Fjallstein)

4.4 Recapture of Adults

All returning grilse and salmon were slaughtered, date and sex, weight and length were recorded in both countries. Microtags were removed from tagged fish and read. Fish that were caught in different release sites than the one they were released from as smolts were recorded as strayers. The strayers were included in the material as observations of returns. The frequency of strayers will not be written up in this report but results will be written up later.

4.5 Statistical analyses

4.5.1 Salmon stock comparisons

Freshwater

Analysis of variance was used to compare the different salmon stocks within years for eggsize, survival and body weight and length in freshwater. Means for each family within stock were used for egg size and survival. Individual weight of 50-100 individuals per family was used in the analysis.
Pearson's correlations were used to compute phenotypic correlations between egg size and survival, body weight and length.

Return rate and grilse ratio to total return

Analysis of variance was used to compare return rate and grilse ratio to total return for each stock. Return rate and grilse ratio to total return for each family released was used as one mean within stock for each release site. Release sites were used as a fixed effect in the analysis model. Contrast analysis were made to compare individual stock to each other.

Body weight at return

Analysis of variance was used to compare body weights of grilse and two-sea winter salmon returning for each stock. Individual body weights were used. Release site and sex were used as a fixed effect. Interactions between release sites and sex were not significant. Contrast analysis was made to compare individual stock to each other.

Least square means (LSM)
Least square means (LSM) values of each stock for return rate, body length and grilse ratio to total return were generated from the model as means adjusted for average effect of release site for return rate and grilse ratio to total return and least square means adjusted for body weight for release site and sex.

Biomass (kg/1000 smolts released)
Biomass as a total yield for each salmon stock was used to evaluate the magnitude of the total variation in biomass caused by effect of stock, release site and interaction of stock and release site. The interaction is computed to estimate if there exists genotype-environmental interaction.

In chapter 7, table 7.5, similar computations were made but only biomass of grilse was used to estimate the effect of sire (half-sibs) nested within stocks and interaction of sire within stock and release site.

4.5.2 Genetic parameters

Freshwater
Genetic parameters during the freshwater period for survival, weight and length were derived by applying a model where sires are nested within stocks and dames nested within sire and stock. Heritabilities are derived from sire components of variance.

Heritability estimates for survival obtained on the observed binomial scale were transformed to the underlying liability scale according to Dempser and Lerner (1950).

Ranching phase
Body weight and body length of the two sexes returning from ranching were significantly different males were larger and had larger variances compared to females within stock. Consequently, a multiplicative correction factor was applied by multiplying individual body weight with ratio of grand mean body weight to mean body weight of each sex within each stock and release site before analyzing the data.

Variance components for weight at return from ranching were estimated by using an animal model using programs based on software written by Meyer (1991). Stocks and release sites were used as fixed effects and interaction of release site and sex. When heritabilities were estimated over years, yearclass was included as a fixed effect.

Variance components for return rate were estimated by using a program called GFCAT procedure of Gianola and Foulley (1983) and Harville and Mee (1984). The program performs a categorical data analysis and provides estimates in terms of the underlying, non-observable normal distribution. The model included stocks and release sites as fixed effects and when computed over years, yearclass was included as fixed effect.

Nested analysis allowed estimation of covariance components to investigate genetic correlations between traits. Genetic correlations were calculated using only the sire components of variance and covariance.

5 Comparison of salmon stocks in the freshwater phase

5.1 Introduction

The juvenile stages of Atlantic salmon live in freshwater. The main traits of interest in the freshwater stage are survival and growth rate.

Results will be presented for various stocks used in the experiment. Results are from two year-classes, 1988 and 1989. Only two year-classes are presented here as it was decided that results from the freshwater phase should only cover the two first yearclasses.

5.2 Results and discussion

The mean temperature for the first 190 days from the beginning of startfeeding for yearclass 1988 was 11.7°C (Standard deviation 0.9 and heatsum 2189 degreedays) and 12.1 °C (Standard deviation 0.9 and heatsum 2021 daydegrees) for yearclass 1989. At Kollafjörður Experimental Fish Farm geothermal heat was used to heat the well water to about 12 °C each year. This ensures nearly constant temperature until records were taken after 190 days on feed, indicating that each family got about the same heatsum from the beginning of startfeeding until about 190 days of age. In 1988 the date of swim-up and startfeeding for each family was from March 24 to April 14, in all 21 days from the first swim up to the last. In 1989 the dates from swim-up varied from March 21 to April 4, a total of 14 days.

Phenotypic means with standard deviations for the observed traits are given in table 5.1 for both yearclasses.Variation in egg size between salmon stocks was not significant ($P>0.05$) in yearclass 1988 but was significant in 1989. The egg size was smaller for Kollafjörður stock in yearclass 1989 than in yearclass 1988 because broodstock was only taken from grilse due to lack of two sea winter fish for that yearclass.

Table 5.1. Means (M) and standard deviations (S.D.) for egg diameter,survival and body size at 190 days of age for five different stocks of Atlantic salmon in 1988 and 1989. Means with the different letter of the alphabet behind the mean-number are significantly different ($P>0.05$).

Stock	Sires	Dams	Egg diameter		Total survival		Weight		Length	
	N	N	M	s.d	M	s.d.	M	s.d.	M	s.d.
Yearclass 1988										
Kollafjörður	31	93	5.6a	0.3	77.5a	14.0	10.9a	5.5	9.4a	1.5
Laxá in Aðaldal	12	36	5.5 a	0.3	51.0b	20.0	6.1b	5.5	7.8b	1.5
Stóra Laxá	7	21	5.7a	0.5	63.9c	14.0	8.2c	3.9	8.7c	1.3
Total	50	150	5.6	-	69.2	-	9.4	-	9.0	-
Yearclass 1989										
Kollafjörður	37	113	4.7a	0.2	54.7a	16.0	11.1a	5.8	9.5a	1.7
Stóra Laxá	3	9	5.4b	0.3	70.7b	8.7	10.9a	5.4	9.6a	1.5
Dalsá	3	7	5.2b	0.3	60.3c	18.0	8.3b	5.8	8.5c	1.7
Isnó	7	19	5.4b	0.2	52.4c	18.0	11.4a	5.8	9.7a	2.5
Total	100	298	4.9	-	55.7	-	11.0	-	9.5	-

Total freshwater survival of 69.2% was higher for yearclass 1988 than for yearclass 1989 which was 55.7%. Variation between stocks as shown in Figure 1, was from 51.0% to 77.5% for yearclass 1988 and from 52.4% to 70.7% for yearclass 1989. Survival was significantly different ($P<0.01$) between stocks for both yearclasses. It was observed that the lowest survival was during the startfeeding period. The mean body weight after 190 days for yearclass 1988 was 9.4 grams and mean body length 9.0 cm. Variation between stocks are as shown in Figure 2, from 6.1 to 10.9 grams for body weight and 7.8 to 9.4 cm for length. Mean weight for yearclass 1989 was 11.0 grams and mean length was 9.5 cm. Variation between stocks was from 8.3 to 11.4 grams for body weight and 8.5 to 9.7 cm for length.

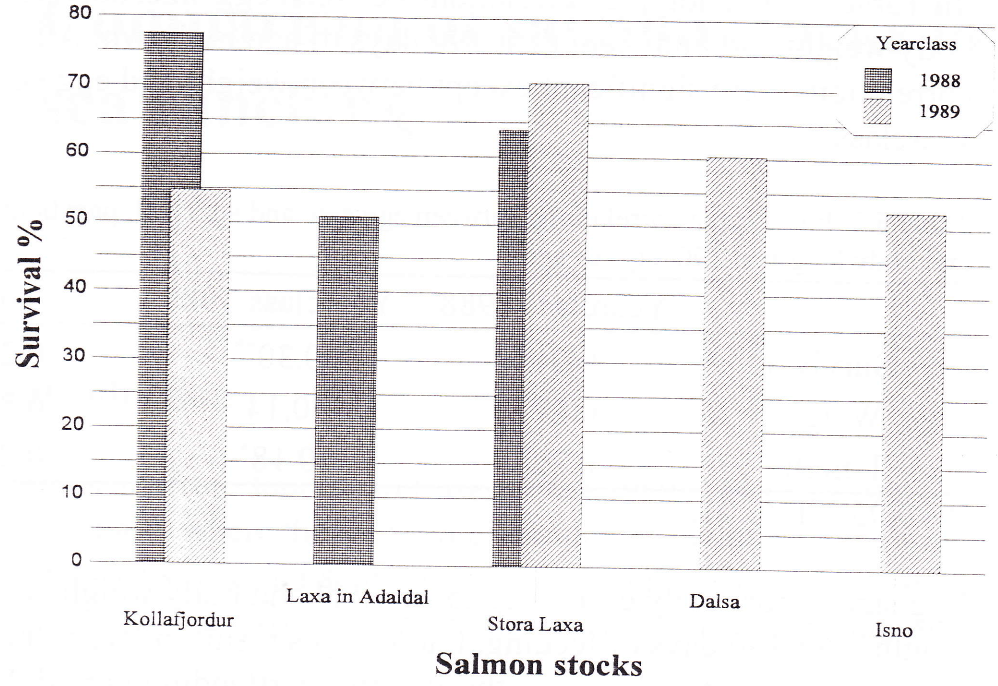

Figure 5.1 Total freshwater survival for salmon stocks in two yearclasses.

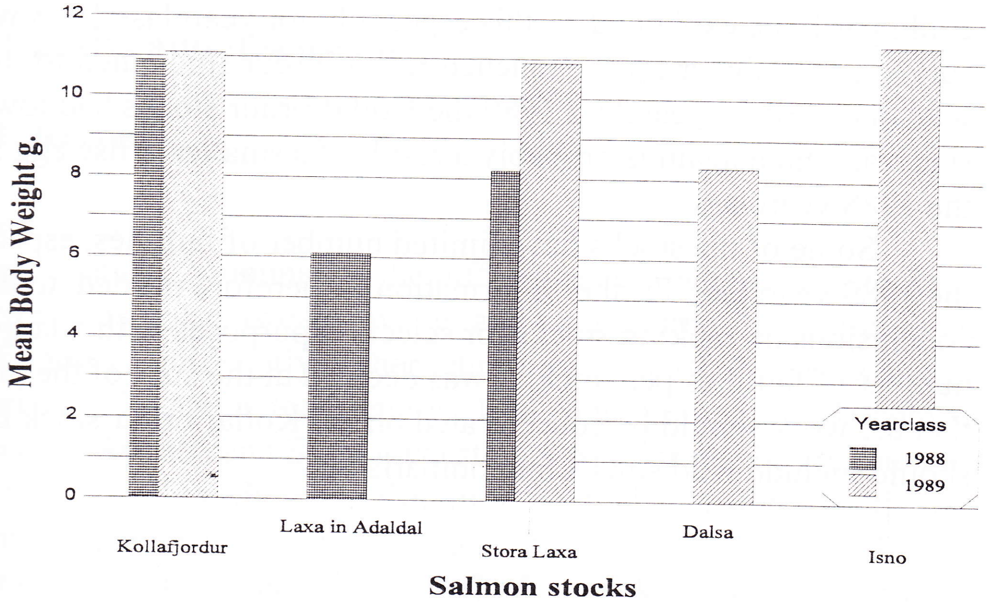

Figure 5.2 Mean body weight of parr from different salmon stocks at an age of 190 days of rearing in freshwater.

In Table 5.2 phenotypic correlations between egg size, survival, parr body weight and body length at 190 days of age is shown. All correlations were significant except between weight and egg size in 1989 yearclass.

Table 5.2 Phenotypic correlations between egg size and survival, parr body weight and body length at 190 days of age.

	Yearclass 1988	Yearclass 1989	Total
Survival	0.21**	0.30**	0.23**
Weight	0.27**	0.14	0.23**
Length	0.25**	0.18*	0.22**

*P<0,05, **P<0.01.

Egg size is positively correlated to survival and body weight and body length after 190 days of feeding. Larger eggs result in larger fry and higher survival at early stages through the startfeeding period. Larger fry also have a head start in size at the beginning of the startfeeding period.

There is considerable variation among stocks in survival at early stages and mean weight at 190 days of age. This can be due to genetic differences or levels of domestication. Differences in freshwater survival could partly be explained by this especially for yearclass 1988 where survival was higher for the ranched Kollafjordur stock then for the two wild ones. But in yearclass 1989 the Kollafjordur stocks had low survival which again is probably a result of a smaller grilse egg size than the 1988 yearclass.

Some of the stocks have limited number of families, especially in the 1989 yearclass. Further information is therefore needed to draw conclusions on ranking stocks for selection purposes with a larger number of families per stock. It was decided at the start of the project that the work should be concentrated on the Kollafjordur stock but should include wild stocks for comparisons.

6 Comparison of salmon stocks in sea ranching

6.1 Introduction

The results are from four yearclasses, 1988,1989, 1990 and 1991 for the ranching phase, where the first three yearclasses include results from grilse and two sea winter salmon but only the grilse stage for yearclass 1991 is included as two-sea winter salmon will return in the summer of 1994.

Number of fish returning, unadjusted means of return rates for grilse and two sea-winter salmon, mean body weight, and mean body length for each release site for Iceland are presented in the appendix.

6.2 Results and discussion

6.2.1 Iceland

Return rates
Table 6.1 and 6.2 summarize the difference between salmon stocks in return rate as grilse, two-sea winter and total returns. The Kollafjordur stock shows significantly higher returns as grilse (0.5%), as two-sea winter (0.53%) and in total returns (1.04%) in yearclass 1988 compared to Laxá in Aðaldal and Stóra Laxá stocks. Similar results are found for the 1989 yearclass where the Kollafjordur stock had significantly higher returns frequency as grilse (2.1%) and total return rate (2.4%) than the other three stocks tested. The Kollafjörður stock had significantly lower return rates as two-sea winter salmon compared to the Isno stock in yearclass 1989 but was not significant from the other two stocks. In the 1990 yearclass the Kollafjörður stock had significantly higher total returns. Only 18 fish returned for the Silfurgen stock so data are too limited to draw conclusions on differences between the two stocks.

