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STUDIES ON ENVIRONMENTAL CONDITIONS AND INFLUENCE ON SALMON FARM PRODUCTION

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Abstract

The study was undertaken to investigate how environmental conditions influence growth of Atlantic salmon, and how different sib groups of salmon respond to different environment. The fish were raised at five different marine fish farms, and environmental conditions, growth and management were controlled routineously. The fish farms had different environmental conditions with regard to concentration of oxygen of ammonium. There were no simple connection between environment and growth. Farm management seems to be the most important single factor controlling growth. In several cases significant differences in family ranking between the fish farms were detected.

Introduction

Fish farms differ in fish health and growth, and accordingly in productivity. At the same time great differences in environmental conditions have been reported, this refers both to the conditions at the seabed beneath the farms and to water quality in the fish pen (Gowen et al 1989). So far these investigations have largely been restricted either to the fish or to the environment. Few studies in the marine environment have included both, and attempts to combine fish farm localization and cost of production have failed (Rusdal 1987). There is however, a general belief that the environment is one of the most important factors controlling health and growth in marine fish farms.

The main aim of this work is to study the influence of the environment on the growth of Atlantic salmon (*Salmo salar*) within the environmental range normally found in Noewegian marine fish farms. In addition, the use of family groups gives the opportunity to investigate how different genetic groups respond to different environmental conditions.

Another aim of the project has been to investigate how different environmental conditions influence fish health. These studies have been carried out as an integrated part of the total project. The results of the health studies will be published later.

This article presents the experimental design and it gives a descriptive presentation of the results from the investigations on environment and growth.

Material and methods

In this four years project, two yearclasses of salmon was placed at different fish farms and followed from the transfer to sea until harvest. Laborious design and high costs made it necessary to limit the number of experimental fish farms to five. Four of these were commercial, the fifth farm was the research station, "Austevoll Havbruksstasjon". The latter was used mainly as a control, and the results are not presented here. In addition there was one reference station not influenced by fish farming in the coastal zone.

In 1987 fish farm B was relocated to a new site with different environmental conditions. This did not fit into the experimental design, and farm B was therefore omitted from the last part of the experiment.

The study was carried out in the vicinity of Bergen, Hordaland county, in Western Norway. The fish farms were situated in a coastal archipelago, hydrographically this area belongs partly to the fjord zone, partly to the coastal zone (Aure 1981).

Salmon smolts were produced at the Matre Aquaculture Station in Matredal and transported to the selected fish farms in June/July. The first yearclass (1985) consisted of 69 full sib groups and all fish used, were tagged by finclipping and cold branding. Each farm received about 5000 fish which could be identified to family group. In the second yearclass (1986) 60 family groups were used and each farm received about 6000 fish.

Water exchange and the fish farmers skill and interest in the experiment were main criteria in selection of fish farms. Regarding maximim current velosity, the farms represented a gradient. However, all farms had long periods of low current velocity. The topography of the sites and the localization of the fish farms are presented in figure 1.

A contract was made with the fish farmers to assure similar treatment of all fish. The contract gave guidelines for the management of the fish, including separate fish pen, pen size, feeding, recording of mortality etc. Meetings were held regularly where the progress of the experiment and the results were discussed.

The appetite of the fish is partly influenced by the environmental conditions. The fish were automatically fed Tess dry feed with amounts comparable to 70 % of the recommended feed ration, and on top of that they were fed by hand until they did not respond to offered feed.

The total sampling program is presented in figure 2. Feed consumption, mortality and mean growth were recorded at regular intervals. After 12 to 14 months in the sea and again at harvest the fish populations were weighed, length measured and identified to family groups.

The physical parameters in the fish pen were measured about every second week during the project. The sampling was done at 2.5 m depth in the net pens. Measured parameters are given in figure 2. The analyses were done by standard methods. Current was measured in discrete periods of 14 days with SD 1000 current meters.
Estimates of feeding convertion factors are based on information of mortalities and weekly feed consumption given by the different farmers.

The environmental data from the individual fish farm and reference station have been compared by means of analysis of variance (procedure ONEWAY, (SPSS/PC+ V2.0. Statistical package).

Results

Environment

Temperature, salinity, oxygen and ammonium are known to influence on fish growth and health. The rest of the measured parameters (NO_2^-, NO_3^-, PO_4^{3-}, $Si(OH_4)$, pH) are not reported to have such an impact in the concentrations measured in this eksperiment.They are therefore considered to be of minor importance.

