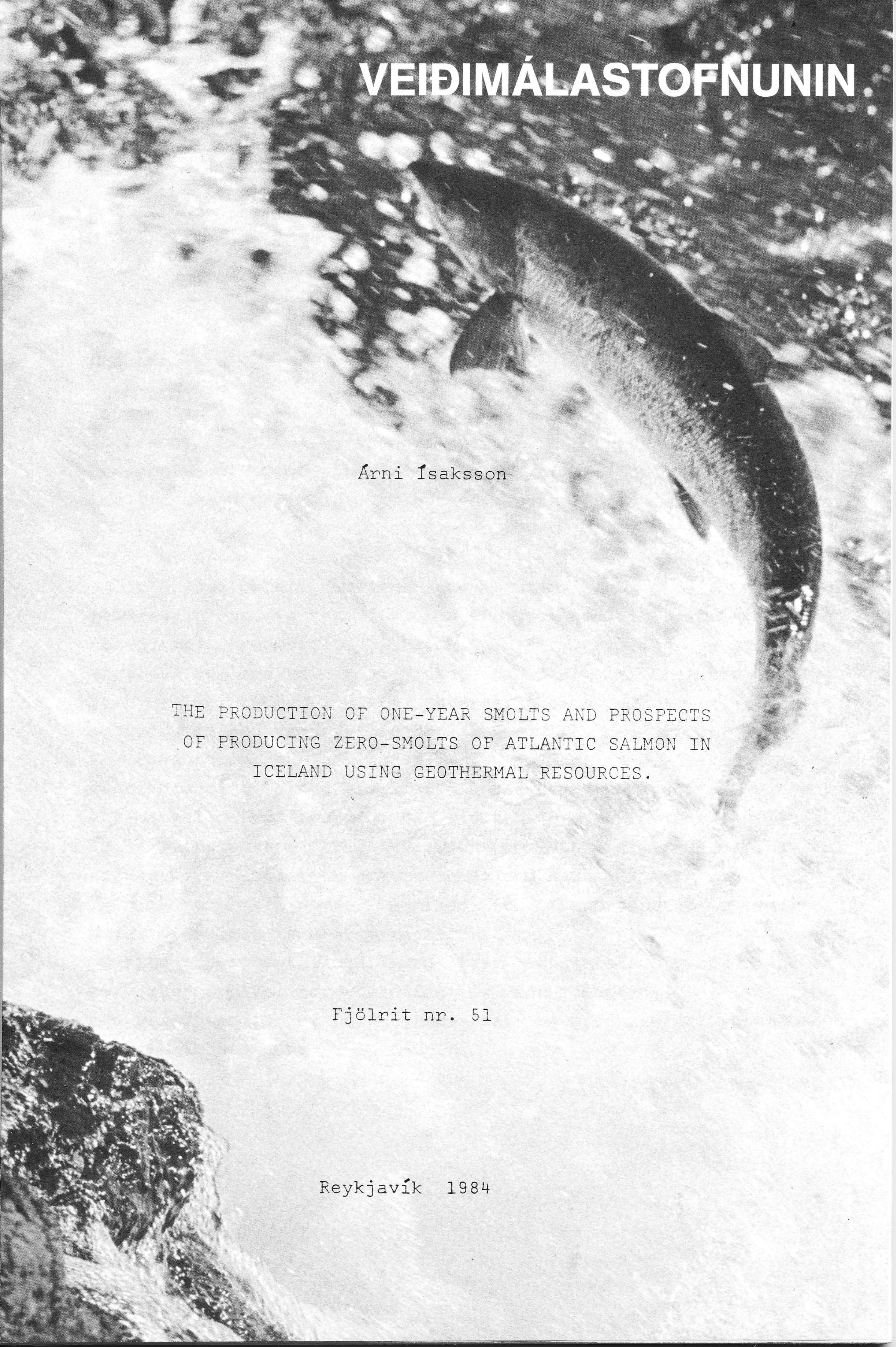

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Árni Ísaksson

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

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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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Abstract.

