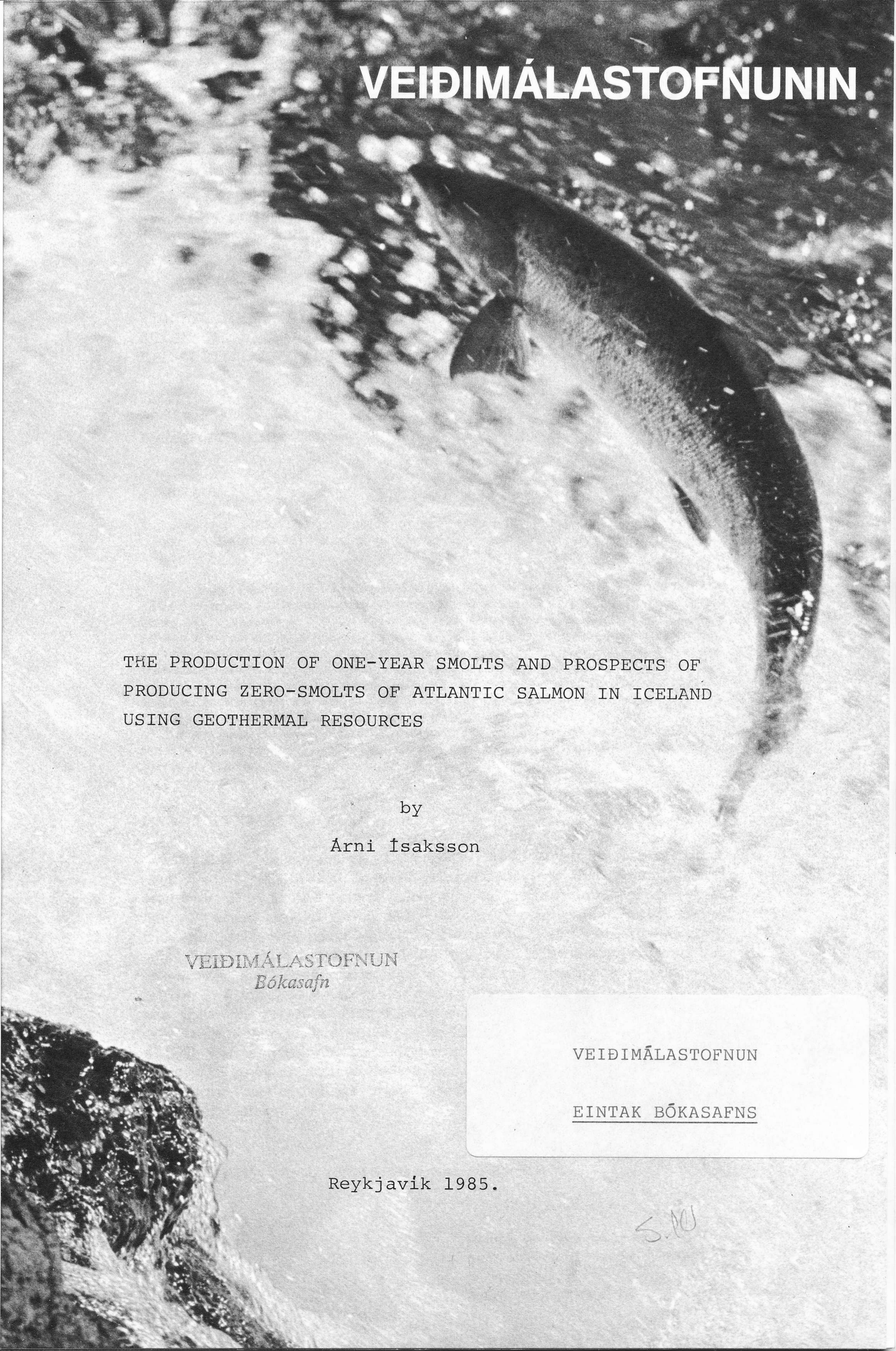

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# THE PRODUCTION OF ONE-YEAR SMOLTS AND PROSPECTS OF PRODUCING ZERO-SMOLTS OF ATLANTIC SALMON IN ICELAND USING GEOTHERMAL RESOURCES

by

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# THE PRODUCTION OF ONE-YEAR SMOLTS AND PROSPECTS OF PRODUCING ZERO-SMOLTS OF ATLANTIC SALMON IN ICELAND USING GEOTHERMAL RESOURCES

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## ABSTRACT

Ísaksson, Á., 1985. The production of one-year smolts and prospects of producing zero-smolts of Atlantic salmon in Iceland using geothermal resources. *Aquaculture*, 45:

The paper describes the rearing and growth rates of zero-age, one-year smolts and 400-gram smolts in Iceland using geothermal resources. The hatching and rearing regimes for accelerated smolts are compared with those for non-accelerated fish. Return rates of one-year smolts are related to photoperiod and temperature regime used.

Two methods of producing adults are discussed, i.e. by rearing smolts to 400 grams with subsequent rearing in sea-pens, and accelerated rearing of adults in tanks to market size. These methods are compared with conventional pen-rearing in Norway with respect to growth rates and sexual maturation. The thermal power required for the production of various sizes of salmon is also presented.