In the 1991 yearclass the Lárós stock had the significantly higher return rates of grilse than the other stocks. The Kollafjörður stock did not have significantly higher return rates than the Eldi stock but significantly higher than the Isnó stock. The Eldi and Isnó were not significantly different.

Table 6.1. Least square means ± standard errors for salmon stocks adjusted for release site for return-rate and adjusted for release site and sex for body weight. Least square means within the same yearclass and column sharing the same letter does not differ significantly (P<0,05). Total biomass return per 1000 smolt release are also shown.

Stock	N	Lsmean as Grilse % (std.err)	Lsmean Salmon % (st.err)	Lsmean Total % (st.err)	Lsmean Grilse kg. (st.err)	Lsmean Salmon kg. (st.err)	kg/1000 Smolts Released
Yearcl. 1988							
Kollafjörð [1)]	608	0.51±.03a	0.53±.04a	1.04±.06a	2.2±.04a	5.6±.07a	40.7
Laxá Aðald[2]	57	0.26±.10b	0.22±.08b	0.49±.13b	1.9±.08b	4.9±.28b	14.1
Stóra Laxá[2]	60	0.54±.10a.b	0.18±.09b	0.72±.14b	2.1±.08a	5.3±.3a.b	17.2
Yearcl. 1989							
Kollafjörð[1]	1756	2.1±.07a	0.30±.02a.b	2.40±.08a	2.4±.01a	6.2±.11a	66.9
Stóra Laxá[2]	72	0.7±.26b	0.41±.08a	1.13±.27b	2.4±.1a.b	7.0±.3b.c	47.2
Dalsá[2]	41	1.0±.40b	0.35±.12a	1.33±.42b	2.3±.1a.c	6.6±.37a.c.d	45.2
Isnó[1]	122	0.7±.19b	0.45±.06a.c	1.10±.20b	2.4±.04a	6.3±.2a.e	50.7
Yearcl. 1990							
Kollafjörð[1]	620	2.7a	0.82a	3.4a	2.7±.02a	6.2±.07a	123.5
Silfurgen[3]	18	1.6a	0.46a	2.1b	2.6±.14a	7.1±.39b	75.7

[1] Ranching stock, where broodfish are used from fish returning to the ranching station.
[2] Wild stock, where the broodfish is taken directly from wild populations in their native rivers.
[3] Hatchery stock, where the broodfish is taken from populations used for traditional pen- or landbased rearing.

Mean Body Weight
Comparison of mean weight between stocks for the 1988 yearclass shows that the Kollafjörður stock had significantly higher mean weight

as grilse and two-sea winter salmon than the Laxá in Aðaldal stock, but

Table 6.2 Least square means ± standard errors for salmon stocks adjusted for release site for return-rate and adjusted for release site and sex for body weight. Least square means within the same yearclass and column sharing the same letter does not differ significantly (P<0,05). Total biomass return per 1000 smolt release are also shown. In the statistical analysis only microtagged smolt releases were used, as Eldi and Isnó were not tagged by coldbranding and finnclipping.

Stock	NUMBER N	%Return as Grilse % (st.err)	Lsmean Grilse kg. (st.err)	kg/1000 Smolts Released
Yearclass				
Kollafj.[1]	600	2.13±.13a	2.3±.01a	46.6
Laros[1]	343	2.73±.18b	2.4±.02b.c	64.3
Eldi[3]	125	1.72±.26a.c	2.2±.04a	34.6
Isno[1]	36	1.3±.40c	2.3±.06a.c	27.0

[1] Ranching stock, where broodfish is used from returning fish to the ranching station.
[3] Hatchery stock, where the broodfish is taken from populations used for traditional pen- or landbased rearing.

not different from the Stóra Laxá stock. For the 1989 yearclass there were no significant differences between stocks in grilse mean weight, except between the Stóra Laxá and Dalsá stocks where the Stóra Laxá stock had larger body weight.

As two-sea winter salmon the Stóra Laxá and Dalsá stocks had higher mean body weights than the other two stocks.

In the 1990 yearclass the two-sea winter salmon of the Silfurgen stock were significantly larger than those of the Kollafjörður stock. But only 4 fish returned as two-sea winter fish in the Silfurgen stock so the precision of the estimate is not high enough to compare the two stocks.

The Lárós stock in the 1991 yearclass had significantly higher mean weight compared to the Kollafjörður and Eldi stocks but not compared to the Isno stock. The Kollafjörður, Eldi and Isno stocks are not significantly different.

Grilse ratio to total return

Table 7.3 lists the grilse ratio to total return. In the 1988 yearclass the Kollafjörður stock had significantly lower grilse ratio to total return than the Stóra Laxá and the Laxá in Aðaldal stocks. No significant difference was found between Laxá in Aðaldal and Stóra Laxá grilse ratio to total return. This was unexpected because the Kollafjörður stock is usually classified as a grilse stock where higher number of grilse returning than two-sea winter salmon. One explanation can be that the broodfish used in the 1988 yearclass were only from two-sea winter salmon. In the 1989 yearclass the grilse to total return ratio for the Kollafjörður stock was significantly higher than for the Stóra Laxá stock and the Isnó stock. This is not surprising because all the broodfish from the Kollafjörður stock for this yearclass were grilse. No attempt was made to compare the two stocks in yearclass 1990 as limited returns were observed for two-sea winter salmon.

Table 6.3. Least square means±standard errors of grilse to total return ratio computed within year-class for different salmon stocks.

	Grilse	2-Sea winter salmon	Grilse vs salmon ratio
Stock	N	N	% ±std.err
Yearclass 1988			
Kollafjörður	288	320	49.4 ±2.5 a
Laxá in Aðaldal	32	25	58.8 ±6.8 a.b
Stóra Laxá	42	18	71.9 ±6.5 b
Yearclass 1989			
Kollafjörður	1524	232	88.4 ±1.0 a
Stóra Laxá	48	24	68.2 ±4.2 b.c
Dalsá	31	10	78.1 ±5.6 a.c
Isnó	67	55	56.2 ±3.3 d
Yearclass 1990[1]			
Kollafjörður	474	146	76.5
Silfurgen	14	4	77.8

[1] No statistical analysis were made for yearclass 1990 due to limited number of salmon returning in the Silfurgen stock.

Genotype-environment interactions

Table 6.4 shows the results of analysis of variance where the aim was to test if genotype-environment interactions existed.

Table 6.4 Analysis of variance for total biomass (kg/1000 smolts) of returning grilse and salmon for salmon stocks and release sites in three yearclasses. In yearclass 1991 analysis is made only for grilse of the Kollafjordur and Laros stocks as they were released at all release sites.

Source of variation	DF	Sums of squares	Mean square	F-value
Yearcl.1988				
Between stock	2	24825.01	12412.51	13.04***
Between release sites	1	3373.08	3373.08	3.54NS
Interact: stock x release site	2	1565.39	782.70	0.82NS
Residual	253	240837.33	951.93	
Sum	258	277383.72		
Yearcl. 1989				
Between stock	3	33379.22	11126.41	7.27***
Between release sites	2	14918.80	7459.40	4.87**
Interact: stock x release site	6	11465.63	1910.94	1.25NS
Residual	399	610726.20	1530.64	
Sum	410	743725.42		
Yearcl. 1991				
Between stock	1	18353.18	185353.18	8.64**
Between release sites	3	51338.16	17112.72	8.06***
Interact: stock x release site	3	11791.37	3930.46	1.85NS
Residual	307	651833.39	2123.24	
Sum	314	728030.69		

The table shows that there is no significant interaction between stocks and release site for the three yearclasses. When there is no interaction, then the best genotype at one release site is best at all release sites. This becomes important when planning future breeding work, where one can base selection on one salmon stock for the different release sites tested.

Selection of ranching stock
In general as shown in figure 6.1 and 6.2 , and tables 6.1 and 6.2 the ranching stocks Kollafjörður and Lárós stocks gave the highest yield in total biomass (kg/1000 smolts released) compared to other stocks tested. This is not unexpected as both stocks have been used in ranching for

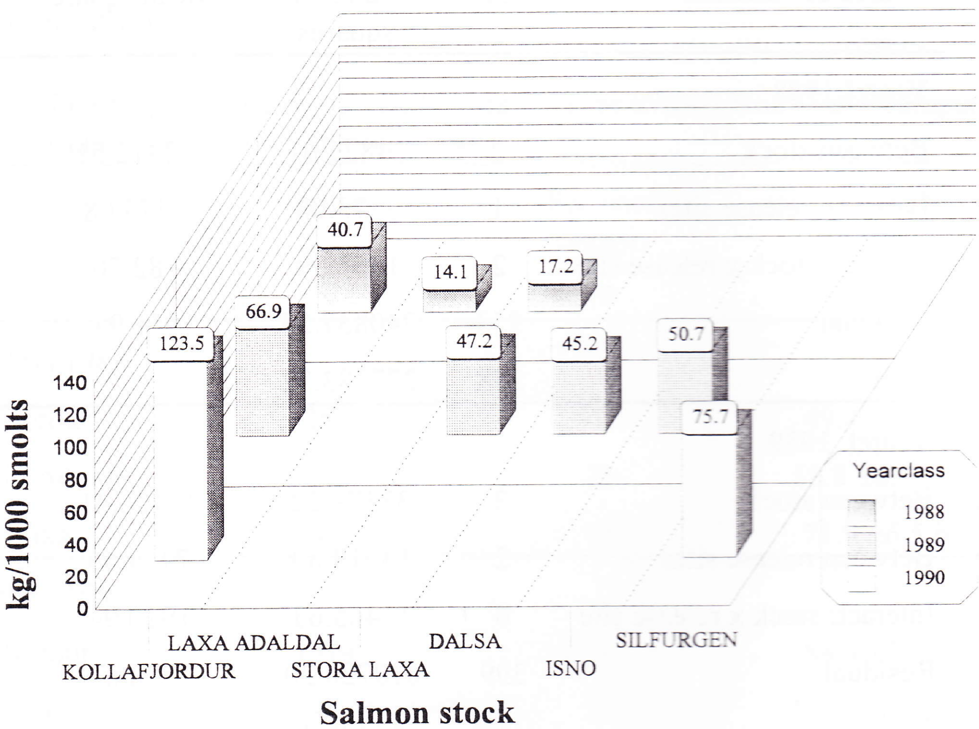

Figure 6.1 Total weight in kg/1000 smolts released for various salmon stocks in three yearclasses.

over 30 years in Iceland. At Kollafjörður Experimental Fishfarm and Lárós ranching station the largest individuals among the returning fish have always been selected as broodstock. In general, the largest grilse males have been selected and mated to both grilse and two-sea winter salmon females (Sigurdur Thórdarson and Jón Kr. Sveinsson personal communication). In table 7.4 in chapter 7 the estimated genetic correlation between body weight of grilse and total return rate to 0.31±0.19 and between weight at tagging and grilse body weight to 0.26±0.13, indicating that selection for increased body size of grilse will increase total return rate and growth rate in freshwater. The selection of

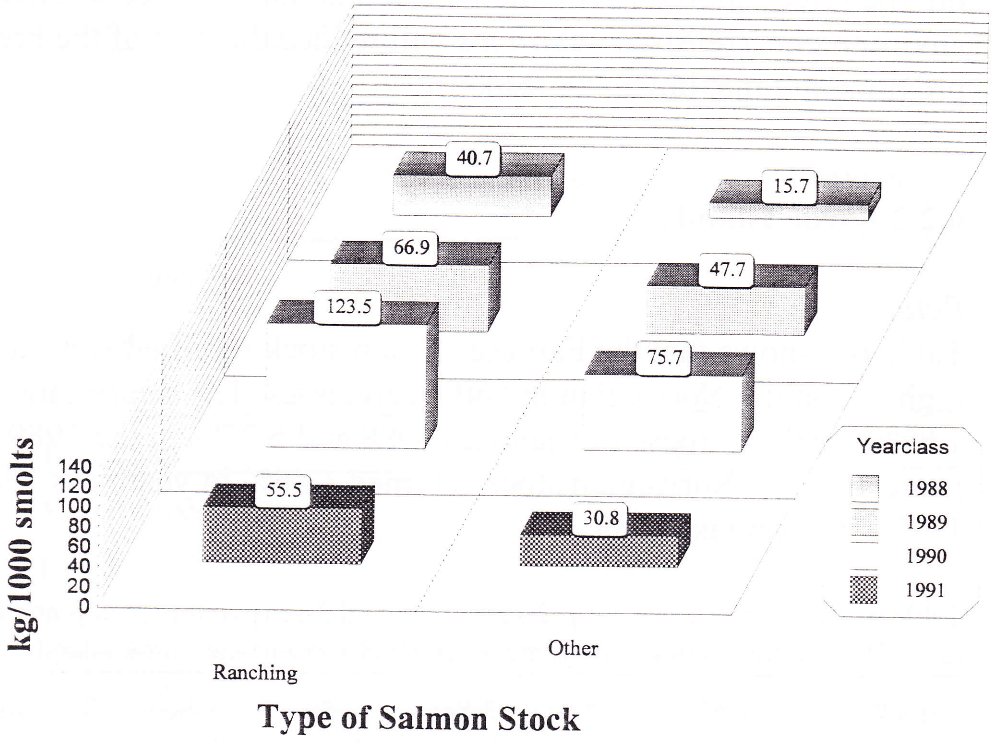

Figure 6.2 Comparison of total weight for 1000 smolts released of Ranched stocks (Kollafjörður and Lárós) via stocks of other origin.

the largest returning grilse males as broodstock at the sea ranching stations may consequently have improved the total return rate. This may be an explanation to the better performance of the sea ranching stocks compared salmon stocks of wild and hatchery origin.