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The paper decribes the rearing and growth rates of zero-age, one year-smolts and 400 gram smolts in Iceland using geothermal resources. Hatching and rearing regime of accelerated smolts is compared to that of non-accelerated fish. Return-rates of one-year smolts are related to photoperiod and temperature regime used.

Production of adults using two methods is 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 would be more energy demanding than in most other countries. Due to the barren nature of the Icelandic countryside, most run-off streams get quite turbid and silted during rainy periods which makes them unsuitable as a water source for 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.

The steady supply of heat thoughout 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 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 following paper presents 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.

A. Growth.

There are numerous variables affecting the rearing process in a production hatchery. Of such variables one might mention variation in the time of maturation 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 periodical 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 startfeeding up to 400 gram 1+ smolts. This was done by using the information shown in table 1. 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 have ranged from 11 to 13°C at Kollafjörður, a freshwater station but temperatures at Sjóeldi have been from 10 to 12°C and salinities around 11°/oo. 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 figure 2. Accuracy of the curve was checked by comparing it to 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 graphical presentation.

In one instance a hypothetical growth curve was constructed for the accelerated rearing of adults up to 4 kilograms (figure 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 Hildingstams (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 has been solely based 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.

B. 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 x 2 meter 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 grams. 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.

C. 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 the rearing of same quantity to 4 kg salmon in heated sea water (12°C). The unit of thermal power used isthe 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 in liters per second.

Cp is the specific heat of water (Cp = 4.186 kj/kg ^{o}C).

ΔT is the necessary elevation of temperature (^{o}C).

1000 is the ratio between megawatts and kilowatts.

When calculating the energy requirement it was assumed that the temperature of 3^{o}C well water had to be raised to 12^{o}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

A. Accelerated rearing of smolts.

1. 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^{o}C and it was only after the feeding stage was reached that the parr were reared in 12 - 13^{o}C water (figure 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. Following 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^{o}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^{o}C throughout the incubation process.

The heating system at Kollafjörður Fish Farm is based on a heat-exchange system where geothermal water is used to heat up 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° incubation group has started feeding.

Temperature profile and hatching program for eggs hatched at 3, 8 and 10°C are shown in figure 3. Shown in the figure are dates spawned and hatched as well as date of 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 to cold water hatching. It should be stressed that the rearing process at Kollafjörður has primarily been accelerated 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.

Figure 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 only reached an average size of 25 grams 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, have started to feed in early February. They have reached an average weight of 15 grams by August at which time the largest can 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 gr.) 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 2 shows the return-rates of comparable accelerated one-year-smolts released in 1980, 81 and 82 at Kollafjörður and Lárós ranching station. 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 adaption to salinities for 3 weeks before release, which occurs over a 24 hour 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 is 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 owing to 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 kilometers of coastline.

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 - photoperiod regime and return-rates. The data in table 2 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 reaching smolt size in January - February.

2. Zero-age smolts.

The production of great numbers of zero-age smolts at a reasonable size (20 gr.) to meet the deadline of release (June) is not yet possible at Kollafjörður Fish Farm . Even at 10°C hatching temperatures, 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 so returns are difficult to confirm.

In early September of 1980, 2000 microtagged zero-age smolts (25gr.) were released at Kollafjörður Fish Farm after one months feeding and adaption to salt water. Maximum salinities were 20‰. 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. Returns to date have been only 3 fish, 2 from the two year group returning in 1981 and 1 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 can be visualized using 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 threshhold 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 alii (1977) suggested a lower optimum hatching temperature for some Canadian river stocks (6°C). They, however, also suggested that there might be considerable strain variations. One should therefore be very cautious not to transpose the present findings to other strains.

From the preceding paragraphs it can be seen that zero-age smolts are a realistic but not 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 it as the smolt of the future.