The experiments have shown that accelerated production of zero-age smolts for ranching is not practical as yet but one-year smolts of 400 grams can be produced for subsequent rearing in sea-pens or land-units.

## INTRODUCTION

During the 30-year history of fish culture in Iceland it has become quite clear that rearing of fish is more energy demanding than in most other countries. Due to the barren nature of the Icelandic countryside, most run-off streams become turbid and silted during rainy periods which makes them unsuitable as a water source for fish rearing. Early rearing trials using run-off water were not successful due not only to turbidity problems but also to the short Icelandic summer which allowed reasonable growth only during 2—3 months; smolt age in rearing stations was up to 3 years. One can therefore conclude that without some form of economical heating, salmon farming in Iceland would not be feasible.

It is well known that Iceland is a volcanic island with fairly frequent eruptions. There are numerous hot springs in the country which are used for central heating of the major towns and many have been harnessed for salmon culture.

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The steady supply of heat throughout the rearing period has enabled salmon farmers to accelerate hatching and rearing processes to the point that all hatcheries produce one-year smolts and some are producing zero-age smolts on an experimental basis. Zero-smolts of coho salmon (*Oncorhynchus kisutch*) have been released successfully on the Pacific coast of America (Brannon et al., 1982). Production of comparable smolts of Atlantic salmon would reduce the production costs of smolts considerably, which is a key factor in salmon ranching.

The present paper is a review of the accelerated rearing of Atlantic salmon in Iceland. It covers the existing production of one-year smolts and the future potential of zero-age smolt production as well as the accelerated rearing of 300—400-gram smolts in 15 months. Such smolts are now being produced for subsequent cage-rearing during the summer months. Thermal power requirements for smolt production and the various adult production methods are also discussed.

## MATERIALS AND METHODS

### *Growth*

Numerous variables affect the rearing process in a production hatchery. Of such variables, one might mention variation in the time of maturation

TABLE I

Growth rates of different sized juvenile salmon in various rearing trials

| Experimental group no. | Initial weight (g) | Final weight (g) | Growth (% of wet weight/ day) | Start of experiment | Duration of experiment (days) | Mean temperature (°C) | Salinity (°/oo) |
|---|---|---|---|---|---|---|---|
| 1 | 0.1 | 1.2 | 3.4 | 12 May 1969 | 74 | 12.5 | 0 |
| 2 | 0.1 | 3.0 | 2.3 | 19 April 1977 | 148 | 13.2 | 0 |
| 3 | 0.1 | 4.8 | 2.5 | 10 April 1977 | 157 | 13.2 | 0 |
| 4 | 0.1 | 6.2 | 2.7 | 10 April 1977 | 157 | 13.2 | 0 |
| 5 | 0.4 | 1.1 | 3.7 | 19 July 1971 | 28 | 13.0 | 0 |
| 6 | 1.2 | 2.3 | 2.2 | 26 Sept. 1974 | 30 | 12.0 | 0 |
| 7 | 1.2 | 2.6 | 2.6 | 26 Sept. 1974 | 30 | 12.0 | 0 |
| 8 | 1.2 | 6.2 | 2.4 | 29 April 1982 | 70 | 12.2 | 0 |
| 9 | 1.2 | 6.8 | 2.5 | 29 April 1982 | 70 | 12.2 | 0 |
| 10 | 2.6 | 4.8 | 2.1 | 25 Oct. 1974 | 30 | 10.9 | 0 |
| 11 | 11.9 | 20.9 | 2.0 | 17 April 1970 | 28 | 12.2 | 0 |
| 12 | 15.3 | 25.6 | 1.9 | 17 April 1970 | 28 | 12.2 | 0 |
| 13[a] | 17.5[b] | 203.0 | 1.5 | 17 Sept. 1983 | 167 | 12.0 | 11—15 |
| 14[a] | 12.0[b] | 125.0 | 1.4 | 17 Sept. 1983 | 167 | 12.0 | 11—15 |
| 15[a] | 203.0 | 374.0[c] | 0.9 | 2 March 1984 | 69 | 10.0 | 11—15 |
| 16[a] | 125.0 | 226.0[c] | 0.9 | 2 March 1984 | 69 | 10.0 | 11—15 |

[a]"Sjóeldi" at Hafnir. [b]Zero-age in September. [c]One-year in May.

of spawners. Experience at Kollafjörður has shown that the progeny of females spawned in late October can, at the earliest, start to feed in early January if incubated at 10°C. Many of the salmon, however, are spawned in November and their progeny start to feed in early February. Overcrowding reduces growth in many hatcheries and occasional shortages of heating water will do the same. Frequent sorting as well as sale of parr at different stages in commercial hatcheries make it difficult to keep track of growth rates for extended periods.