The results show that traditional sea ranching stocks generally had higher return rates and should be used as base population if available when starting a breeding program for sea ranching.

Some of the stocks used in this experiment were represented by a limited number of families, especially in the year-classes 1989 and 1990. Strong conclusions about the ranking of the sea ranching performance of those stocks should consequently not be drawn.

The results have implications for sea ranching of Atlantic salmon where the main goal is to maximize total biomass at return per smolt released. The biomass at return can be determined by the return rate and body weight at return. In a breeding program for sea ranching where the goal is to increase return rate and body weight at return by combined individual and family selection it is a great advantage to be able to carry out the selection in one common stock that may be used in different environments (release sites). This will reduce the cost of the breeding program and maximize the response.

6.2.2 Faroe Islands

Return rate

Table 6.5 shows that the Faroese salmon stock returned significantly higher than the Norwegian in both yearclasses. The return rate was 1.82% for the Faroese in yearclass 1988 and 6.37% in the 1989 yearclass. The Norwegian stock returned 1.46% in yearclass 1988 and 1.77% in yearclass 1989.

Table 6.5 Return rate of grilse, 2-sea-winter and 3-sea-winter salmon and total return rate of two salmon stocks for yearclasses 1988,1989 in the Faroe Islands.

Stock	Grilse N	% Return as Grilse	2-Sea-Winter N	% Return as 2-Sea-Winter	3-Sea-Winter N	% Return as 3-Sea-Winter	Total return percent
Yearcl. 1988							
Faro Island	227	1.67a	20	0.15	1	0.01	1.82
Norwegian	159	1.11b	49	0.34	2	0.01	1.46
Total 1988	386	1.38	69	0.25	3	0.01	1.64
Yearc.1989							
Faro Island	280	6.30a	5	0.11	-	-	6.37
Norwegian	109.	1.48b	21	0.29	-	-	1.77
Total 1989	389	3.29	26	0.22	-	-	3.51

Body Weight

The mean body weight (table 6.6) and body length (table 6.7) is significantly higher for the Norwegian stock in both yearclasses. This results in higher biomass (kg/1000 smolts) for the Norwegian stock in yearclass 1988 even though the return rate was lower. The total biomass was higher for the Faroe Islands stock in yearclass 1989.

Table 6.6 Mean weight and standard deviation of grilse and two sea-winter salmon for two yearclasses in the Faroe Islands. Total weight expressed as kg/1000 smolts released is also presented.

Stock	Grilse N	Grilse Mean (kg)	s.d.	2-Sea-Winter N	2-Sea-Winter Mean (kg)	s.d.	kg/1000 smolts
Yearcl.1988							
Faro Islands	221	1.6a	0.4	20	2.8	0.9	31.5
Norwegian	152	2.5b	0.6	49	5.5	1.2	46.1
Total 1988	373	2.0	0.6	69	4.7	1.7	38.0
Yearcl. 1989							
Faro Islands	265	2.1a	0.6	3	3.0a		134.7
Norwegian	106	2.4b	0.4	21	5.8b	1.3	52.3
Total 1989	371	2.2		24	5.5	1.3	80.3

Table 6.7 Mean length and standard deviation of grilse and two sea-winter salmon for two yearclasses in the Faroe Islands. Total expressed as kg/1000 smolt released smolts is also presented.

Stock	Grilse N	Grilse Mean (cm)	s.d.	2-Sea-Winter N	2-Sea-Winter Mean (cm)	s.d.
Yearclass 1988						
Faroe Islands	221	56.0a	4.6	20	66.4a	6.7
Norwegian	152	64.6b	4.3	49	83.8b	7.8
Total 1988	371	59.8		69	78.8	
Yearclass 1989						
Faroe Islands	265	59.9a	4.9	3	71.4a	
Norwegian	106	62.8b	3.7	21	80.3b	6.0
Total 1989	371	60.7		24	79.2	

Table 6.8 shows that the Faroese stock has higher grilse ratio to total return compared to the Norwegian stock. This is not unexpected as the Faroese stock is originally from a typical grilse river (Elliðaár) in Iceland and the Norwegian stock is originally from the Norwegian breeding system for cage rearing, which is known to have a high percentage of two-sea salmon.

Table 6.8 Grilse ratio to total return for salmon stocks in the Faroe Islands for two yearclasses.

Stock	Grilse	Msw-winter Salmon	Grilse ratio to total return
Yearclass 1988			
Faroe Islands	227	21	91.5a
Norwegian	159	51	75.7b
Yearclass 1989			
Faroe Islands	265	3	98.9a
Norwegian	106	21	83.4b

When comparing the return rates between the releases in Iceland and the Faroe Islands the return rate for the 1988 yearclass was 0.96% in Iceland and 1.64% in the Faro Islands. In the 1989 yearclass the return rate was 2.3% in Iceland and 3.5% in the Faroe Islands. The reason for the difference between the two countries is not known.

It is interesting to see that the mean body weight for grilse is lowest for the Faroe stock in the 1988 yearclass. The two-sea winter salmon returning from the same yearclass were also smallest of the salmon returning. The Norwegian stock is more similar in body weight both for grilse and salmon compared to the stocks in Iceland.

Ranching of salmon is not a major activity in aquaculture in the Faroe Islands. Cage rearing of Atlantic salmon is the main industry. The only interest for ranching in the Faroe Islands is in connection with rod fishing. To get highest returns for rodfishing the Faroe Islands stock would be preferred but often in rod fishing two-sea winter salmon is preferred to grilse. In that case the Norwegian stock might be preferred even though return rates are lower.

7 Genetic variation

7.1 Estimation of family variation

In fishbreeding family selection in combination with individual selection is very effective. Therefore the magnitude of variation between families for different traits during the life cycle is of great importance for the significance of genetic change obtained.

7.1.1 Freshwater phase

Figure 7.1 shows mean body weight of parr for the five largest and the five smallest families in the yearclass of 1989 at an age of 190 days from startfeeding. The average sizes vary from 16.1 grams for the largest family to 4.8 grams for the smallest.

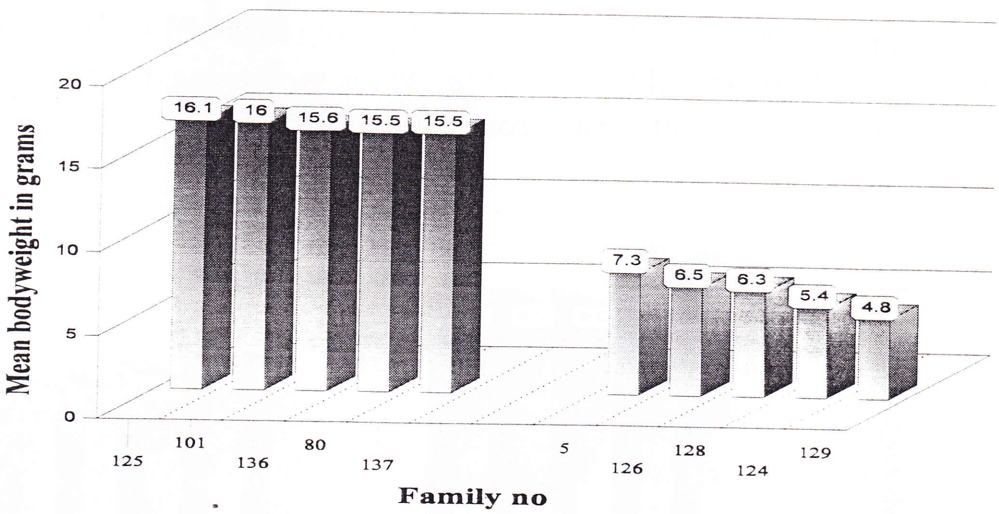

Figure 7.1. Mean body weight of family groups for the 5 largest and 5 smallest families at an age of 190 days from startfeeding. Mean body weight of all 148 families was 11.0 grams.

7.1.2 Seawater phase

Return rate of grilse for yearclass 1991 is shown in Figure 7.2 and the figure shows the variation between the five highest and the five lowest families in return rate. Return rates vary from 8.2 to 0% between families. This is a very large variation and shows that response to selection is possible for return rate.

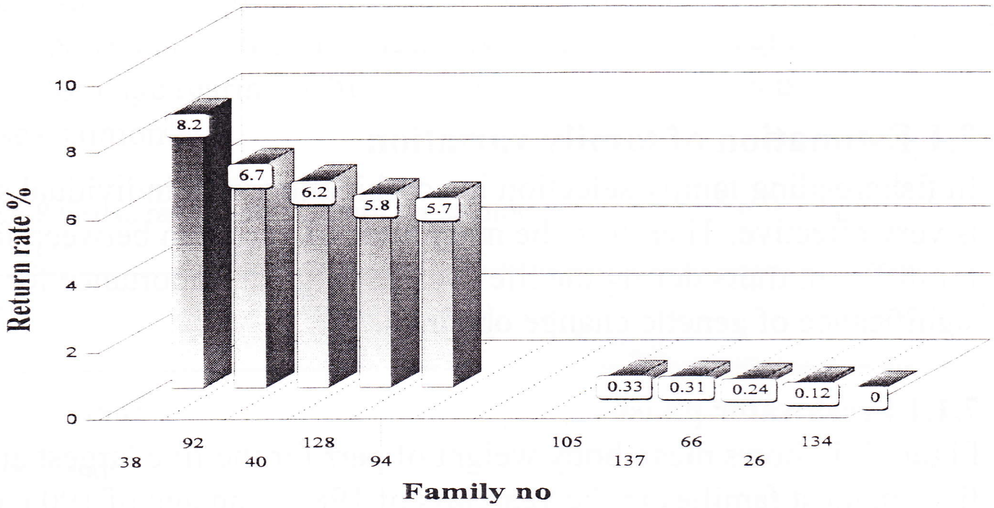

Figure 7.2 Return rate for all release sites of five best and ten lowest families in yearclass 1991(5 families with no return are not shown). Mean return was 2.25 % of 145 families tested.

In Figure 7.3 the mean body weight of grilse is shown for 10 families having the highest and the lowest grilse mean weights of yearclass 1991. The mean bodyweight varies from 2.7 kg to 1.8 kg.

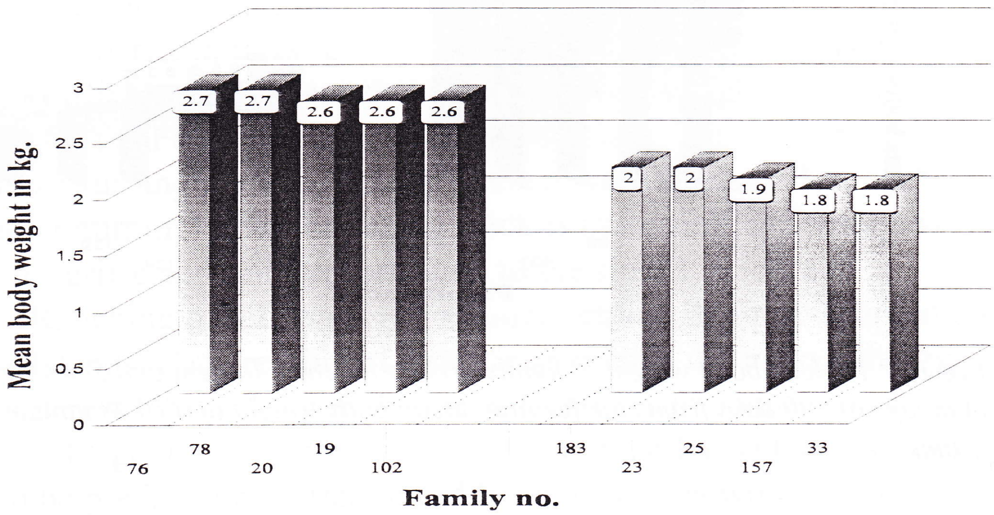

Figure 7.3 Mean body weight across release sites of the 10 families having the highest and lowest weight in yearclass 1991. Mean body weight was 2.33 kg for 145 families tested.

Family means as presented here may be influenced by factors like tray-tank-, maternal- and other environmental effects that can not be eliminated from the family averages. These effects may reduce accuracy in predicting breeding values. As it is of importance for breeding work to rank the families for their breeding quality, it is important to eliminate all non-genetic factors that result in variation between families. Therefore one mates one randomly sampled male (sire) to three randomly sampled females to make full- and halfsib families. The three halfsib groups will represent the genes from their common father (sire). If there is variation in return rate or body weight between sire groups then it is said that it is partly due to the pure additive gene effects and gives a picture of additive variation. In this way one rules out effects of dams (females) in the parent generation, as well as non-additive-, tray- and tank effects.
Figure 7.4 shows the return rate for the five best and the five poorest sire groups showing variation from 5.3 to 0% of the total 56 sire groups tested in yearclass 1991.

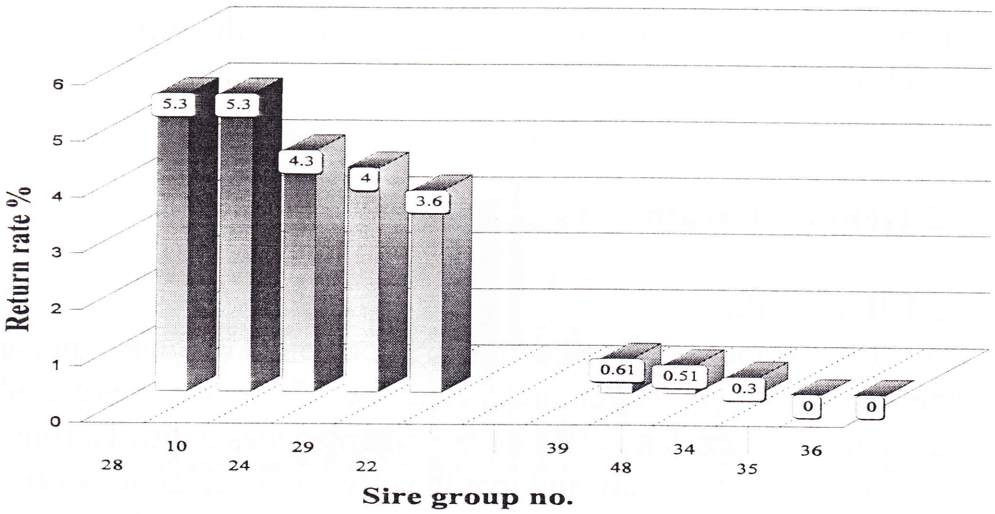

Figure 7.4 Return rate for all release sites of offsprings to the five best and five lowest sire groups (half-sib) in yearclass 1991. The mean return rate was 2.25 for 56 sire groups tested.