B. 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. 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 gram smolts according to the schedule shown in figure 2, and rearing subsequently in sea-cages from May through October. Winter rearing in Iceland is not possible due to the low temperature of seawater, frequently approaching -1°C, but the lethal temperature for Atlantic salmon in seawater has been found to be -0,7°C (Saunders et al. 1975). Limited experience in southern Iceland, however, indicates that 400 gram smolts when 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 figure 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 gram 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 11-15°/oo water 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 gr. 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 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 (figure 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 Kollafjörður strain and therefore have tendency towards maturation as grilse in ranching experiments.

Saunders et alii (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 grams) 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 figure 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. It takes, on the other hand, 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 that the turnover of fish in the facility is fast. Strains used must therefore have high growth during the first sea-year. year.

C. Thermal power requirements.

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

Once the 400 g size is reached one would assume that seawater rearing would be desirable at least during the summer months (Saunders and 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 thousand smolts to 4 kilograms, 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°C).

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 grams at release can have good return rates. Smolts which are intensively reared in 12-13°C water 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 needed 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 confined 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 2x2 meter 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 approximate weight of 10 grams and there is no doubt that zero-age smolts of Atlantic salmon would have to be at least 20 grams for satisfactory survival. It is furthermore 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 grams in May (R.Severson pers. comm.) but Atlantic salmon fry started at the same time reach only 2-3 grams. This is true, even when rearing temperatures are elevated to 14-15°C (D.Groman pers. comm.) indicating that higher rearing temperatures 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.). 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 by enhancing 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 seawater 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 indicate 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 include 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.). These methods are, however, relatively more sensitive to a reduction in salmon prices than conventional pen-rearing methods. It is, however, likely that future development of salmon culture in Iceland will be along these lines together with pen rearing during the summer and salmon ranching. These methods, however, 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 great cost of building rearing stations and the time that one has to wait for financial return, it seems likely that they 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 puplic 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 expected to thrive in Iceland.