It was therefore decided to describe the acceleration process in Icelandic salmon culture by constructing an average growth curve from start feeding up to 400-gram 1+ smolts. This was done by using the information in Table I. It shows various rearing trials performed at the parr stage at Kollafjörður Fish Farm and for the rearing of accelerated smolts at the "Sjóeldi" facility at Hafnir. Temperatures in these rearing trials ranged from 11 to 13°C at Kollafjörður, a freshwater station; at Sjóeldi temperatures ranged from 10 to 12°C and salinities were around 11°/₀₀. The growth rates in these rearing trials were calculated as percent of wet body weight per day as an average value for the whole rearing period.

These values were then plotted against the means of the initial and final weights in the rearing experiments (Fig. 1). A logarithmic curve was fitted through the points and the equation shown in the figure was obtained. From this equation one could calculate the growth curve for one-year smolts shown in Fig. 2. Accuracy of the curve was checked by comparing it with values obtained in rearing experiments using the Kollafjörður strain. Those observations agree well with the calculated curve. In this paper the curves are mainly used for graphic presentation.

In one instance, a hypothetical growth curve was constructed for the

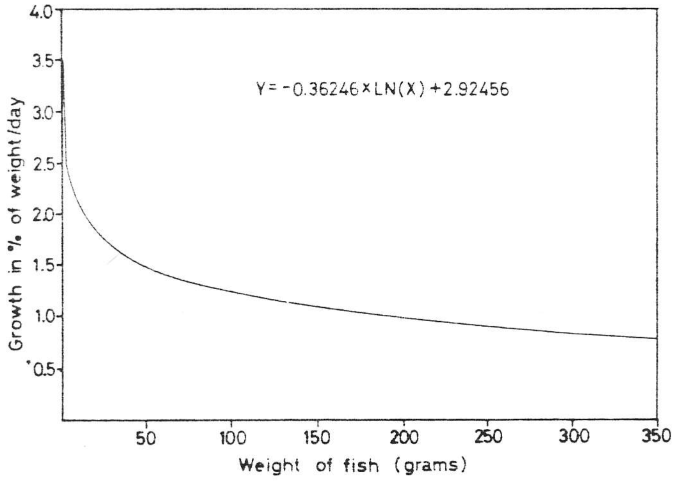


Fig. 1. Relationship between growth in percent of body weight per day and fish size from the start-feeding stage through 350-gram smolts.

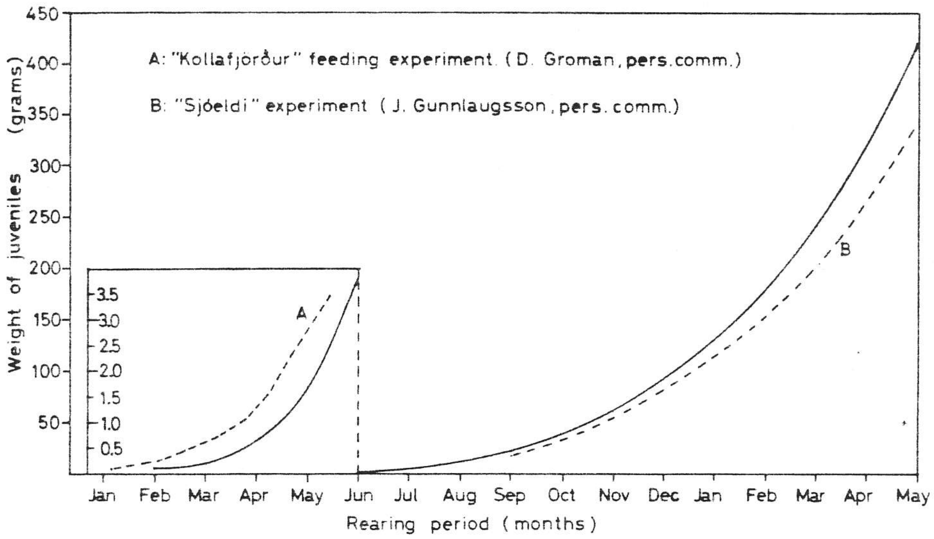


Fig. 2. Calculated growth of accelerated juvenile salmon during 15 months starting in February. Observed growth values (A and B) are inserted for comparison.

accelerated rearing of adults up to 4 kg (Fig. 5). In this instance I assumed a linear drop in growth rate from 1% of wet body weight at 200 grams to 0.75% at 2 kg as calculated from Hildingstam's (1976) data for pen-rearing in Norway during the summer months. Limited information in Iceland indicates that this is conservative. It should be pointed out that the growth data in this paper have been based solely on the Kollafjörður strain which has been a semidomesticated ranching strain for over 20 years. Considerable selection for fast growing fish has taken place and most wild stocks would not have comparable growth rates.

*The rearing process*

Hatching and rearing equipment at Kollafjörður is very conventional. Hatching takes place in fiberglass troughs. When the fry are ready to feed they are moved to 2 × 2-m Swedish-type tanks with circular flow. These tanks are half-covered with black plastic throughout the rearing process to reduce stress on the fish and prevent nipping. Rearing here takes place at 11—13°C and fish are only moved from these tanks when they have reached 20—25 g. They are then put in concrete outdoor ponds, 9 m in diameter. These ponds are supplied with unheated ground-water which ranges in temperature from 2 to 4°C during the winter months. Grading into these ponds usually starts in August—September and the last smolts are usually put out in February—March. Those, however, have not been accelerated for the whole rearing period.