The temperature measurements are presented in figure 3. The temperature shows the seasonal variation normal for Western Norway with minimum and maximum values of respectively 2.8 and 15.6 ^oC. The variation from year to year is small. As might bee expected with sites situated in the same coastal archipelago, the variations between the fish farms are small and seems to be unsystematic. The statistical analyses show no significant differences in the temperature between any of the stations (Table 1).

The salinity varies between 28.22 and 34.09 ppt as seen in figure 4. There are some seasonal variations, with high values in winter and lower in spring and fall. The variance between the different years are clear, and precipitation and runoff seems to be more important than season. The variations between the fish farms are greater than they were for temperature, especially divergent is farm B which in periods has lower salinity than the rest of the farms. The results confirm that fish farm A, C and D are situated in the coastal zone with salinity higher than 30 ppt. Farm B is in the transition zone with salinity in long periods between 25 and 30 ppt (Aure 1981). Local runoff however, might influence the salinity in this farm located in a small land locked bay.

There are no statistical differences between the salinity at the sampling stations situated in the coastal zone. These stations are the reference station and the fish farms A, C and D. Fish farm B in the transition zone is, however, significantly different at the 0.05 % level (table 1). The mean salinity at this farm is almost 1 ppt lower than at the rest of the stations.

As expected the oxygen levels are highest in spring and summer when assimilation is prevailing, and lower in fall and winter when dissimilating processes dominate (figure 5). The concentration of oxygen varies between 4.35 and 8.35 ml/l.

Unlike the two preceding parameters, oxygen is strongly influenced by the fish farming activity. The values are lower in all the fish farms than at the reference station. There are also clear differences between the individual farms. The differences are relatively small in the period from February to April, this is the part of the year with the highest oxygen concentrations and lowest fish metabolism. The differences than gradually increase until August - November.

The values are especially low in fish farms C and D.
As can bee seen in table 1, farm C has a mean value for all measurements of 6.05 ml/l oxygen, compared to 6.36 for farm D and 6.84 at the reference station. The lowest measured saturation was 74 % in farm C in september 1988. In farm A and B the differences between the farms and the reference station were smaller, but these farms also showed the same pattern with relatively low concentrations during the fall.

The oxygen concentration in farm C is significantly different from all other sampling stations at the 0.05 % level (table 1). Farm D is different from farm B and the reference station at the same level of significance.

Figure 6 presents the results from the ammonium measurements. They are presented as total ammonium, the sum of ammonia (NH_3) and ammonium(NH_4^+). As can be seen the ammonium concentrations in the fish pen are completely ruled by the fish farming activity, and natural variation has minor influence. The lowest values occur in the period from January to May - June, the ammonium content in the fish pens increases until maximum concentrations is reached in August - November. Thus high ammonium and low oxygen concentrations coincide when both the fish biomass in the farms and the feeding rate are at a maximum.

As for oxygen the water quality in fish farm C and D are most influenced. Highest recorded ammonium value for these farms are 9.57 and 11.82 μM, compared to 5.36 and 3.81 μM for fish farm A and B. The mean values for fish farm C and D are respectively 4.77 and 3.66 μM (table 1). At the reference station the mean value is 1.02 μM

The analyses of variance shows that fish farm C is significantly different from all the other sampling stations (table 1). Farm D is different from the reference station and from farm A and B. The reference station is significantly different from all the fish farms. All levels of significance are 0.05 %.

Based on the values of oxygen and ammonia the fish farms can be classified in two groups. The first group is farm A and B which has slightly, but not significantly reduced oxygen concentrations. The ammonium concentrations are about twice as high as the values at the reference station and significantly different.

The second group consists of fish farm C and D. The levels of oxygen are here clearly reduced, and significantly different from fish farm B and the reference station. The ammonium concentration is strongly elevated. In fish farm C the levels are significantly different from all other stations, in farm D they are significantly different from the reference station and from fish farm A and B (table 1).

Growth and feed consumption at different farms.