Figure 7.5 shows mean bodyweight of offspring for 10 sire groups having the highest and the lowest mean weight, showing variation from 2.7 to 1.9 kg.

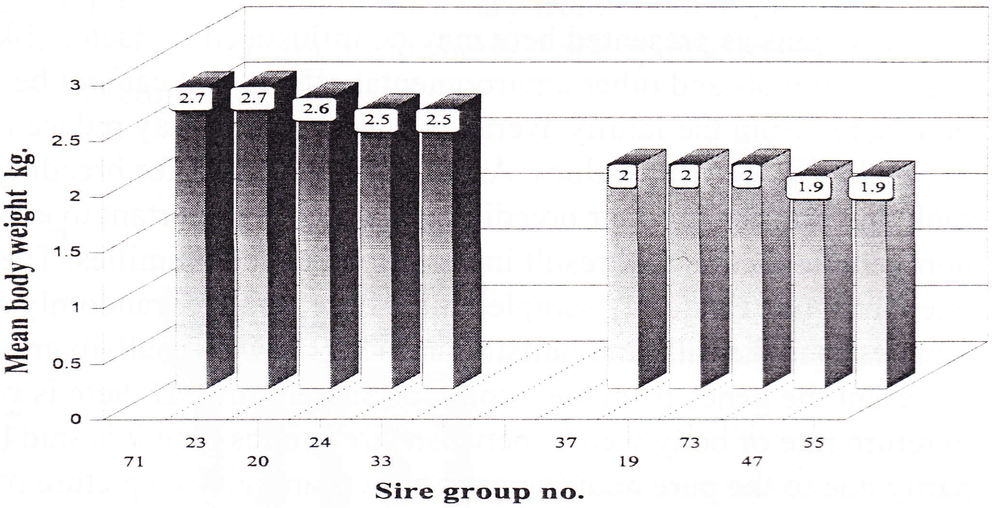

Figure 7.5 Mean body weight for all release sites of offsprings for 10 sire groups (half-sib) having the highest and lowest mean body weights in yearclass 1991. Mean body weight was 2.33 kg for 56 sire groups tested.

The figures shown here give an example of the variation between full- and half-sib families for given traits. Similar results were obtained for all yearclasses.

7.2 Genetic parameters

7.2.1 Heritabilities

Traits to be improved by selection are controlled by genes that are inherited additively, which means that the effects of genes are added. In quantitative genetics it is known how many genes control a trait, but we know that there are many and that the effect of each gene is very small. We can not estimate the individuals genotype for quantitative traits, but we can measure the phenotype of each individual. By estimating the phenotypes of a large number of animals that are related (half- and full-sibs). One can estimate the magnitude of the genetic variance.
Traits to be improved by selection must show continuous variation. Looking at frequency distributions for traits like return rate (figure 7.6) and growth rate (figure 7.7) they both show continuous variation. The distribution for return rate is skewed towards zero because the mean is only 2.4% for all families. If the mean had been higher one would expect the distribution to be more normal.

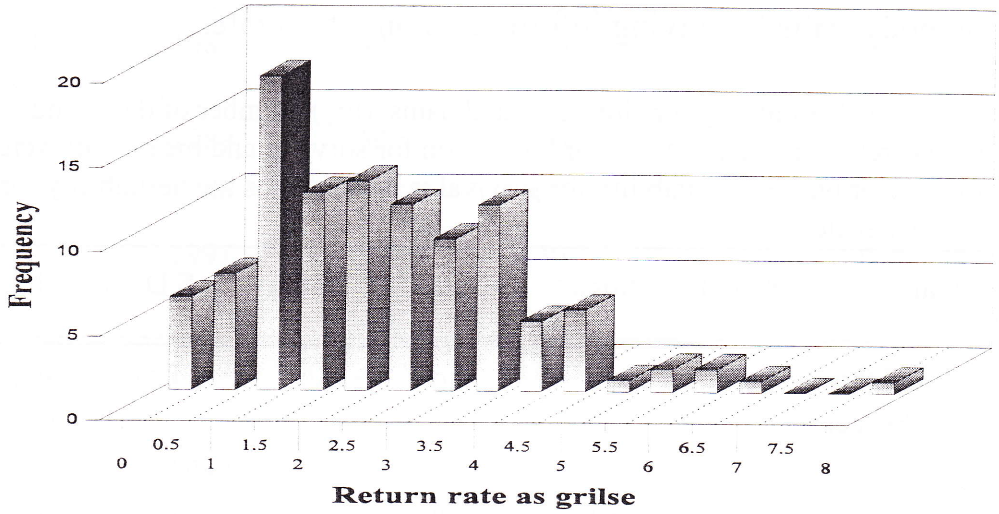

Figure 7.6 Frequency distribution for return rate in yearclass 1991 as grilse. 145 full-sib families tested.

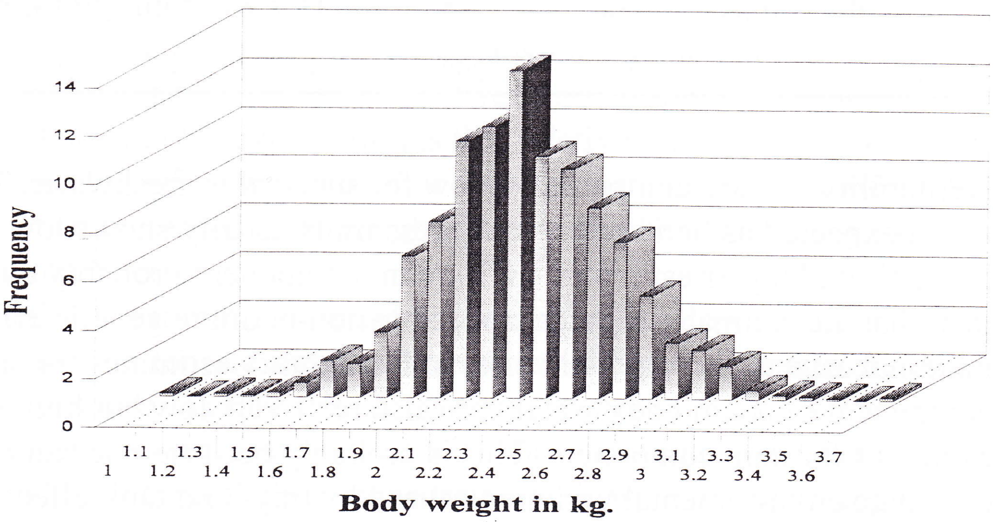

Figure 7.7. Frequency distribution for weight of grilse in yearclass 1991. Individuals of 145 full-sib families.

Table 7.1, 7.2, 7.3 and show the heritability estimates based of sire and dam components for the production traits in sea ranching. The tables do not show the same number of sires and dams available for the data analysis. This is due to fact that some of the families were not microtagged even though there is data available for the freshwater period. Also some of the families did not return from sea ranching giving no data on body traits but giving information on return rate.

Table 7.1. Heritability for sires (h^2_s) and dams (h^2_d), number of dams and sires used per yearclass, means and standard deviation for survival and mean bodyweight in freshwater phase. Heritability for survival is presented as the heritability for the liability scale.

Trait	Yearcl	Sires	Dams	Mean	S.D.	h^2_s	h^2_d
Survival in Freshwater	1988	50	150	69.2	19.11	0.02	(1.1)
--	1989	50	148	55.6	16.6	0.23	0.82
Total		100	298	-	-	0.1	0.9
Weight at 190 days	1988	50	150	9.4	5.2	0.19±.04	0.58±0.0
--	1989	50	148	11	5.8	0.15±.03	0.26±0.0
Total		100	298	-	-	0.16±.02	0.36±0.0

Heritability for sire component is low for survival in freshwater. This is not unexpected as heritability for fitness traits usually shows low heritability. Higher estimates are for dam component probably due to the fact, that the estimates include a possible non-additive genetic effects, maternal effects and tray/tank effects. Heritability estimates for sire component of mean body weight are also relatively low but higher estimates for dam component. This is probably because one can not eliminate environmental variation caused by tray- and tank effects. Due to low additive genètic variance for survival during the freshwater period, family selection is the only method for improving the survival rate. Increased survival can be achieved in the short term mainly by optimising environmental condition and management.

Estimates of heritability for body weight in freshwater show that the prospects for improving body size through selection are quite good, especially by applying family selection. The importance of the freshwater period in a salmon ranching system will be discussed later in connection with the genetic correlation between economic traits in salmon ranching.

Table 7.2. Heritability, number of dams and sires used per yearclass, means and standard deviation for mean body weight in sea ranching.

Trait	Yearcl.	Sires	Dams	Mean	S.D.	Heritab.
Weight of grilse	1988	44	100	2.21	0.41	0.24±0.24
--	1989	50	136	2.26	0.33	0.19±0.10
--	1990	38	87	2.76	0.44	0.36±0.20
--	1991	54	139	2.33	0.34	0.28±0.15
Total		186	462	2.37	0.38	0.36±0.11
Weight of Salmon	1988	42	106	5.24	0.72	0.03±0.20
--	1989	50	121	5.68	1.0	0.0±0.12
--	1990	34	64	5.9	0.78	0.11±0.36
Total		126	291	5.5	0.85	0.0±0.15

Heritability for body weight of returning grilse is relatively high but low for body weight of returning two-sea winter salmon (Table 7.2). The reason for this large difference between grilse and two-sea winter salmon is not known. One explanation is that relatively few salmon returned compared to grilse which gives a poor estimate of the heritability. Results show that increased body weight could easily be achieved by individual selection of grilse.

Heritability estimates of return rate are relatively low (Table 7.3). Similar estimates are for sire and dam component. Higher estimates are obtained for return rate of grilse than for two sea winter salmon. This is not unexpected as survival traits usually show low additive genetic variance. Survival is a typical all-or-none traits or binary. For improving these traits family selection must be used according to these estimates. The prospects for improving return rate by selection is quite good especially for the return rate of grilse.

Table 7.3. Heritability for sires (h^2_s) and dams (h^2_d) components, number of dams and sires used per yearclass, means and standard deviation for return rate of grilse and salmon in sea ranching. Heritability for return rate is presented as heritability on the liability scale.

Trait	Yearcl.	Sires	Dams	Mean	S.D.	h^2_s	h^2_d
Return % grilse	1988	50	136	0.48	0.63	0.13	0.15
--	1989	50	140	1.86	1.5	0.11	0.07
--	1990	38	91	1.98	2.11	0.24	0.2
--	1991	56	145	2.53	2.32	0.08	0.12
Total		194	512	1.81	1.91	0.12	0.12
Return % salmon	1988	50	136	0.32	0.72	0.03	0.03
--	1989	50	140	0.31	0.54	0.07	0.04
	1990	38	91	0.76	0.41	0.01	0.11
Total		138	367	0.42	0.83	0.02	0.06
Total return [1)]		138	367	1.81	1.67	0.08	0.07

[1)] Total return of grilse and salmon for three yearclasses

7.2.2 Genetic correlations

Until now parameters for each trait have been discussed. But in breeding work one must also study the correlations among the traits in order to investigate the correlated responses in other traits. To look at this more closely genetic correlations between the traits should also be estimated. Table 7.4 lists genetic correlations for the traits listed above. In addition correlations are estimated for kg/1000 smolts released which is a measure of the biomass returning for both grilse and salmon.

Survival in freshwater

Survival in freshwater is positively correlated genetically to all traits studied. The estimate of genetic correlation of survival with two-sea winter salmon body weight is unrealistic possibly due to few salmon returning. Survival in freshwater is positively correlated with return rate of grilse, salmon and total return rate. This is interesting since if one selects for increased return rate one would also increase survival in the freshwater period. The highest and significant genetic correlation is observed with biomass as kg/1000 smolt released.

Table 7.4 Genetic correlations calculated from sire components of variance and covariance for lifehistory traits in salmon ranching.

	Survival freshwater	190 day body weight	Tagging body weight	Return rate as grilse	Grilse body weight	Return rate salmon	Salmon body weight	Return rate total	Biomass grilse	Total Biomass
Survivival freshwater		0.31±0.26	-0.22±0.13	0.27±0.14	0.04±0.20	0.20±0.19	(-1.5±1.5)	0.33±0.14*	0.19±0.16	0.37±0.16*
190 day body wei.			0.60±0.11***	0.19±0.10	0.14±0.13	0.24±0.16	0.30±0.76	0.05±0.12	0.01±0.11	0.15±0.12
Tag bodywei.				0.17±0.10	0.26±0.13*	0.24±0.15	0.15±0.72	0.01±0.12	0.01±0.13	0.11±0.13
Return rate as grilse					0.16±0.16	-0.29±0.16	0.08±0.67	0.98±0.01***	0.98±0.01***	0.90±0.04***
Grilse bodywei.						0.20±0.20	-	0.31±0.19	0.23±0.16	0.61±0.19*
Return rate as salmon							0.33±1.2	-0.09±0.17	-0.29±0.16	0.12±0.19
Salmon bodywei.								0.14±0.74	0.21±0.69	0.36±0.86
Return rate total									0.94±0.03***	0.92±0.03***
Biomass grilse										0.92±0.03***

* $p<0.05$, ** $p<0.01$, *** $p<0.001$

190 day bodyweight
The 190 day bodyweight is positively correlated to all traits, the highest genetic correlation is with weight at tagging. This is not unexpected as tagging took place 1 to 2 months after the 190 days bodyweight was recorded. Relatively low correlations are observed with other traits but of those it is highest with return rate of salmon.