*Thermal power requirements*

Due to the dependence of Icelandic salmon culture on geothermal water, it is of great importance to be able to quantify the heat necessary for a production unit. This was calculated for the production of 100 000 juvenile salmon up to 400 grams as well as for the rearing of the same quantity to 4 kg in heated sea water (12°C). The unit of thermal power used is the megawatt, which is a standard unit used by the geothermal industry in Iceland. The formula used is the following:

$$\text{Megawatt} = m \times Cp \times \Delta T/1000$$

where: $m$ is the flow of heated rearing water (l/s); Cp is the specific heat of water (Cp = 4.186 kJ/kg °C); $\Delta T$ is the necessary elevation of temperature (°C); and 1000 is the ratio between megawatts and kilowatts.

When calculating the energy requirement it was assumed that the temperature of well water (3°C) had to be raised to 12°C for reasonable growth. Flow of rearing water was obtained by multiplying the biomass in the hatchery at a certain time by the rate of flow per kilogram of salmon as presented by Edwards (1979).

## RESULTS

*Accelerated rearing of smolts*

*One-year smolts*

Production of one-year smolts started in Iceland around 1965. In the early years the eggs were hatched in cold water, 3–4°C, and it was only after the feeding stage was reached that the parr were reared in 12–13°C water (Fig. 3). Since the fry started to feed relatively late in the year (May), most of them had to be fed in constant temperature and light almost up to the time of release in May–June of the following year. Salmon ranching experiments at Kollafjörður Fish Farm around 1970 showed that these smolts had very poor return rates compared to two-year smolts (Guðjónsson, 1973) and measures were taken to correct the situation. Subsequent experiments at Kollafjörður indicated that one-year smolts that were reared under natural temperatures and photoperiod during the better part of the winter (Isaksson, 1976) had considerably better return rates than those exposed to constant light and temperature.

In 1970 experiments were started at Kollafjörður where hatching temperatures were raised to 8°C at various stages in the hatching cycle. Initially, this was only done at the eyed egg stage but the elevation of temperature was gradually moved to earlier stages, and after 1975 it was clear that newly fertilized eggs could tolerate temperatures as high as 10°C throughout the incubation process.

The heating system at Kollafjörður Fish Farm is based on a heat-exchange

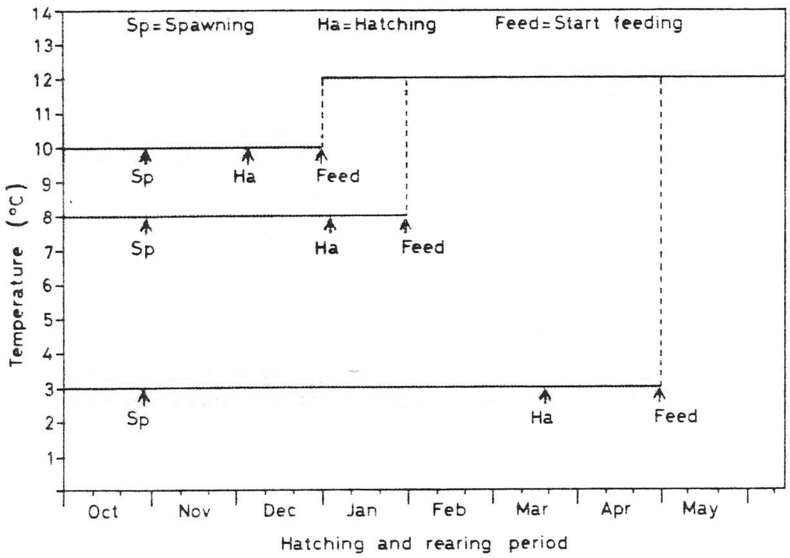


Fig. 3. Effect of temperature on incubation and rearing program at Kollafjörður Fish Farm. Shaded areas show the amplitude of variation in temperature. Acceleration of smolts in Iceland has primarily been accomplished by speeding up incubation.

system where geothermal water is used to heat ground-water. Direct mixing is not possible due to harmful chemicals in the hot water. Exact temperature control is difficult when heat-exchangers are used since mixing of heated and cold water is controlled by automatic valves which respond to a temperature sensor. Any malfunctioning in this equipment can be very detrimental to the eggs, and most of the hatching at Kollafjörður has therefore been done at 8°C. Backup groups of eggs are incubated at natural temperatures. These are later accelerated using heated water after the 8°C incubation group has started feeding.

Temperature profiles and hatching programs for eggs hatched at 3, 8 and 10°C are shown in Fig. 3. This figure also shows the dates of spawning, hatching and first feeding. Elevation of hatching temperatures to 8°C advances hatching and rearing by 3 months but elevation to 10°C accelerates the corresponding processes by almost 4 months compared with incubation and hatching in cold water. It should be stressed that the rearing process at Kollafjörður has been accelerated primarily by advancing the start-feeding period, and rearing temperatures have ranged from 11 to 13°C depending on the availability of hot water and the temperature of the cold water to be heated. The station has only had sufficient thermal power since 1980 to keep up a constant rearing temperature of 13°C for the on-growing fish.