The mean weights of fish at different times during the ongrowing period for the 1985 yearclass are shown in figure 7, a. Clearly, the fish have a low growth rate during the first 10 months in seawater. Measurements of the whole population after 14 months in the sea give mean weights varying from 1.2 (farm B) to 1.5 (farm C). At this time the exact number of fish in the pens were known and based on information of feed consumption given by the farmer, the feed conversion factors were calculated (see legend to figure 7). As shown, farm B has a very low consumption of food compared to the other farms, and not surprisingly, the number of fish in the pen was dramatically reduced during the first year in sea.

Farm C obtained the best production result at harvest after 22 months. The mean weight at harvest was 3.4 kg compared to 2.7 kg at farm D. Taking into account the actual number of fish at harvest, the difference in mean weight (0.7 kg) between the two farms with genetically identical groups of fish represent 5 metric tonnes of salmon. For all farms the feed conversion factors were low in the first part of the ongrowing period. The factor increased substantially, however, during the last period towards harvest. Considering the total growth period, farm C has the lowest feed consumption factor (1.2) and obtained the highest production result. On the other hand, farm D has the highest conversion factor (1.53), but obtained only a moderate increase in growth during the last months before harvest.

Similar results were obtained with regard to the 1986 yearclass (figure 8). As shown the fish obtained a substantially higher weight during the first year in the sea compared with the 1985 yearclass. The mean weights after 15 months were 1.8 (farm A and D) and 1.9 kg (farm C). The feed conversion factors were low in the same period (see legend to figure 8), but increased during the second year in the sea. Farm D obtained the highest mean weight (3.2 kg) at harvest compared to 2.7 kg at farm A. As for the 1985 yearclass, the best producing farm has the lowest feed conversion factor.

Family ranking at different farms

Based on the measurements carried out at harvest and identification of the fish to family group by finclipping and cold branding, the mean weights for each family on different farms were compared. The estimates are directly compared in figure 9, and the ranking profile obtained at farm D is used as a reference. Only families with more than 10 individuals were used in the comparisons.

As demonstrated for farm D, the 10 best families seemed to be superior compared to the other families. This observation was confirmed also for the other farms and the second yearclass (data not shown).

The data obtained for the 1985 yearclass are shown in figure 9. Farm D and A seem to have a similar ranking of the families, but some of the high ranking families at A are found among the lower ranking families at farm D (such as no 33 and 38). The same observations, but even more striking, are seen in the comparisons with farm B and C. At both farms several superior families had a low ranking at the reference farm.

With regards to the 1986 yearclass, a similar picture was obtained ,but these data are not shown here. In the statistical comparisons (Kendall's test of concordance) of family ranking we used three different family groups. These are the 10 best families, 25 best families and all families based on the ranking obtained at farm D. The family test groups are indicated in figure 9, and the results are summarized in Table 2 and Table 3.

For the 1985 yearclass significant variation in family ranking (10 best families; 25 best families) were found in the test involving all farms. In the pairwise comparisons significant difference was detected comparing all families at farm A and D. Comparisons of the other family groups reveal, however, very similar family ranking. On the other side, significant differences in family ranking were detected in comparisons with farm B and C, especially for the high ranking family groups. Farm B differ for all family groups compared.

The statistical test results obtained from the 1986 yearclass are summarized in Table 3. The significant differences are found for the best family ranking groups confirming the results from the other yearclass.

Discussion

The Norwegian salmon farming industry is located over a large geographic area along the coast as well as within large fjords. Thus, the farmed salmon are exposed to different environmental conditions with regards to physical parameters. The local farming environment offered to the fish, also consist of management factors such as fish density, food availability and the health status. The growth of the fish at each farm and accordingly the production of the farm, is dependent on the total set of environmental conditions exposed to the fish.

The genetic origin of the fish in question is very important. The large variation in growth rate between different strains of salmon and also between different families within the same strain (Gunnes and Gjedrem,1978; Nævdal et al.,1978) make it difficult to compare growth performance at different commercial farms under normal conditions. Therefore, this experiment reported here was set up with fish of known genetic origin which was tagged and could be identified to sib group. Based on this experimental design, the differences in growth, and especially in the production results at harvest, must be related to the farm environmental conditions offered to the fish.

The experiment involved a comprehensive sampling program for analyses of important physical factors in the farming environment. The measurements of temperature, salinity, oxygen content and especially total ammonium at the different farms, permit a classification the physical environment at each farm. Significant variation between farms were detected during the experimental period for all these factors except temperature.