Bodyweight at tagging
Body weight at tagging is similar to 190 day bodyweight and positively correlated to all other traits. The highest genetic correlation is with grilse bodyweight.

Return rate as grilse
Return rate as grilse is positively correlated genetically to grilse body weight, total return rate and biomass. It is not unexpected that return rate is positively correlated to biomass as most of the returns are grilse. Return rate for grilse is negatively correlated to return rate of two-sea winter salmon. This correlation indicates that these two characters are different traits that link negatively genetically.

Grilse bodyweight
Grilse body weight is positively correlated to all traits except two-sea winter salmon body weight where correlations could not be calculated due to a limited sample size as only 1-3 salmon in average return per family. The highest correlations were observed between biomass and total return rate.

Return rate as two-sea winter salmon
Genetic correlations with all traits are in general low or unrealistic due to few two-sea winter salmon returning.

Two-sea winter salmon body weight
Generally the correlations between salmon body weight and other traits are of less importance. This is due to the large standard errors observed for genetic correlations between salmon body weight and other traits.

Total return rate
Total return rate id positively correlated to biomass. This is not unexpected as most of the returns are grilse.

In general the genetic correlations in table 7.4 show high genetic correlations between the return rate of grilse and biomass of grilse as well as total biomass. Rather low genetic correlation are observed for return rate of two-sea winter salmon and total biomass. This indicates that if one wants to increase biomass in a ranching system one would concentrate the work on increasing return rate of grilse by selection.
The high genetic correlations between grilse return rate and grilse biomass indicate that the trait is highly dependent on return rate and less on individual body weight.

7.3 Genotype-environmental interaction

As mentioned previously the families were split up at tagging and released from different release sites. Table 7.5 shows the results of analysis of variance where the aim was to test if there exists genotype-environment interactions for biomass of grilse between the same families at different release sites.

Figure 4.1 shows the locations of the different release sites. The analysis shoves that the highest source of variation is for sires within stocks, considerable higher than for between stocks. There may be two reasons for the interaction, either a scaling effects due to different biomass to different release sites or reranking of sire groups between release sites.

The table shows that there is no significant interaction between stocks and release site or between sire(stock) and release site for the three yearclasses. When there is no interaction one expects the best genotype at one release site is best at all release sites. Here the genotype are stocks and sire within stocks. The results thus indicate that there is little or no genetic-environmental interaction between release sites for biomass. Even though the interaction is not significant and 8.7-9.9 % of the variation is explained by the interaction of sire(stock) and release site the interaction should not be ignored. Therefore one can base selection on one salmon stock rather then having a separate salmon stock for each release site and families must be tested at two or more release sites to secure overall performance of the families in the selection program.

Table 7.5 Analysis of variance for total biomass (kg/1000 smolts) of returning grilse three yearclasses. In yearclass 1991 analysis is made only for the Kollafjörður and Lárós stocks as they were released at all release sites.

Source of variation	DF	Sums of squares	Mean square	F-value	% of sums of squares
Yearcl.1988					
Stock	2	1739.9	870.0	4.75***	3.1
Release sites	1	290.5	290.5	1.59NS	0.5
Sire(stock)	45	18785.3	417.5	2.28***	33.1
Stock x rel.	2	151.4	75.7	0.41NS	0.3
Sire(stock) x release site	44	5884.4	133.7	0.73NS	10.3
Residual	164	30039.0			
Sum	258	56716.9			
Yearcl. 1989					
Stock	3	65825.3	21941.8	29.51***	13.5
Release sites	2	4972.5	2486.2	3.34**	1.0
Sire(stock)	47	14147.2	3109.5	4.18***	30.3
Stock x rel.	6	5074.2	845.7	1.14NS	1.04
Sire(stock) x release site	92	48490.1	527.1	0.71NS	9.9
Residual	260	193298.6	1448.93		
Sum	410	487519.3			
Yearcl. 1991					
Stock	1	23930.58	23930.588	13.4***	3.3
Release sites	3	47127.46	15709.15	8.8***	6.5
Sire(stock)	30	205409.84	6847.00	3.84***	28.2
Stock x release site	3	10824.71	3608.24	2.02NS	1.5
Sire(stock) x release site	75	71171.10	948.95	0.53NS	9.8
Residual	202	360579.64	1785.05		
Sum	314	728030.69			

7.4 Comparison of body weight of families returning as grilse in ranching and families reared on a land based farm

For the evaluation of a breeding plan for salmon ranching one of the possibilities is to rear samples of all the families that are released in a land based farm for later use as broodstock. In order to estimate the genotype-environment interaction for body weight, genetic correlations between the two environments can be calculated.

In the 1991 yearclass, 96 families were split into six subgroups, one for rearing on land at Stofnfiskur and five were released in sea ranching. Figure 7.8 shows the locations for each release site and the landbased rearing unit at Stofnfiskur on the Reykjanes peninsula.

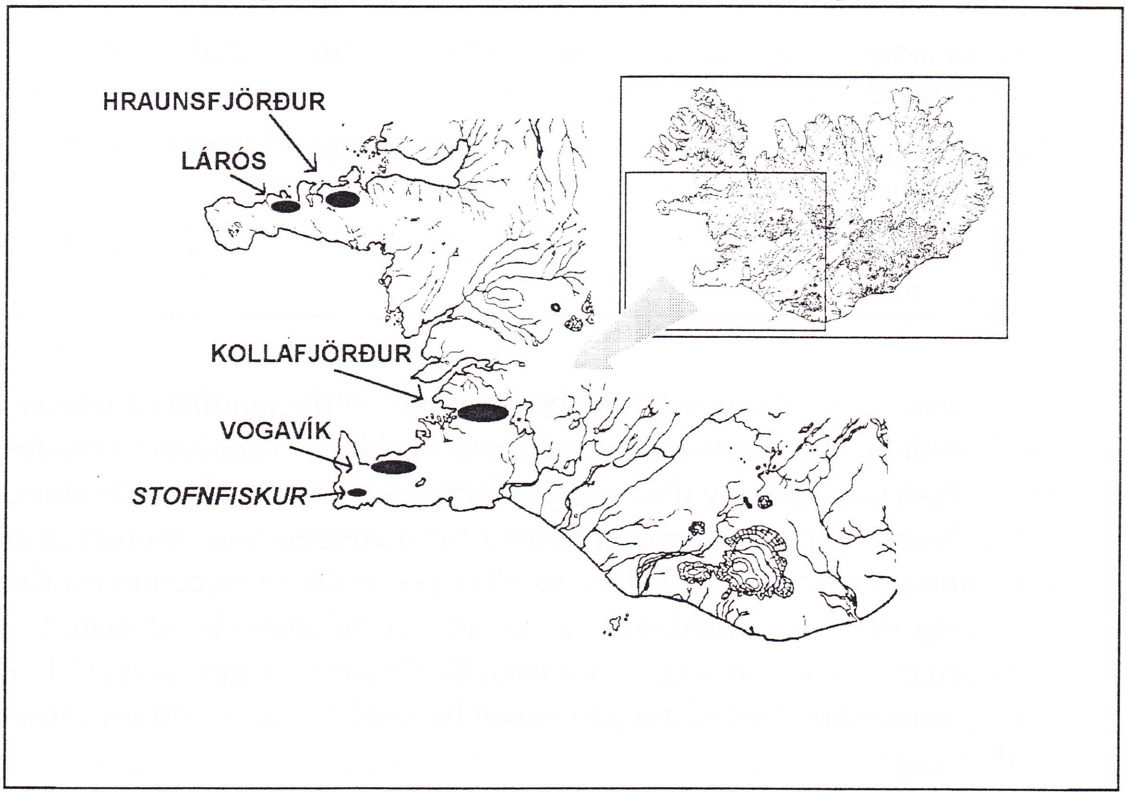

Figure 7.8 Locations of ranching release sites and Stofnfiskur landbased fish farm.

All families that were reared in the landbased unit in Stofnfiskur were tagged by using the combination of coldbranding and finclipping. A comparable group (Kollafjörður 2) was also freezebranded and finnclipped and released from Kollafjörður Experimental Fish Farm. Comparable groups were also microtagged and released from Kollafjordur, Vogavík, Silfurlax (Hraunsfjörður) and Lárós.

Table 7.6 lists the number of families used in the experiment. Body weight and other data are presented for the releases from Kollafjörður

Experimental Fish Farm and the total material for returns to all release sites. Results for other individual release sites are not presented as the number of fish per family returning there was limited.

Table 7.6 Overview of material used for calculations of genetic correlations between landbased bodyweight and bodyweight in sea ranching.

Rearing/release site	Sires	Dams	Smolt size(g)	N	Mean weight	S.D.	h^2 ±st.err
Landbased at Stofnfiskur	31	96	36.4	1884	0.67	0.30	0.27±0.11
Kollafjordur microtagged	31	96	23.5	469	2.25	0.33	0.23±0.22
Kollafjordur coldbr/finncl.	31	96	36.4	400	2.45	0.32	0.05±0.18
Total ranching (incl. Kollafjordur)	31	96	~24.0	1504	2.33	0.35	0.29±0.15

Genetic correlations between body weight in the landbased unit and body weight of grilse from sea ranching (Table 7.7) are low to moderate (0.23-0.46), suggesting that using information on growth performance in a landbased unit as a selection criteria for increased body weight in sea ranching unit would be 23-46% as effective as direct selection on fish returning from sea ranching. High genetic correlations is estimated between the two groups released from Kollafjörður Experimental Fish Farm, suggesting that either group can be used for selection for increased body weight.

Table 7.7. Estimated genetic correlations for bodyweight in a landbased farm and grilse returning from sea.

Rearing/release site	Kollafjordur microtag.	Kollafjordur cold/fincl.	Total ranching
Landbased at Stofnfiskur	0.23±0.34	0.46±0.29	0.23±0.34
Kollafjordur microtagged	--	0.96±0.16	--

The reason for the low genetic correlations between bodyweight in landbased farm and grilse from sea ranching is not clear. One of the reason might be that fish measured are quite different in sizes, all the fish in tanks on land were not mature but all fish returning were approaching maturity.

The genetic correlations between body weight at return in sea ranching and body weight in landbased farming was low to medium and not significant showing that these two traits are probably partly controlled by different sets of genes. This suggests the existence of genotype by environment interaction . The growth trait in the present study is an expression of genetic potential within two widely different test environments. In salmon ranching, body weight may be affected by genes controlling survival, age at maturity, success in capturing pray, temperature, behaviour etc. Growth in landbased farm will be affected by stress sensitivity, temperature, behaviour (eg. aggression), food conversion efficiency etc. Natural selection in salmon ranching may bias the estimate of genetic correlation between ranching and landbased farming as return rate was low where over 97% of released smolts do not return as grilse.

In a selection program in salmon ranching, where the breeding goals are increased return rate and body weight, the best selection method would be combined individual and family selection by using returning fish for broodstock. The ranking of the families for selection should be based on their performance in return rate and growth rate in the sea. Therefore enough smolts must be tagged and released per family to get a estimate on the families breeding value. However, low returns occur frequently in sea ranching which means few fish in each family and individual selection within families for body weight will be difficult and inefficient. Therefore by securing enough broodstock from all the released families on a landbased farm one will be able to perform selection even though returns were low. This will at the same time secure big enough supply of eggs to the industry. The production capacity of eggs in the landbased unit should depend on the demand from the industry.

Even though the genetic correlations are low between sea ranching and land based farming for body weight one should also use the largest fish on the landbased farm for broodstock but the efficiency of selection for increased body weight will be lower compared to using returning fish from sea ranching as broodstock.

8 Realized and expected response to selection for increased return rate of grilse

From various breeding programs it is clear that production parameters, such as growth rate can be improved by selection. One of the most important principles of selection is that genetic gain is additive and traits will continuously by improved as long as selection is being carried out. The main objective of a breeding program, for a normally distributed trait is to move the mean value of the trait in the desired direction (Figure 8.1); or for a trait with discrete classes, to increase the frequency of the desired class(es). A change in the population mean or class frequencies from one

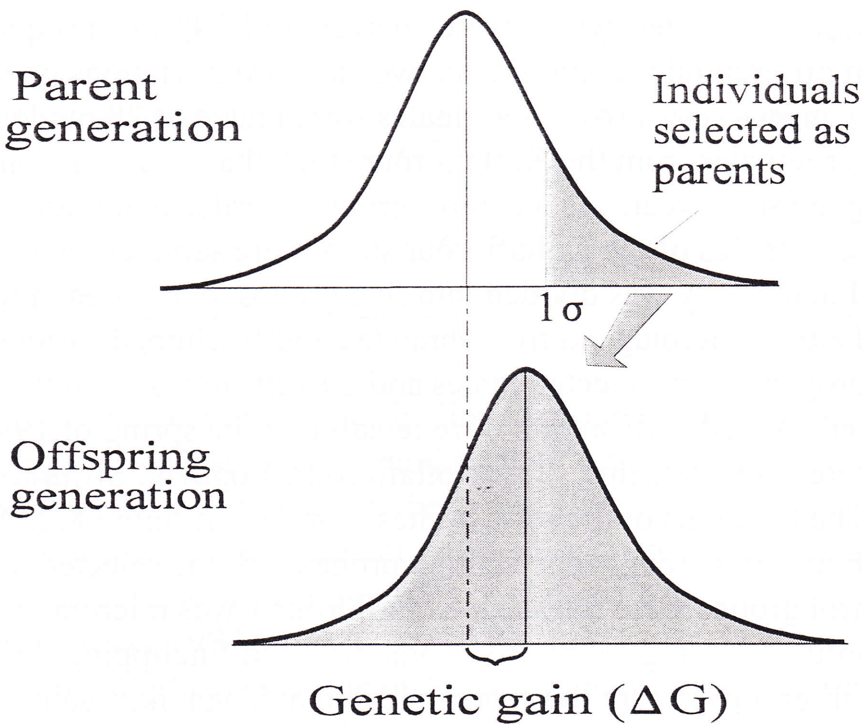

Figure 8.1 Illustration of genetic gain obtained by one generation for selection of one standard deviation above the mean in the parent generation.

generation to the next is termed genetic gain. While selection is practised the genetic gain will be added in future generations and increase the yield for each generation. Genetic gain can be obtained by applying different breeding strategies. As return rate in a ranching system for Atlantic salmon is a binary trait (typical for survival traits), family selection is the best selection method to obtain response. By family selection whole families are selected or rejected as units according to the mean return rate of the family. The magnitude of genetic gain is dependent on: intensity of selection, heritability, standard deviation and the generation interval.