Fig. 4 shows the growth rate of accelerated smolts (hatched at 8°C) versus non-accelerated (hatched at 2–4°C). The non-accelerated group usually started to feed in early May and reached an average size of only 25

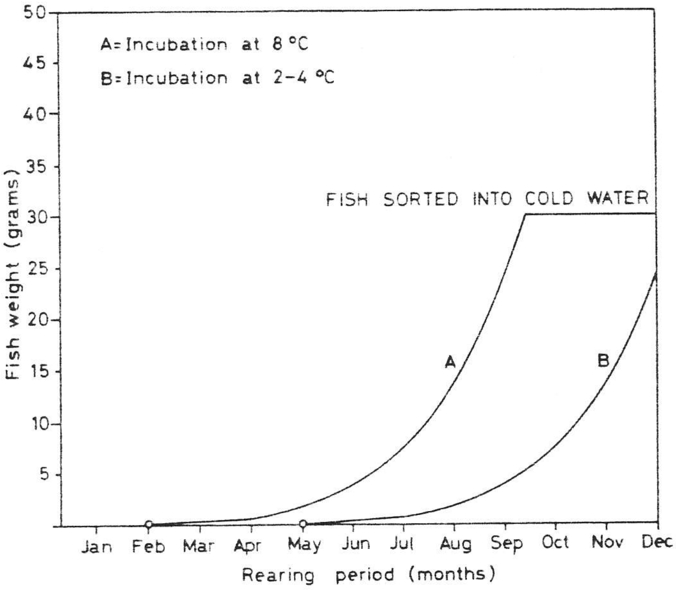


Fig. 4. Comparison of growth of accelerated smolts (A) and smolts hatched in cold water (B) at Kollafjörður Fish Farm. Growth rates are the same but start-feeding has been advanced by 3 months.

g by the end of the first year. Less than half of the fish had reached smolt size at that time and most of the fish had to be grown onwards in heated water. Accelerated smolts, on the other hand, started to feed in early February. They reached an average weight of 15 g by August at which time the largest could be put in cold water for storage until the following spring. Unfortunately, sufficient hot water has not been available at Kollafjörður for onward growing of the fish. Since 1980, 80—90% of accelerated smolts at Kollafjörður have reached smolt size (25 g) before the end of the year. Smolts in this size range seem to give reasonable return rates when microtagged and released in ranching experiments.

Table II shows the return rates of comparable accelerated one-year smolts released in 1980, 1981 and 1982 at Kollafjörður and Lárós ranching stations. The groups are subjected to natural temperature (well water) at different times and released in two ways, either by voluntary migration from freshwater release ponds, which can take weeks, or by adaptation to salinities for 3 weeks before release, which occurs over a 24-h period. No consistent differences between the two release methods have been observed at Kollafjörður but freshwater releases have yielded higher returns at Lárós.

Considering the return rates for both ranching stations, there was clearly better survival in the 1980 and 1982 releases than in the 1981 experiment. Likely explanations for this are more favourable spring and better release conditions in 1980 and 1982. Notice, however, the great difference in returns to Lárós and Kollafjörður in the 1980 experiment which must be caused by local differences at the time of release, e.g. in estuarine feeding conditions. This is not surprising considering that the two sites are separated by over 200 km of coastline.

TABLE II

**Return rates of microtagged accelerated one-year smolts reared at Kollafjörður and released there and at the Lárós ranching station**

| Ranching site | Year of release | Date in outdoor ponds | Mean weight at transfer (g) | Mean weight at tagging (g)[b] | Rate of recapture (%) 1 and 2 sea-winter salmon | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Freshwater release | | Salinity adaption | |
| | | | | | Number released | % return | Number released | % return |
| Kollafjörður | 1980 | Sept. | 18 | 22 | 2001 | 6.4 | 2034 | 7.1 |
| | | Nov. | 27 | 28 | 4070 | 8.6 | 5079 | 7.2 |
| | | Feb. | 17 | 19 | 1012 | 6.8 | 1036 | 3.2 |
| | 1981 | Dec. | 26 | 28 | 2066 | 5.7 | 4020 | 5.9 |
| | | Jan. | 25 | 28 | 2020 | 7.7 | 2116 | 7.2 |
| | 1982[a] | Sept. | 18 | 21 | 2022 | 8.3 | 2015 | 9.0 |
| | | Oct. | 22 | 26 | 2019 | 7.7 | 2051 | 8.0 |
| | | Nov. | 20 | 26 | 2019 | 8.1 | 2020 | 11.0 |
| | | Jan. | 35 | 35 | 2021 | 11.0 | 2019 | 11.1 |
| | | Mar. | 30 | 30 | 1053 | 8.1 | 536 | 8.4 |
| Lárós | 1980 | Sept. | 18 | 23 | 3356 | 12.6 | 3115 | 10.9 |
| | 1981 | Aug. | 26 | 28 | 2620 | 7.6 | 2820 | 5.4 |
| | 1982[a] | Jan. | 35 | 35 | 3020 | 10.9 | 3020 | 8.8 |

[a]One year at sea only.
[b]Tagging time is March—April.