Acknowledgement

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

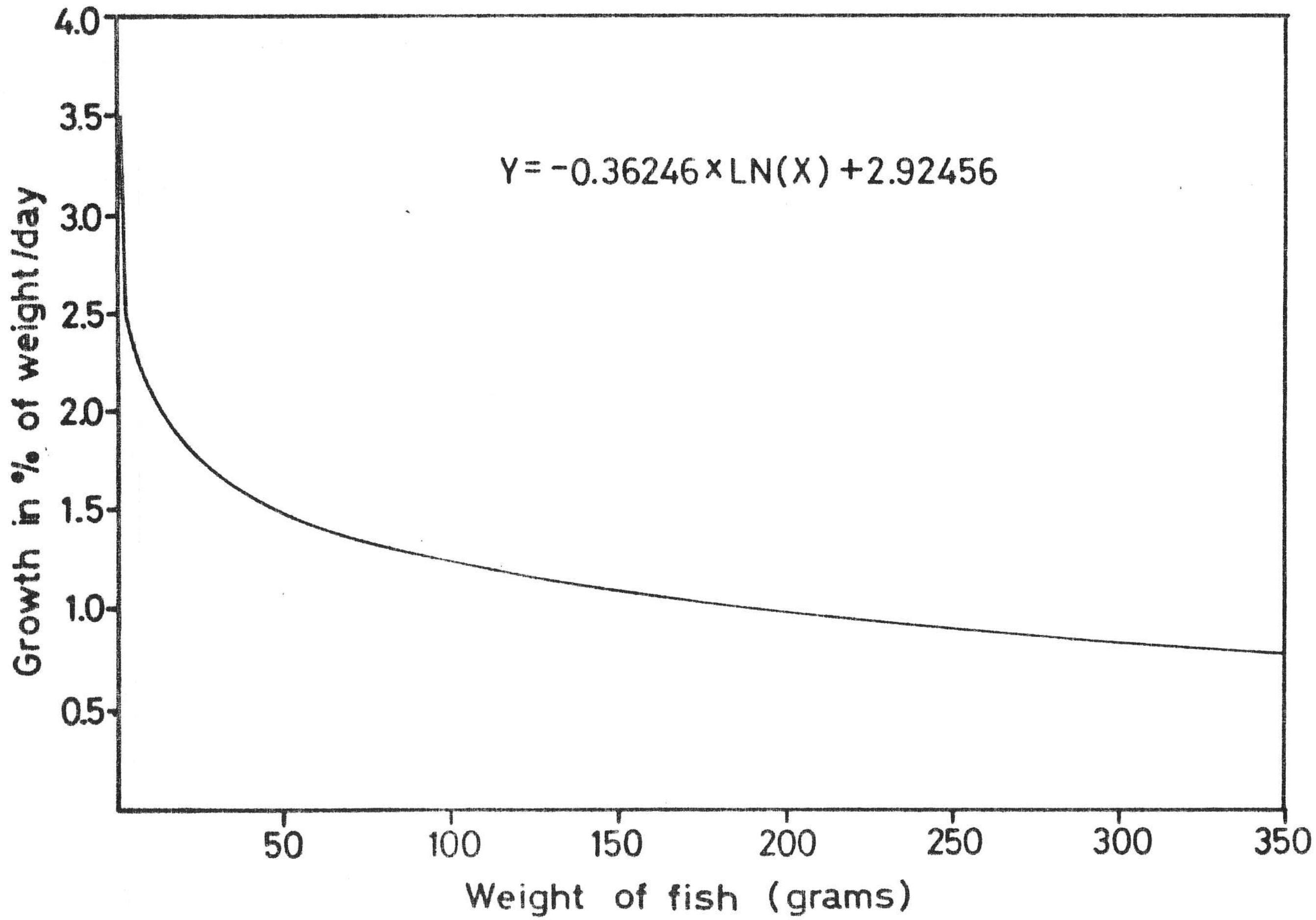

Figure 2. Calculated growth of accelerated juvenile salmon during 15 months starting in February. Observed growth values (A and B) are inserted for comparison.