8.1 Material

Realized response

In 1989 136 families were released from Kollafjörður Experimental Fish Farm and Vogavik in Iceland. Grilse return rate in 1990 was on average 0.51% (standard deviation 0.57) for all families. As return rate was low, no grilse females were available as broodstock from the returning families. A family selection of returning males from sea ranching as grilse was used. Six grilse males were selected from the 6 families with the highest return rates, which were on average 1.74%. Consequently, the selection differential was more than two standard deviations on the scale of family means (i=2.116). These males were mated to 28 random two-sea winter females from the Kollafjörður stock that returned from sea ranching the same year. As a control group 16 grilse males and 45 two-sea winter females of the Kollafjörður stock were sampled randomly and mated. Each family was divided into five groups, one for each release site, and either microtagged freezebranded and finclipped. A total of 16.286 progeny from selected males and 20.720 smolts from the control group were tagged. All smolts were released in the spring of 1992 from four different sea ranching sites: Kollafjörður, Vogavík, Silfurlax and Lárós. The locations of the release sites is shown in figure 8.2. At Kollafjörður, two groups representing progeny of the selected males and two control groups were released. Kollafjörður 1 was microtagged, Kollafjörður 2 was tagged by freezebranding and finclipping. Prior to release, all groups except the group released at Vogavík, a salmple was measured for body weight and body length. It was not possible to record the difference between the selected and control groups at weighing just before release in May 1992 as the groups were microtagged and tags could not be read on live fish.

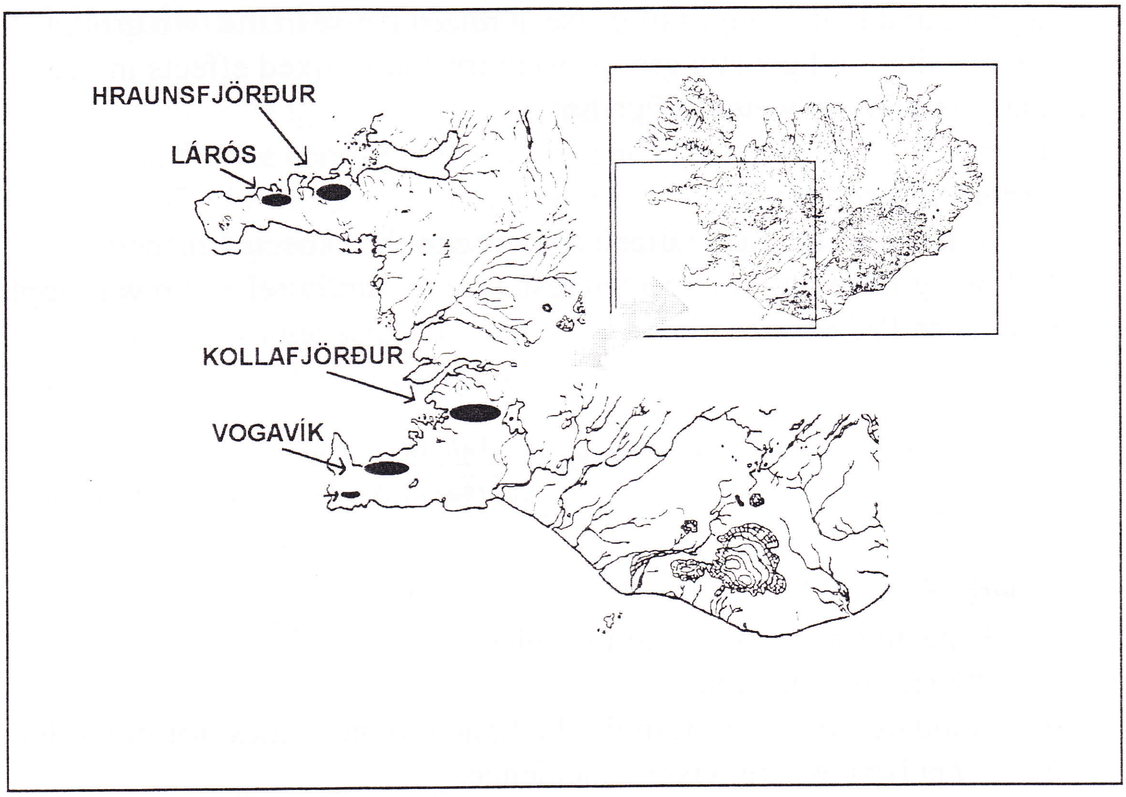

Figure 8.2 Locations of ranching release sites.

Table 8.1 shows the size of smolts at each release site prior to release.

Table 8.1 Sizes of smolts prior to release in May 1992 at three different release sites.

Release site	Kollafjörður 1	Kollafjörður 2	Silfurlax	Lárós
Weight (gr)	23.5±5.5	36.4±9.8	21.8±5.5	27.5±5.8
Length (cm)	12.9±1.2	14.7±1.3	12.8±1.3	13.3±1.3

The freezebranded and finclipped group released as Kollafjörður 2 was largest. Because of coldbranding they were kept at higher temperature for two months in the fall of 1991.

Fish from the experiment returned as grilse during the summer of 1993 to all release sites and returns of two-sea winter salmon is expected during summer 1994.

The significance of the difference in return rate between progeny from the selected males and from the control groups was tested by an analysis of variance for categorical data (CATMOD procedure, SAS 1988), where the fixed effects of release sites (1-5) and test-groups (1-2) and their interaction were included in the model. A generalized least square model was used to test the difference in body weight of parr at tagging and body weight of grilse at return between the two groups. Sex, release sites and genetic groups were treated as fixed effects in the analysis of body weight of grilse.

Expected response

To compare the realized response to the expected response the following formula for expected response to family selection was applied (Falconer 1989):

$$R_f = i\sigma_p h^2 \frac{1+(n-1)r}{\sqrt{n(1+(n-1)t)}}$$

Where

R_f = Expected response of family selection

i = intensity of selection

σ_P = standard deviation of individual phenotypic values, for binomial traits $\sqrt{p(1-p)}$, where p is the incidence.

h^2 = heritability of the trait

r = the additive genetic relationship between family members for full-sib, $r = \frac{1}{2}$

t = correlation of phenotypic values between family members. A large family sizes, $t \cong rh^2$

n = number of individuals per family.

In the predictions it is assumed that the return rate of the base population is 2.2% as was the case for the control group (Table 8.2). It is assumed that the intensity of selection is 2.116 (6 families out of 134 were slected, or 4.5%). The average number of full-sibs per family (n) was 430. The estimated heritability for return rate of grilse to 0.12 on the liability scale (Table 7.3). The trait return rate is a binary trait and the heritability estimate on the observed scale will consequently depend on the incidence (p). The estimate was transformed from the liability scale to the observed scale according to by the following formula (Dempster and Lerner, 1950)

$$h_x^2 = h_b^2 \left(\frac{1-p}{i^2 p}\right)$$

where h^2_x is the heritability on the liability scale and the h^2_b is the heritability on the observed scale for a binary trait, p is the incidence and i the corresponding mean liability.

8.2 Results and Descussion

The mean body length of the 6 selected males was 64.8 cm as compared to 64.0 cm for the control males used. The difference was not significant (P>0.05). The body weight at tagging was 17.4 grams for the control group and 18.4 grams for progeny of selected males. The difference was not significant (P>0.05).

Progeny of the selected males had higher return rates at all release sites compared to the control group (Table 8.2).

Table 8.2 Size at tagging, return rate and mean body weight at return of selected and unselected groups at different release sites.

GROUP	PLACE OF RELEASE	NUMBER RELEASED	NUMBER RETURN	RETURN RATE	BODY WEIGHT
Control	Kollafj. 1	9042	157	1.7	2.22 kg
Selected	Kollafj. 1	5654	144	2.5	2.22 kg
Control	Kollafj. 2	4802	168	3.5	2.44 kg
Selected	Kollafj. 2	2802	109	3.9	2.43 kg
Control	Vogavík	2399	34	1.4	2.07 kg
Selected	Vogavík	2703	56	2.1	2.14 kg
Control	Silfurlax	3011	53	1.8	2.28 kg
Selected	Silfurlax	2789	61	2.2	2.36 kg
Control	Lárós	1466	35	2.4	2.35 kg
Selected	Lárós	2338	65	2.8	2.45 kg
Control	Total	20720	449	2.2	2.29 kg
Selected	Total	16286	437	2.8^{***}	2.31 kg^{NS}

***P<0.0001 (NS) Non Significant (P>0.05)

The mean return rate of progeny of selected males was 2.8% as compared to 2.2% in the control group. As shown in Table 8.3 this difference was highly significant. A significant difference in return rate was also found between release sites. The body weight of smolts at release sites varied substantially between release sites (Table 8.1). However, no interaction was observed between the test groups and release sites, suggesting that genotype by environment interaction did not occur. For body weight of grilse no significant difference was observed between progeny of selected males and the control group (Table 8.3).

Table 8.3 Analysis og variance table for return rate, using test groups (selected and control), release sites and interaction between release sites and test groups as dependent variables.

	DF	Chi - square	Prob
Test groups	1	8.86	0.003
Release site	4	53.22	0.0001
Interaction	4	1.31	0.860

The expected response to the selection applied (R_f) was 2.4%. However, this estimate assumes that both sires and dams were selected, since dams in the present experiment were unselected, the esimate should be divided by two, giving an expected response of 1.2% or an increase in return rate from 2.2 to 3.4%.

The results from the present experiments are the first recorded estimates of response to selection for increased return rate in Atlantic salmon known to the authors. A family selection intensity of 2.116 standard deviations on the scale of full sib family means in one sex only (sires) resulted in an increase of return rate from 2.2% to 2.8% or a response to selection to 27%. This is lower than the predicted response which was estimated as an increase in return rate from 2.2% to 3.4% or a predicted response to selection to 45%. This is not uncommon that the predicted response are higher than observed. The reason for the difference is not known. A possible explanations are that natural selection in the sea can hinder the response, an overestimation of the heritability and selection differential, or that six sires were used from six families and the sires used may not necessarily reflect the families true breeding value.

The observed return rates varied between release sites, and also between the two groups released at the Kollafjörður Experimental Fish Farm. The main reason was probably the size difference of smolts between the groups at release and release methods used at each release site (Table 8.1).

No significant genotype by environment interaction is observed as the progeny of the selected sires returned in the highest at all release sites. No significant salmon stock by release site interactions was demonstrated in table 6.4 . This demonstrates the advantage of being able to use one common salmon stock for future breeding work.

McIntyre et al. (1988) reported an experiment where 30 full-sib families of Coho salmon were tested in sea ranching. They observed return rates of families ranging from 0.18% to 3.65%, averaging 1.57%. In 1971 they mated 30 single pair matings from the eight families with the highest return rates. Fifteen pairs of random breeders were used to produce a control group. In the following year-classes they used a hierarchial mating design were one male was mated to 2 to 5 females. In 1974 they produced 22 families from selected parents and 10 control families, in 1977 they produced 10 families from selected parents and 12 control families and in 1980 they produced 30 families from selected families and 30 control families. They observed a positive response to selection for return rate in the 1974 yearclass where the progeny of selected parents had a significantly higher return rate ($P<0.05$) compared to the control families, but not in 1971, 1977 and 1980. In 1977 and 1980 the control groups seemed to show a non significantly higher return rates than the progeny of selected parents. They suggested that a possible trend towards lower return rates in the selected line may have occurred because of changes in the oceanic conditions or because of accumulation of deleterious inbreeding. They concluded that selection was not an efficient method to increase survival of smolts in coho salmon ranching at Big Creek Hatchery. The life cycle of Coho Salmon is similar to the life cycle of Atlantic salmon.

The trait return rate has obviously been under continuous natural selection for thousands of years, and the natural selection intensity has been high. Still the trait seems to show genetic variation (Table 7.3) and considerable response to selection was obtained in the present experiment. The maintenance of genetic variation may be caused by several possible mechanisms:

The trait may be subjected to stabilizing selection, since the genetic correlation between return rate as grilse and as two winter salmon may be negative (Table 7.4). The relative success of grilse and two sea winter spawners in the river may then determine the balances between the selection for return rate of the two age groups.

The trait may also be subjected to indirect counterselection. The Kollafjörður sea ranching stock and the Lárós sea ranching stock showed higher return rates then wild stocks (Table 6.1 and 6.2). The main differences between these ranching stocks and the wild stocks has probably been that sea ranched spawners returning to Kollafjörður Experimental Fishfarm and Lárós Fishfarm have been selected for increased body weight, and that the stocks have been protected from the strong natural selection that occurs in natural rivers during the period from spawning and hatching until smoltfication. Body weight shows a positive genetic correlation with return rate (Table 7.4). However, increased body weight does not necessarily increase fitness of spawners and progeny in the rivers. Other fitness related traits during the fresh water period may also be genetically correlated to return rate in a way that may result in indirect counterselection for return rate.