It might be mentioned that the salmon fishing in southwestern Iceland has been relatively poor during this period, only recovering in 1983 (1982 smolts). This points to some problems in the streams and shows that returns to ranching stations can give corroborative information on problems in neighbouring salmon streams.

It is of interest to see if there is a positive relationship between the length of exposure to natural temperature and photoperiod regimes and return rates. The data in Table II indicate that smolts put in outdoor ponds in March (ca. 3 months before release) have equally high return rates as smolts put in outdoor ponds much earlier. This is a very important observation for smolt producers in Iceland since the slowest growing one-year smolts in an accelerated program would be ranching smolt size in January—February.

*Zero-age smolts*

The production of great numbers of zero-age smolts at a reasonable size (20 g) to meet the deadline of release (June) is not yet possible at

Kollafjörður Fish Farm. Even at a hatching temperature of 10°C, only a limited number of fish reach the smolt size. Some private hatcheries, however, have produced and released considerable numbers of zero-age fish in late summer (August—September). Most of these questionable smolts have been untagged, and so returns are difficult to confirm.

In early September of 1980, 2000 microtagged zero-age smolts (25 g) were released at Kollafjörður Fish Farm after one month of feeding and adaptation to salt water. Maximum salinities were 20°/₀₀. Control groups of one- and two-year smolts, 1000 in each group, were also released. Mortalities before release were lowest in the zero-age fish (1/2000) and visual inspection before release indicated that they became silvery with loose scales. Only three fish have returned to date, two from the two-year group returning in 1981 and one zero-smolt returning in 1982. These strikingly poor return rates, even in one- and two-year smolts, indicate that the reasons may lie in improper release time rather than in the quality of the zero-smolts. It seems, therefore, that a production scheme for zero-age smolts must be based on the assumption that they be smolt size and ready for tagging in May and release in June.

In order to get reasonable numbers of zero-smolts for experimental releases it would be essential that the fry start feeding in early December, a month earlier than has been possible even when the eggs are hatched at 10°C using early maturing spawners. Further acceleration of the process may be achieved using a number of methods. The most promising might be to speed up maturation of the spawners by some chemical or physical method. It seems likely that the upper threshold temperatures for incubation have been reached. Temperatures higher than 10°C have not been tried at Kollafjörður Fish Farm, but that temperature seems to be safe for the Kollafjörður strain with no excessive mortality. Peterson et al. (1977) suggested a lower optimum hatching temperature for some Canadian river stocks (6°C). They also suggested that there might be considerable strain variations. One should, therefore, be very cautious when applying the present findings to other strains.

From the preceding paragraphs, it can be seen that zero-age smolts are not a real possibility in Iceland today. Much research is needed, especially into the physiology of such a smolt, along with release trials, before one can accept this strategy as a useful one.

*Production of adults*

Although Icelandic smolts have primarily been used for salmon ranching in the past, there are gradually opening up new possibilities for accelerated rearing of adults using geothermal resources, wholly or partly. The most promising methods are: (1) a mixture of accelerated rearing and pen-rearing during the summer months; (2) accelerated rearing in tanks to full size.

*Accelerated rearing and pen-rearing*

The first method depends on the production of 400-g smolts according to the schedule shown in Fig. 2, and rearing subsequently in sea-cages from May through October. Winter rearing in Iceland is not possible due to the low temperature of the sea water, frequently approaching -1°C; the lethal temperature for Atlantic salmon in sea water has been found to be -0.7°C (Saunders et al., 1975). Limited experience in southern Iceland, however, indicates that 400-g smolts put in sea-cages in early May could reach 1.5—2 kg in October. This implies that some mixture of land- and sea-rearing may be profitable.

Accelerated rearing of large one-year smolts has been performed at "Sjóeldi" facility at Hafnir. The growth information in these experiments is shown in Fig. 2, along with a calculated growth curve which assumes maximum utilization of space and heated water, but these have been limiting factors in the "Sjóeldi" experiments. As seen from the figure, it is possible to produce 400-g smolts in 15 months from the time of start-feeding. "Sjóeldi" experiments have shown that these fish which are kept at high temperatures throughout the winter (10—12°C), with limited exposure to natural light, smoltify readily in water at 11—15°/oo and can tolerate an abrupt change to full salinities (35°/oo) in May. Subsequent rearing is done in sea-pens.