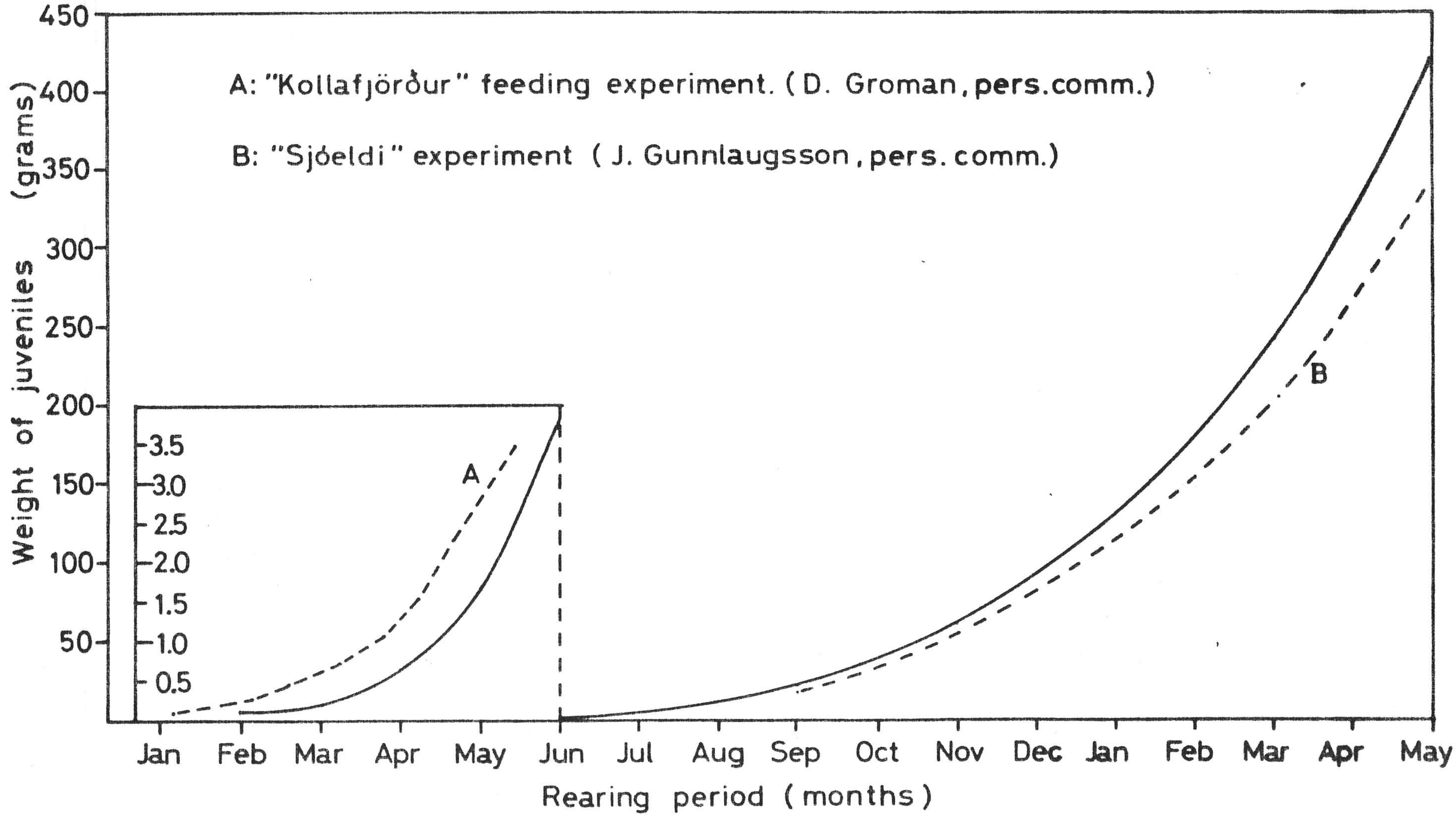

Figure 3. Effect of temperature on incubation and rearing program at Kollafjörður Fish Farm. Shaded areas show the amplitude of variation in temperature. Acceleration of smolts in Iceland has primarily been accomplished by speeding up incubation.