Finally, genetic variation in return rate may also be maintained in wild stocks if the properties determining survival and success during natural selection in sea water are variable from one year to another. If this is the case, artificial selection based on family performance will probably result in a more stable selection. The return rate of a family will probably reflect a wider range of genetic adaptations than the success of one individual.

9 Breeding plan for commercial sea ranching

9.1 Introduction

This project has demonstrated considerable and significant additive genetic variation in return rate and body weight in sea ranching of Atlantic salmon. It has also shown considerable response to selection for return rate. An efficient breeding plan should have as an aim to maximise genetic gain per generation within a realistic dimension and cost. The breeding plan discussed here is in accordance with Gjedrem (1986) and is limited to the traditional sea ranching system for anadromous fish where smolts are released in a river system and the returning fish are captured at the release site.

Selection of a site for sea ranching is important and it is recommended that conditions important for a good site are carefully studied. There need not necessary be a salmon stock in the selected riversystem as was the case in Kollafjörður Experimental Fish Farm. The most important thing is, that the rancher must have all fishing rights in the watersystem to be used for a breeding program.

Breeding goal

The breeding goal for a sea ranching breeding program should include all traits of economic importance in the production system applied. The largest production cost in sea ranching is production of the smolts. Survival- and growth rate of the fish during the freshwater period are therefore important traits. For the economic output it is essential that these traits are improved. Since however return rate and biomass of returning fish are the end products in sea ranching, freshwater traits may be used as correlated traits in order to increase productivity in sea ranching.

Traits of economic importance in sea ranching were discussed in a previous section. Taking total biomass as the final goal, it was shown that the genetic correlation between total biomass and biomass of grilse was 0.92±0.03 and between total biomass and return rate of grilse 0.90±0.04. Since the genetic correlation between total biomass and grilse biomass is close to unity these two traits measure approximately the same character. By choosing grilse biomass as a breeding goal the generation interval will be 3 years compared with 4 if total biomass is selected. It is therefore concluded for breeding goals in Iceland that biomass of grilse per 1000 smolts released should be the breeding goal in a sea ranching program.

Base population

If there is a salmon run in the selected riversystem, this stock should be tested from the very beginning. However, this project has clearly shown significant differences between stocks in return rate and biomass. The consequence of these findings is that one should introduce promising stocks and compare them in the sea ranching program in order to increase the genetic variance. The stocks should be crossed to study the magnitude of heterosis. If the heterosis effect is low a synthetic population should be formed from the available genetic material. If the heterosis effect is considerable a combined crossbreeding selection program is more promising.

Breeding methods

There are particularly two breeding methods or mating systems to choose from, purebreeding and crossbreeding. It is not known whether crossbreeding has been tried in sea ranching. In salmon farming Gjerde and Refstie (1984) studied the effect of crossbreeding on growth rate and survival. They found significant heterosis effect for both traits but it accounted for only a small part of the total variation. Therefore until it is shown that effect of heterosis is considerable for the biomass of returning fish, purebreeding should be applied in a breeding program for sea ranching.

In a breeding program identification of fish is essential in order to keep pedigree records. Tagging of fish should be done as early as possible to keep the maternal effect low. If the fish is tagged at about 10g size, this limits the rearing of families in separate tanks (Common environment) to 8 months. In this project a combination of microtag and cold-branding has been used and until better methods are available they should be applied.

Selection methods

Biomass of returning fish is a product of return rate of a family and its average body weight. Thus biomass is a family trait. Among the two traits return rate has the largest variation and is highly correlated with both biomass of grilse and total biomass as shown in Table 7.4 in chapter 7. Since the main breeding goal is measured as a family trait, family selection must be the main selection method in sea ranching. As there may be both additive, nonadditive genetic variance and maternal effect in biomass for grilse a hierarchical mating system should be used in order to produce both full- and half-sib families. It is recommended that milt from each male should be used to fertilize eggs from 3-5 females.

Since body weight is one of the economic traits, individual selection should be used to select the heaviest fish within the selected families.

Testing of breeding value

As already explained family selection should be the main selection method in a breeding program for sea ranching. In order to achieve a high genetic gain for biomass of grilse selection intensity must be kept high. To obtain a high genetic gain many families must be tested each year. How many families should be tested each year is not easy to determine. Given a certain structure of a population the genetic gain obtainable depends primarily on:

* Selection differential, the stronger the selection the higher the gain.
* Inbreeding depression which depends on number of families selected per generation.

Thus the genetic gain will increase as the number of families tested each year increases. But the cost of testing is usually proportional to the number of families tested. Therefore one should aim at estimating an optimal number of families to be tested each year taking into consideration expected economic value of genetic gain as well as the total expense to achieve this response.

The economic value of genetic gain will mainly depend on genetic gain per generation and the size of the population used in sea ranching. It is therefore not possible to calculate an optimal number of families to be tested for each generation before the dimension of the ranching industry in known. One could, however, reflect about a minimum number of families to be tested per generation. In order to keep the inbreeding relatively low, one must use broodstock from at least 10 to 20 families in each generation. By testing 100 families per generation it is possible to select broodstock from the best 10 to 20 % of the families which, however, is a low selection intensity. Therefore 100 families should be a minimum number of families to be tested in each generation and according to Gjerde (Personal communication) the genetic gain can be increased considerable by increasing the number of families to 200-400 per generation.

The evaluation of breeding values can be centralised at a breeding station. Here testing and rearing of families should take place together with the release of smolts and recapture of returning fish. Necessary resources for a breeding station are separate hatching trays and tanks where individual families can be reared until the fingerlings can be tagged at a size of about 10g. A cheap tag with a large capacity of tagging is essential. With the present technology and prices a combination of microtags and freeze-branding is proposed. The number of smolts which should be tagged and released from each family depends on the return rate. As a guideline if one would need 15-10 returning salmon per family, then 150-200 smolts should be tagged assuming a return rate of 10%. After tagging all families can be merged and fish kept in large units until they are released into the sea. Some investments is necessary at the release site. A pond for acclimatising the smolts prior to release must be made and a system for capture of returning fish is necessary.

In spite of insignificant interaction between release site and salmon stocks as shown in chapters 7 and 8, the strategy should be to use 2 to 4 release sites, test stations, in addition to the one at the breeding station. Such a broad system for testing of breeding values will take care of a possible genotype - release site interaction. It will also reduce the possibility of obtaining yearclasses with zero or very low return rate which may easily happen if the release site at the breeding station is the only one in use.

In years with low return rates at the breeding station the selection intensity of broodstock will be very low. This will affect the cooperating industry dramatically. To reduce these problems and ensure sufficient supply of eggs and milt from families with high breeding value, production of some broodstock could take place under farming conditions in cages or in land based farms.

Besides applying family selection for the biomass of grilse one can also practise individual selection for body weight within the selected families. The efficiency of individual selection within families of broodstock under farming conditions will, however, not be high because of a rather low genetic correlation between body weight of fish in sea ranching and under farming conditions.

Estimating breeding values

Data to estimate breeding values must be recorded and sent to the breeding station. In the freshwater period the traits to be recorded are:

* Survival
* Body weight of parr (Weight at 190 days on feed)

As the fish return to the fish trap the following traits are recorded:

* Body weight
* Body length
* Sex and age
* Identification

In order to read the microtags the fish have to be killed and the tag must be retrieved and read out which takes time. Only freeze-branded fish can be identified on the spot and kept alive in a pond until selection of broodstock can take place (Fig 1).

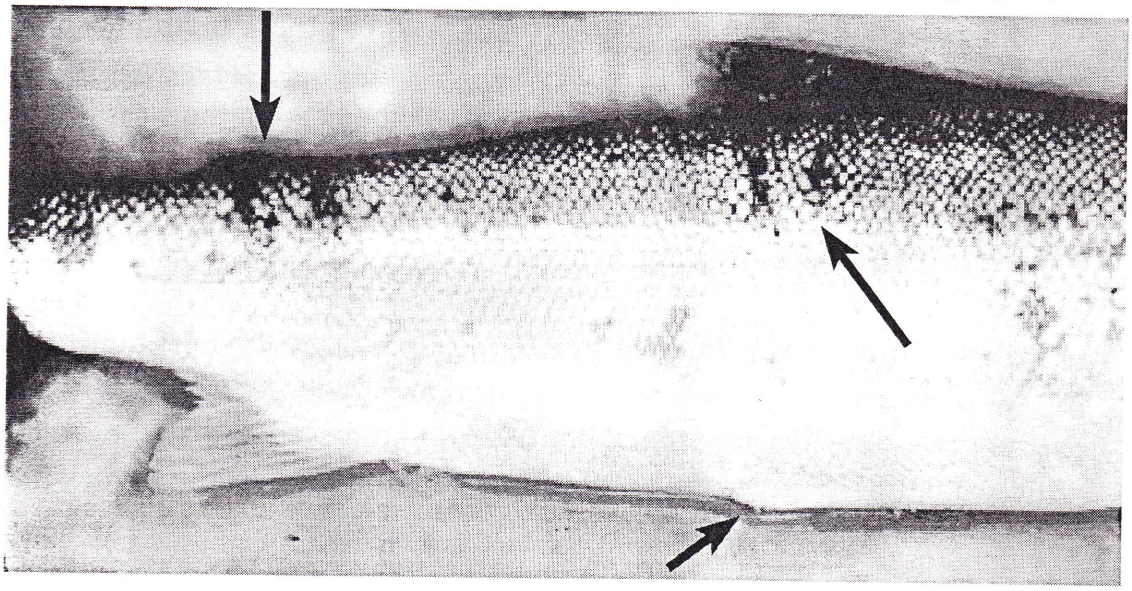

Figure 9.1 Freeze branded and finclipped grilse at return from sea ranching. Arrows indicate freeze brands and clipped fin. (Photo Jonas Jonasson)

Selection of broodstock
One should preferably select broodstock from the returning fish, because they have been exposed to a phenotypic selection under ranching conditions in the sea. However, with the return rates experienced so far there will be relative few fish available in order to practise a strong selection, therefore fish from a farming unit should be available. This will be of particularly importance if several sea ranching companies are members of the breeding program. The number of farmed fish should be sufficiently high for a strong selection to be applied in the program.

Selection indexes should be developed since index selection has been shown to be more efficient, and never less efficient, than other methods of selection when more than one trait are involved (Hazel and Lush, 1942). Index selection make it possible to apply multi trait animal model utilizing available pedigree-matrixes (Henderson, 1973).

Control groups
A breeding program should measure genetic response. There are several methods available, among which are repeated matings over generations and unselected control groups. A combination of these methods could be used, but since it is possible and not too expensive to freeze semen from Atlantic salmon repeated mating is perhaps the best method for practical use in a sea ranching program.

9.2 Plan for selection in Iceland

At Kollafjordur Experimental Fishfarm selection of the best families takes place each year, when 100 families are made. Nearly 50.000 smolts from these families are tagged annually and released at different release sites. Figure 9.2 gives practical information on the breeding work in Iceland for sea ranching.

Selection will be made to increase return rate. More attention will be paid to mean body weight of grilse in addition to return rate as genetic parameters for weight show that one can select for increase growth rate in the sea.

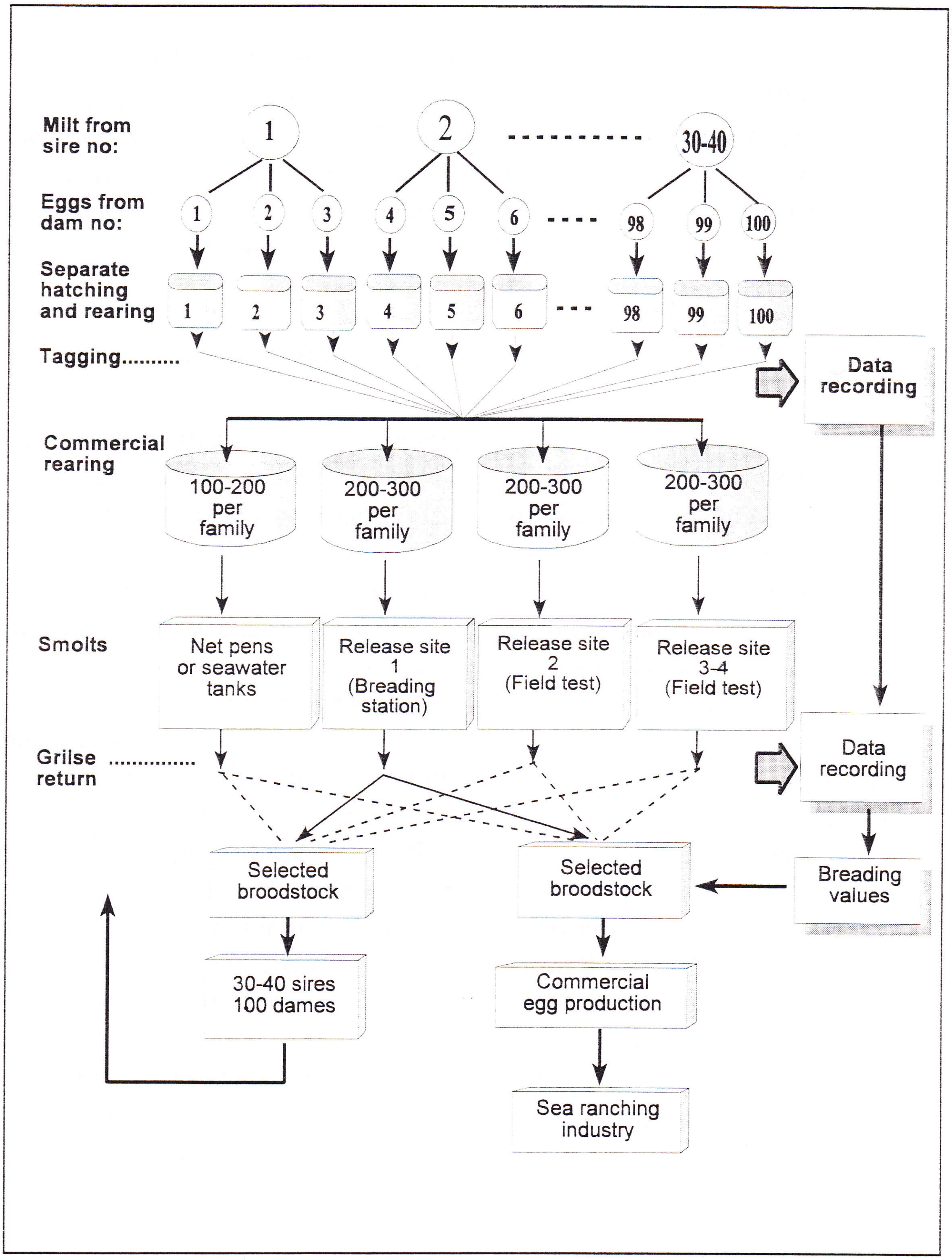

Figure 9.2. Practical information on the Breeding work in Iceland for sea ranching.