Pen-rearing during the summer of 1983 using 330-g two-year smolts showed that none of the females and very few males became sexually mature despite a mean size of over 1.5 kg in August. Similarly, pen-reared one-year smolts averaging 0.95 kg (range 0.4—1.6 kg) in early September

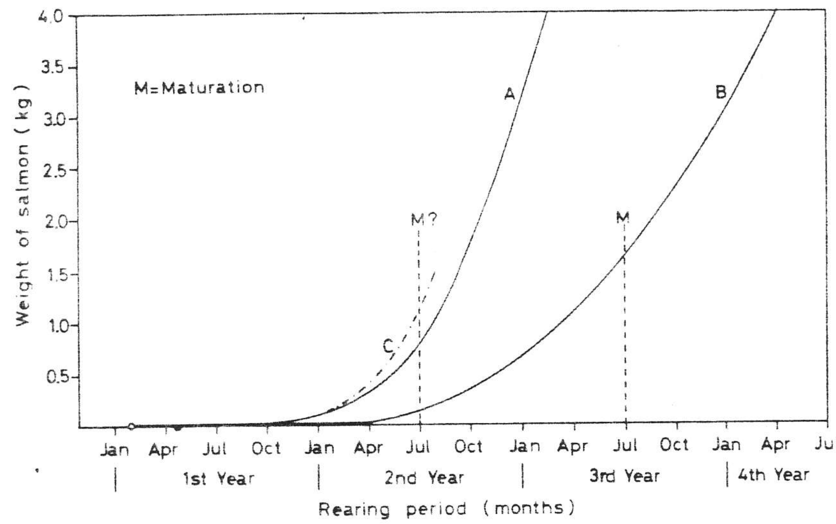


Fig. 5. Comparison of projected growth rates for accelerated rearing of adults at 12°C in Iceland (A) and conventional rearing in Norway (B) (from Braaten and Hogoy, 1982). Also shown is a growth curve (C) experienced at "Eldi" facility (Helgason, 1982). M indicates the likely time for sexual maturation.

1984 were checked for stage of sexual maturation. Out of 107 fish, 51 (48%) were males. Only 4 of those (8%) were advanced in maturation (stages 3—5, Kesteven (1960)). None of the females showed any sign of imminent maturation (stage 1). Using a hypothetical growth curve for intensive rearing to market size (Fig. 5), one can speculate that these fish could be reared to a mean size of 3—4 kg the following April without interference from maturation processes, assuming that maturation only occurs during the summer months. The fish used in these experiments were of the Kollafjörður strain and therefore have a tendency towards maturation as grilse in ranching experiments.

Saunders et al. (1983), observing abnormally low incidence of grilse in cage-reared salmon compared to ranched salmon of the same strain, hypothesized that this might be due to reduced feeding in mid-winter caused by low temperatures which induced the fish not to mature the following summer. Similarly, abnormally small size (100 g) in January in these experiments could upset the physiology of the fish enough for them not to mature the succeeding summer.

*Accelerated rearing to adult size*

A hypothetical growth curve for an accelerated rearing program to adult size (4 kg) is shown in Fig. 5. Also shown is a generalized growth curve for pen-rearing of salmon in Norway (Braaten et al., 1982). The figure shows that it would take close to 2 years from initial feeding to rear a 3—4-kg salmon under an accelerated program at 12°C. On the other hand, it takes an additional year or more to reach the same size in conventional rearing in Norway, which is subjected to seasonal fluctuations in temperature at all rearing stages.

It is likely that intensive rearing of salmon to market size in Iceland will be done in land-units with great expenditure of energy for heating and pumping. This requires fast turnover of fish in the facility. Strains used must, therefore, have high growth during the first sea-year.

*Thermal power requirements*

The thermal power required to heat water from 3°C to 12°C for the production of 100 000 oversize smolts is shown in Table III. Also shown are monthly mean weights and corresponding waterflows. Experience at Kollafjörður indicates that 100 000 30-g smolts could be produced with one megawatt. This corresponds to 3 l/s of 90 usable degrees centigrade (100°C) water. This assumes that grading of smolt-size fish (25 g) into unheated water starts in August—September. Further rearing of these smolts to 400 g the following spring requires approximately 8 megawatts, corresponding to 22 l/s of 90 usable degrees centigrade.

Once the 400 g size is reached, one would assume that sea water rearing would be desirable at least during the summer months (Saunders and

TABLE III

Energy required to produce 100 000 one-year smolts of up to 400 g by heating rearing water from 3°C to 12°C

| Month | Numbers of fish (× $10^3$)[a] | Mean weight of fish (g) | Total flow of heated water (l/s) | Thermal power required (megawatts) |
|---|---|---|---|---|
| February | 160 | 0.1 | 0.3 | 0.01 |
| March | 130 | 0.2 | 0.5 | 0.02 |
| April | 120 | 0.7 | 1.4 | 0.05 |
| May | 115 | 1.7 | 2.9 | 0.10 |
| June | 110 | 3.7 | 5.0 | 0.20 |
| July | 109 | 7.4 | 8.7 | 0.30 |
| August | 108 | 13.8 | 14.9 | 0.50 |
| September | 107 | 24.1 | 21.4 | 0.80 |
| October | 106 | 39.7 | 31.5 | 1.20 |
| November | 105 | 62.3 | 46.8 | 1.70 |
| December | 104 | 93.3 | 64.6 | 2.40 |
| January | 103 | 134.0 | 87.4 | 3.30 |
| February | 102 | 185.6 | 116.7 | 4.40 |
| March | 101 | 248.6 | 146.4 | 5.50 |
| April | 100 | 325.7 | 179.1 | 6.70 |
| May | 100 | 426.1 | 213.0 | 8.00 |

[a]Theoretical mortality rates.