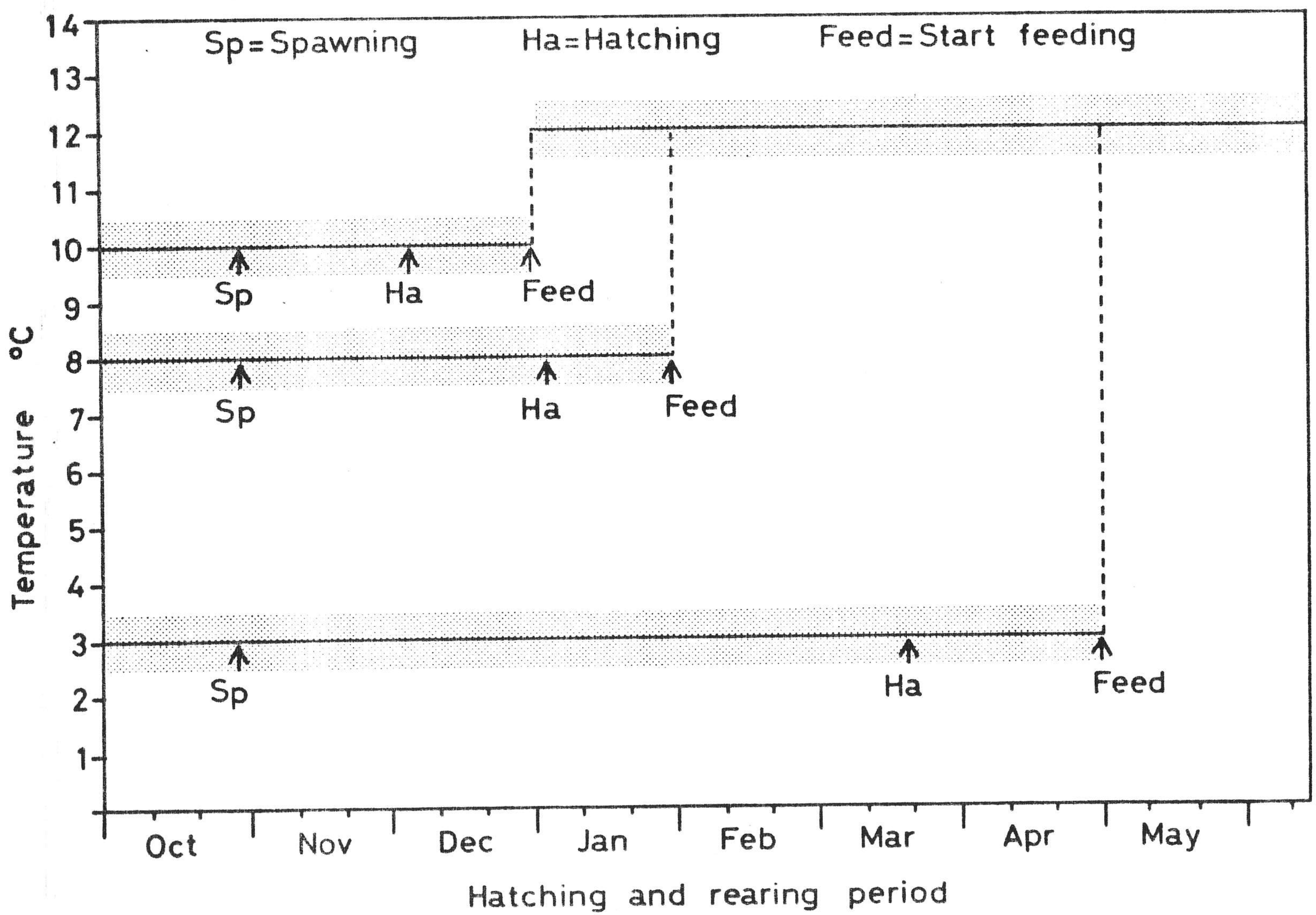

Figure 4. Growth comparison of accelerated smolts (A) and those hatched in cold water (B) at Kollafjörður Fish Farm. Growth rates are the same but startfeeding has been advanced by 3 months.