10 Conclusion remarks from the steering group

A meeting was held in the steering committee of the project (Havbeiteutvalget), in Copenhagen 24. and 25. of February 1994. Present members were Chairman Árni Ísaksson (Iceland), Liisa Siitonen (Finland), Ingvard Fjallstein (Faroe Islands), Lars-Ove Eriksson (Sweden), Jens Ole Frier (Denmark), Jónas Jónasson (Iceland) and Trygve Gjedrem (Norway).

10.1 Conclusion of the project

Results show that there exits genetic variation in return rate from ranching and body weight of grilse. Prospects for improving return rate by selection are very good and it is shown that response to selection can be achieved by selecting individuals from families with high return rate.

When starting a breeding program it is important to test several salmon stocks because it is shown in the project that there is a considerable variation in return rate between stocks. Stocks used in ranching show higher return rate then wild stocks or stocks used in penrearing.

There is no genotype-environmental interaction between stocks used and release site. This means that one can develop one salmon stock for sea ranching and use it in different salmon ranching stations.

Results show that there is a positive genetic correlation between survival in freshwater and return rate, but lower positive genetic correlation between growth rate and return in the sea. A negative genetic correlation found between return rate as grilse return rate in two-sea winter salmon which means that if one selects for increased return rate of grilse one will reduce return rate of salmon. At last positive correlation was found between growth rate of individuals from the same families reared in a landbased farm and released to sea ranching.

10.2 Recommendations

* The committee recommends that selective breeding should be applied to sea ranching programs and that it will be economical when the activity has reached a certain limit.
* There is no doubt that selective breeding is effective in sea ranching.
* It is difficult to recommend what the selection criteria should be for sea ranching (grilse or two-sea winter salmon) especially for the Baltic. In Iceland there is largest potential to select for return rate of grilse. In general for the Atlantic coast grilse is most preferable as return rate of two-sea winter salmon is so low.

10.3 Breeding plan for the Baltic.

A breeding plan for the Baltic will probably be different. Registrations of body weight has to be taken when the fish are caught in the open sea. The problem is that the information is dependent where the fish is caught and when. Usually the survival in the Baltic is high or 10-20 % in general. Most of the fish are caught in the fisheries in the Baltic by only 0.3-0.5% return to the rivers.

The committee recommends that a breeding program should be developed for use in Sweden and Finland. How it should be developed must be further studied as the catch is mostly in the fisheries. The Fish and Game Institute in Finland has started investigating in this direction.

10.4 Other species

Breeding program should also be used for other ranching species, like seatrout, searun char and rainbow trout.

10.5 Future joint nordic projects

The principle that has been developed for Atlantic salmon, can probably be developed for seatrout. Releases of seatrout to ranching is quite considerable and growing. The releases in the past years are over 3 million in the Nordic countries:

* Denmark 1,5-2,0 million per year
* Sweden 1 million per year

* Iceland minimal
* Norway minimal

Seatrout is of special interest for ranching as the species has variable life cycle. Seatrout also shows high return rate or up to 20%.

A project for seatrout should have as a priority to investigate genetic variation in the life cycle and the length of the generation interval

Denmark in building up new research facilities and could start such a program. Finland has resources in Åland. Sweden in Umeä and at the Salmonoid Research Institute. Iceland has some background in enhancement of seatrout. Norway has large potentials for sea ranching of seatrout and has research facilities at Ims. An interesting cooperation partner inside EU is Ireland.

The committee proposes that a ranching research project with seatrout is a future cooperative nordic project. The Danish delegate Jens Ole Frier was asked to work more closely for a future research plan and investigate the possibilities to apply for research money from the Nordic Council of Ministers and from EU.

Appendix

Table 11.1 Return rates of grilse and 2-sea-winter salmon and total return rates for yearclasses 1988,1989 and 1990 for various salmon stocks and release sites.

Stock	Place of Release	Grilse Return N	% Return as grilse %	2-Sea-Winter N	% Return as 2 Sea winter %	Total Return rat[e] %
Yearcl.1988						
Kollafjörður	Kollafjörður	221	0.53	265	0.63	1.17
	Vogavík	67	0.47	55	0.39	0.86
Laxá in Aðaldal	Kollafjörður	29	0.36	22	0.27	0.63
	Vogavík	3	0.11	3	0.11	0.23
Stóra Laxá	Kollafjörður	34	0.50	13	0.19	0.69
	Vogavík	8	0.44	5	0.22	0.66
Total 1988		362	0.48	363	0.48	0.96
Yearcl.1989						
Kollafjörður	Kollafjörður	933	2.77	160	0.47	3.24
	Vogavík	258	1.55	20	0.12	1.67
	Silfurlax	334	1.96	51	0.30	2.26
Stóra Laxá	Kollafjörður	35	1.24	13	0.46	1.69
	Vogavík	8	0.56	5	0.35	0.92
	Silfurlax	5	0.34	6	0.41	0.75
Dalsá	Kollafjörður	25	1.62	7	0.45	2.01
	Vogavík	2	0.48	0	0	0.48
	Silfurlax	4	0.80	3	0.60	1.4
Ísnó	Kollafjörður	29	0.52	38	0.68	1.2
	Vogavík	13	1.04	8	0.64	1.68
	Silfurlax	25	0.9	9	0.32	1.22
Total 1989		1671	1.94	320	0.37	2.3
Yearcl.1990						
Kollafjörður	Kollafjörður	474	2.68	146	0.82	3.5
Kollafjörður	Dyrhólalax	137	1.79	7	0.09	1.9
Silfurgen	Kollafjörður	14	1.64	4	0.46	2.1
Total 1990		625	2.38	157	0.6	3.0

Table 11. 2 Return rate of grilse for Yearcl. 1991 for various salmon stocks and release sites.

Stock	Place of Release	Grilse Return N	% Return as grilse %
Yearcl.1991			
Kollafjörður	Kollafjörður 1	300	2.04
	Kollafjörður 2	280	3.68
	Vogalax	104	1.96
	Silfurlax	114	1.97
	Lárós	97	2.55
Lárós	Kollafjarður 1	169	3.14
	Kollafjörður 2	123	4.29
	Vogalax	41	1.67
	Silfurlax	55	2.41
	Lárós	96	3.57
Eldi	Kollafjörður 1	67	1.58
	Silfurlax	58	1.57
Ísnó	Kollafjörður 1	20	1.30
	Silfurlax	16	1.05
Total 1991		1540	2.41

Table 11.3. Mean weight and standard deviation of grilse and two sea-winter salmon for three Yearcl.es in Iceland released from different release sites. Total weight expressed as kg/1000 smolts released is also presented.

Stock	Place of Release	Grilse N	Grilse Mean kg	s.d.	2-Sea-Winter N	2-Sea-Winter kg	s.d.	kg/1000 smolts released
Yearcl.1988								
Kollafjörður	Kollafjörður	221	2.2	0.4	265	5.2	1.1	44.8
	Vogavík	67	2.4	0.5	55	5.4	0.8	32.4
Laxá Aðaldal	Kollafjörður	29	1.9	0.5	22	4.0	1.2	17.8
	Vogavík	3	1.9	0.3	3	5.8	1.0	8.7
Stóra Laxá	Kollafjörður	34	2.1	0.4	13	4.9	0.5	19.8
	Vogavík	8	2.4	0.4	5	5.6	0.7	20.7
Total 1988		362	2.2	0.4	363	5.2	1.1	35.6
Yearcl.1989								
Kollafjörður	Kollafjörður	933	2.2	0.4	160	5.4	1.0	86.5
	Vogavík	258	2.4	0.5	20	5.9	1.1	44.4
	Silfurlax	334	2.4	0.4	51	5.8	1.2	64.5
Stóra Laxá	Kollafjörður	35	2.3	0.3	13	6.5	1.5	58.2
	Vogavík	8	2.7	0.4	5	7.7	0.8	42.4
	Silfurlax	5	2.9	0.5	6	5.8	2.7	29.6
Dalsá	Kollafjörður	25	2.1	0.3	7	5.3	1.0	58.0
	Vogavík	2	1.9	0.3	0	0		9.1
	Silfurlax	4	2.7	0.7	3	7.3	1.5	65.7
Ísnó	Kollafjörður	29	2.3	0.4	38	5.7	1.2	50.9
	Vogavík	13	2.4	0.4	8	6.1	1.1	64.2
	Silfurlax	25	2.5	0.4	9	6.1	0.7	42.1
Total 1989		1671	2.3	0.4	320	5.7	1.2	65.9
Yearcl.1990								
Kollafjörður	Kollafjörður	474	2.7	0.6	146	5.9	1.0	121.0
Kollafjörður	Dyrhólalax	137	3.0	0.6	7	6.3	1.2	59.3
Silfurgen	Kollafjörður	14	2.8	0.8	4	6.4	0.6	75.5
Total 1990		625	2.8	0.6	157	5.9	1.0	102.1

Table 11.4 Mean weight and standard deviation of grilse from the 1991 Yearcl. released from different release sites in Iceland returning in the summer 1993.

Stock	Place of Release	Grilse N	Grilse Mean kg	s.d.
Yearcl.1991				
Kollafjörður	Kollafjörður 1	300	2.2	0.4
	Kollafjörður 2	277	2.5	0.4
	Vogalax	89	2.1	0.3
	Silfurlax	114	2.3	0.4
	Lárós	97	2.4	0.4
Lárós	Kollafjörður 1	169	2.3	0.4
	Kollafjörður 2	123	2.5	0.4
	Vogalax	41	2.2	0.3
	Silfurlax	55	2.5	0.4
	Lárós	78	2.5	0.4
Eldi	Kollafjörður 1	67	2.3	0.5
	Silfurlax	58	2.3	0.4
Isnó	Kollafjörður 1	20	2.3	0.4
	Silfurlax	16	2.4	0.4
Total 1991		1504	2.3.	0.4

Table 11.5 Mean body length and standard deviation of grilse and two sea-winter salmon for three Yearcl.es in Iceland released from different release sites.

Stock	Place of Release	Grilse N	Grilse Mean cm.	s.d.	2-Sea-Winter N	2-Sea-Winter cm	s.d.
Yearcl.1988							
Kollafjörður	Kollafjörður	221	58.4	3.7	265	79.9	6.6
	Vogavík	67	60.1	4.0	55	79.5	6.2
Laxá Aðald.	Kollafjörður	29	55.1	4.4	22	72.5	8.2
	Vogavík	3	56.0	3.6	3	82.0	4.4
Stóra Laxá	Kollafjörður	34	58.1	4.1	13	79.1	2.9
	Vogavík	8	59.4	3.5	5	82.4	5.6
Total 1988		362	58.5	4.0	363	79.4	6.7
Yearcl.1989							
Kollafjörður	Kollafjörður	933	59.6	3.5	160	81.0	5.5
	Vogavík	258	61.4	4.0	20	81.8	5.7
	Silfurlax	334	61.5	3.7	51	82.3	5.4
Stóra Laxá	Kollafjörður	35	60.5	2.5	13	85.9	6.7
	Vogavík	8	63.9	3.1	5	87.6	4.9
	Silfurlax	5	64.6	4.2	6	87.0	6.8
Dalsá	Kollafjörður	25	58.3	3.0	7	81.0	4.0
	Vogavík	2	56.0	2.8	0	0	
	Silfurlax	4	64.3	4.6	3	86.7	7.2
Ísnó	Kollafjörður	29	60.4	2.9	38	82.3	5.3
	Vogavík	13	61.7	3.5	8	81.6	4.0
	Silfurlax	25	62.3	3.6	9	85.3	3.8
Total 1989		1671	60.4	3.7	320	82.0	5.6
Yearcl.1990							
Kollafjörður	Kollafjörður	474	63.3	4.4	146	83.2	4.7
Kollafjörður	Dyrhólalax	137	67.0	4.1	7	84.4	6.2
Silfurgen	Kollafjörður	14	63.0	6.3	4	84.5	2.4
Total 1990		625	64.1	4.6	157	83.3	4.8

Table 11.6 Mean length and standard deviation of grilse released from different release sites in Yearcl. 1991 in Iceland returning summer 1993.

Stock	Place of Release	Grilse N	Grilse Mean cm	s.d.
Yearcl. 1991				
Kollafjörður	Kollafjörður 1	300	59.5	3.3
	Kollafjörður 2	277	61.3	3.1
	Vogalax	89	58.4	3.2
	Silfurlax	114	60.0	3.6
	Lárós	97	61.9	2.9
Lárós	Kollafjörður 1	169	59.7	3.4
	Kollafjörður 2	123	61.4	3.4
	Vogalax	41	59.6	3.1
	Silfurlax	55	61.6	3.7
	Lárós	78	62.3	3.5
Eldi	Kollafjörður 1	67	58.4	5.1
	Silfurlax	58	58.3	4.2
Ísnó	Kollafjörður 1	20	59.1	4.1
	Silfurlax	16	59.9	3.0
Total 1991		1504	60.3	3.6

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