Henderson, 1969). As previously mentioned, this can be done in two ways, either by pen-rearing during the summer months or by accelerated rearing in saltwater tanks with heated water. In the case of pen-rearing, no further heating is needed and 100 000 oversize smolts could be used to produce over 200 tons of 2-kg salmon. Rearing in tanks to full size is very energy demanding both with respect to heating and pumping. One can estimate that accelerated rearing of the 100 000 smolts to 4 kg, approximately 350 tons assuming normal mortalities, would require 30–50 megawatts of thermal power for heating during the coldest part of the year. This assumes the heating of sea water at natural temperatures, and the lower figure applies to the south coast of Iceland (3°C) while the high figure refers to all other areas (<0°).

## DISCUSSION AND CONCLUSIONS

Most of the artificial production of salmon in Iceland is 1+ smolts, since all rearing stations are using geothermal or other energy sources to accelerate rearing. Ranching experiments at Kollafjörður Fish Farm indicate that smolts over 25 g at release can have good return rates. Smolts which are intensively reared in water at 12–13°C up to the time of tagging (March) give satisfactory returns. All smolts spend at least 1 month in cold water (3–5°C) before going into release ponds in early May. Release takes place in early to mid-June.

Earlier experiments at Kollafjörður indicated that smolts need over 20 weeks in outdoor ponds before release (Isaksson, 1976) in order to adjust to natural photoperiod and temperature, which seem to be prerequisites for normal smoltification (Saunders and Henderson, 1970). The present experiments have reduced this to only 4—6 weeks, but indoor rearing has undergone major changes and is not comparable. Firstly, there has been a reduction in indoor lighting, allowing the fish to respond better to natural light entering through overhead windows. Secondly the 2 × 2-m tanks are now half-covered with black polyethylene, creating a natural shade which the fish tend to favour.

The growth rates given in this paper have all been worked out for the Kollafjörður strain. Norwegian experience shows that there is a great variation in growth rate between strains and even between families within the same strain (Refstie, 1978). He also concludes that most domesticated stocks in Norway would have better growth rates than the best wild stocks. The data presented here should therefore not be considered representative for all Icelandic strains. Many hatcheries, in fact, using Kollafjörður fish, have found them faster growing and easier to rear than most wild strains.

Brannon et al. (1982) conclude that good return rates of zero-age coho (*Oncorhynchus kisutch*) smolts can be obtained (3—6%) if the smolts are over 10 cm in fork length at the time of release. This corresponds to an approximative weight of 10 g and there is no doubt that zero-age smolts of Atlantic salmon would have to be at least 20 g for satisfactory survival. It is also clear that the growth rates obtained with the coho are much higher than those obtained with salmon in Iceland. Coho fry start-fed in February can reach an average weight of 15—20 g in May (R. Severson, pers. comm., 19xx) but Atlantic salmon fry started at the same time reach only 2—3 g. This is true, even when rearing temperatures are elevated to 14—15°C (D. Groman, pers. comm., 19xx), indicating that higher rearing tenperatures would be of questionable value for the Kollafjörður strain.

Growth rates of coho at Oregon-aqua facility in Oregon have increased a great deal in recent years, probably as a result of selection for rapid growth (R. Severson, pers. comm., 19xx). Further progress in the production of zero-smolts in Iceland must therefore depend on further acceleration of the hatching process, selection for rapid growth and enhancing early maturation of the adults.

Limited experience with zero-age smolts in Norway indicates that they do not perform satisfactorily when put in seawater pens, compared with one-year smolts (Boge, 1983). It should, however, be considered that these fish were put in sea water in fall and winter when temperatures are not as favourable as in the early summer. Fall releases of smolts in Iceland have given poor return rates and indicates that early summer releases should be used.

Apart from salmon ranching, Iceland seems to have some realistic methods of producing salmon for export using its geothermal resources. This is in most cases quite capital intensive with respect to facilities and running costs including both a great deal of electricity for pumping and thermal power for heating the rearing water. Recent studies in Iceland indicate that such plants would be economical at the present salmon price levels, especially when combined with thermal power plants (G. Björnsson, pers. comm., 19xx). These methods are, however, relatively more sensitive to a reduction in salmon prices than conventional pen-rearing methods. However, it is likely that future development of salmon culture in Iceland will be along these lines, together with pen-rearing during the summer. These methods all make such demands on local conditions with respect to geothermal energy, water supply, etc., that the production will probably be limited to relatively few sites with a great quantity produced at each site.

Due to the high cost of building rearing stations and the time that one has to wait for financial return, it seems likely that the stations will be owned by communities, large corporations or government. Since such industry must be considered high risk for a number of reasons, there has been very little public support or funding available for investment in salmon culture. The same is true for research in support of such aquaculture development. Those trends must change if salmon culture is to thrive in Iceland.

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