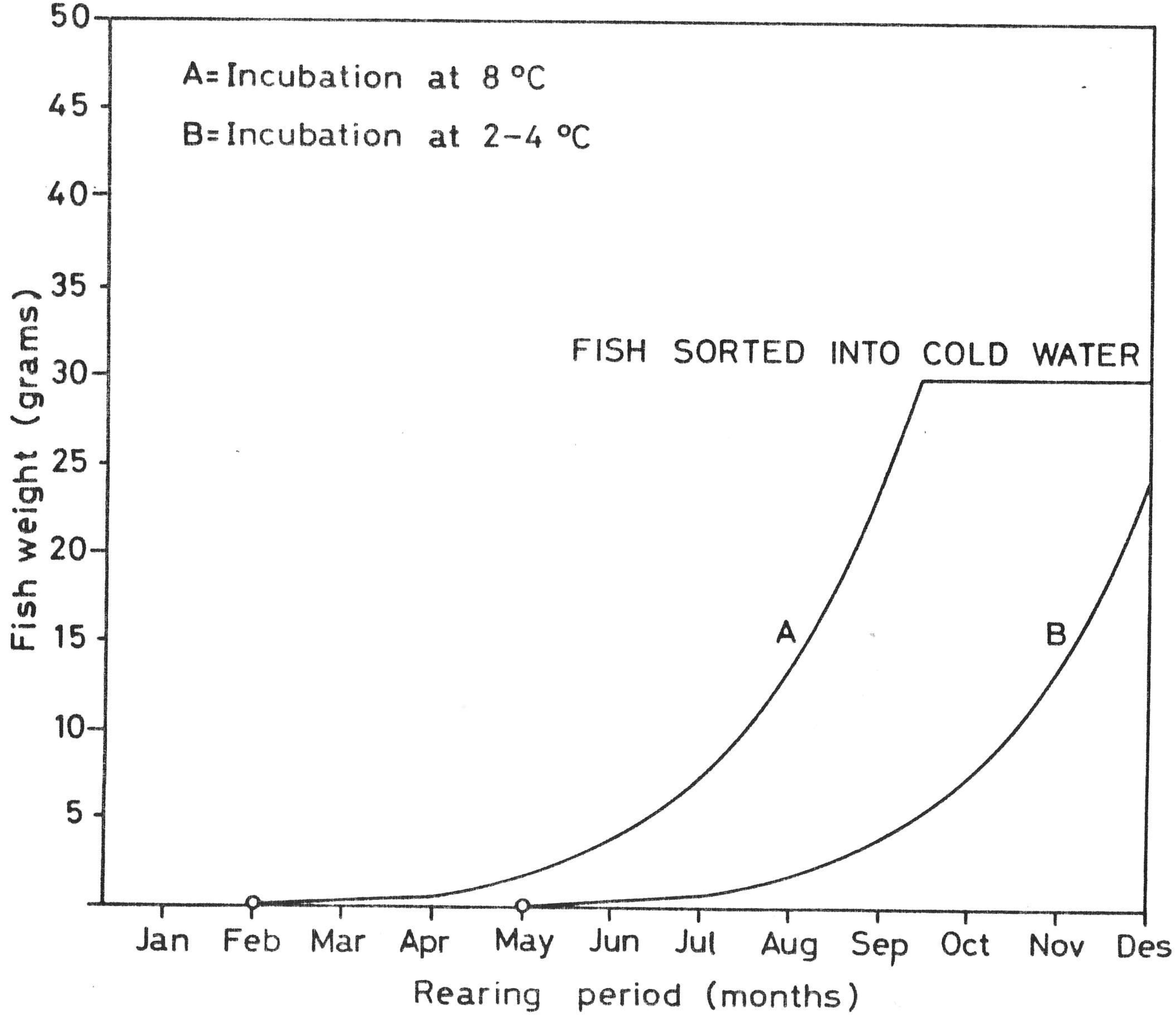

Figure 5. Comparison of projected growth rates for accelerated rearing of adults at 12°C in Iceland (A) and conventional rearing in Norway (B). Also shown is a growth curve (C) experienced at "Eldi" facility (Sig.St.Helgason 1982). M indicates the likely time for sexual maturation.

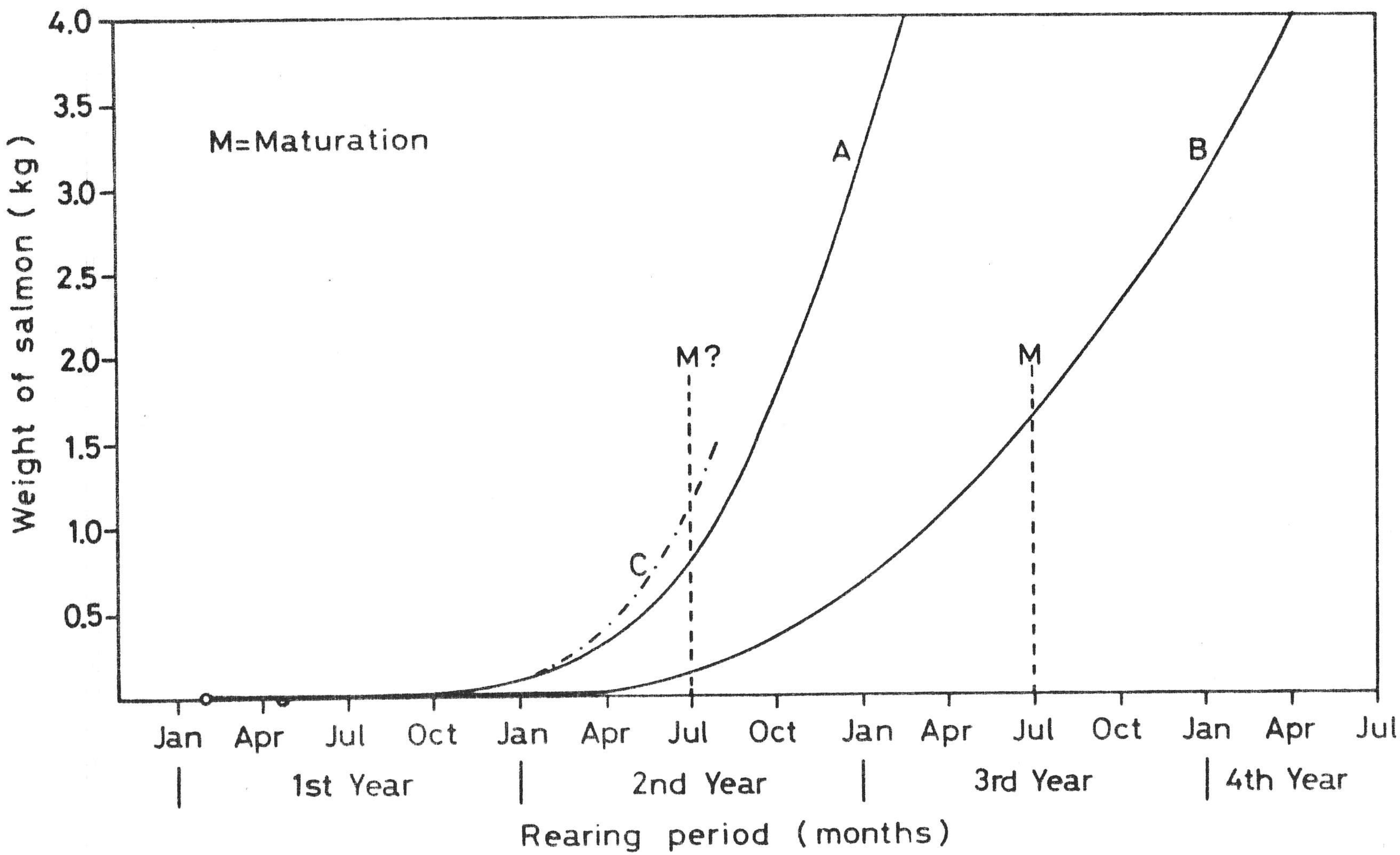

Table 1. Growth rates of different sizes of salmon juveniles in various rearing trials.

Experimental group no.	Initial weight (gr.)	Final weight (gr.)	Growth % of wet weight/ day	Start of experiment	Duration of experiment	Mean temperature ^{o}C	Salinity $^{o}/oo$
1	0,1	1,2	3,4	May 12 1969	74	12,5	0
2	0,1	3,0	2,3	April 19 1977	148	13,2	0
3	0,1	4,8	2,5	April 10 1977	157	13,2	0
4	0,1	6,2	2,7	April 10 1977	157	13,2	0
5	0,4	1,1	3,7	July 19 1971	28	13,0	0
6	1,2	2,3	2,2	Sept 26 1974	30	12,0	0
7	1,2	2,6	2,6	Sept 26 1974	30	12,0	0
8	1,2	6,2	2,4	April 29 1982	70	12,2	0
9	1,2	6,8	2,5	April 29 1982	70	12,2	0
10	2,6	4,8	2,1	Oct 25 1974	30	10,9	0
11	11,9	20,9	2,0	April 17 1970	28	12,2	0
12	15,3	25,6	1,9	April 17 1970	28	12,2	0
*13	**17,5	203,0	1,5	Sept 17 1983	167	12,0	11-15
*14	**12,0	125,0	1,4	Sept 17 1983	167	12,0	11-15
*15	203,0	***374,0	0,9	March 2 1984	69	10,0	11-15
*16	125,0	***226,0	0,9	March 2 1984	69	10,0	11-15

* "Sjóeldi" at Hafnir   ** Zero age in September   *** One-year in May

Table 2. 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 (gr.)	Mean ** weight at tagging (gr.)	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*	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*	Jan.	35	35	3020	10.9	3020	8.8

* One year at sea only
** Tagging time is March-April

Table 3. Energy required to produce 100 thousand one-year smolts up to 400 gr. by heating rearing water from 3°C to 12°C.

Month	Numbers of fish x 10^3 *	Mean weight of fish (gr.)	Total flow of heated water litres/sec.	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

* Theoretical mortality rates