The highest growth of the fish was, however, not associated with the farm having the best physical conditions. In the experiment reported, farm management and feeding regime are possibly the most important factors responsible for the observed differences in growth among the commercial farms. The differences in feeding regimes are indicated by the total feed conversion factors.

Based on family group tagging a significant variation in family ranking between farms was detected. This was most clearly expressed when considering the highest ranking families. In all comparison some superior families at one farm was found in the lower part of the family ranking at the other farms. This suggest that some families have a specific growth response related to a given environment.

The large scale salmon breeding program in Norway is based on developing a single, high performance strain for the whole farming industry. As known, the farms are located in areas with varying environmental conditions. The variation in family ranking presented here indicate a significant genotype - environmental interaction which must be evaluated in relation to different breeding strategies. Developing one high performance salmon strain for farming, must be based on selection of families which have a high rank in all environments. This strain should perform well under a great varieties of environmental conditions.

In some cases, however, it is of interest to develop a farmed strain for e specific set of environmental conditions. In such cases the selection must be based on high performance families in that specific environment. Thus, a high ranking in one environment, and a low in another, indicate a specific genotype-environmental interaction which can be utilized in developing a strain for the environment in question.

Acknowledgement

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Table 1 Pairwise statistical comparison (Procedure ONEWAY, SPSS/PC + V2.0 statistical package) between farms and reference station for four environmental parameters.

The data from the whole experimental period are used. Mean values are given in the paranthesis. * : $P < 0.05$.

	Station (mean value)		Sampling station				
TEMPERATURE (°C)			ref.	A	B	C	D
	ref.st.	(9.03)					
	A	(8.86)	-				
	B	(8.99)	-	-			
	C	(8.56)	-	-	-		
	D	(8.35)	-	-	-	-	
SALINITY (ppt)			ref.	A	B	C	D
	ref.st.	(31.81)					
	A	(31.57)	-				
	B	(30.62)	*	*			
	C	(31.74)	-	-	*		
	D	(31.87)	-	-	*	-	
OXYGEN (ml/l)			ref.	A	B	C	D
	ref.st.	(6.84)					
	A	(6.62)	-				
	B	(6.82)	-	-			
	C	(6.05)	*	*	*		
	D	(6.36)	*	-	*	*	
AMMONIA (μM)			ref.	A	B	C	D
	ref.st.	(1.02)					
	A	(1.97)	*				
	B	(1.83)	*	-			
	C	(4.77)	*	*	*		
	D	(3.66)	*	*	*	*	

Table 2 Statistical testing (Kendall's test of concordance, SPSS/PC+ V2.0 statistical package) of family ranking groups between different farms for the 1985 yearclass at harvest. In the pairwise tests farm D is used as a reference farm. The tests are based on the data from fig.9 where the family ranking groups are indicated.

Farms	**Family ranking groups**	**Kendall's test** **W**	X^2	**P**
A, B, C, D	1 - 10	0.3875	11.6250	0.0088 *
	1 - 25	0.1367	10.2490	0.0166
	all	0.0167	3.4520	0.3270
A, D	1 - 10	0.0000	0.0000	1.0000
	1 - 25	0.0760	0.1818	0.6698
	all	0.0859	5.0700	0.0243 *
B, D	1 - 10	0.5102	3.5714	0.0588 *
	1 - 25	0.1936	4.8400	0.0278 *
	all	0.0985	5.1200	0.0237 *
C, D	1 - 10	0.5444	5.4440	0.0196 *
	1 - 25	0.2381	5.0000	0.0253 *
	all	0.0002	0.0154	0.9013

Table 3 Statistical testing (Kendall's test of concordance, SPSS/PC+ V2.0 statistical package) of family ranking groups between different farms for the 1986 yearclass at harvest. In the pairwise tests farm D is used as a reference farm.

Farms	**Family ranking groups**	**Kendall's test W**	**X^2**	**P**
A, C, D	1 - 10	0.4105	8.2105	0.0165 *
	1 - 20	0.1256	5.0256	0.0810(*)
	all	0.0190	2.2400	0.3259
A, D	1 - 10	0.4500	4.5000	0.0339 *
	1 - 20	0.1778	3.5556	0.0593(*)
	all	0.0615	3.6296	0.0568(*)
C, D	1 - 10	0.6400	6.4000	0.0114 *
	1 - 20	0.1600	3.2000	0.0738(*)
	all	0.0000	0.0000	1.0000

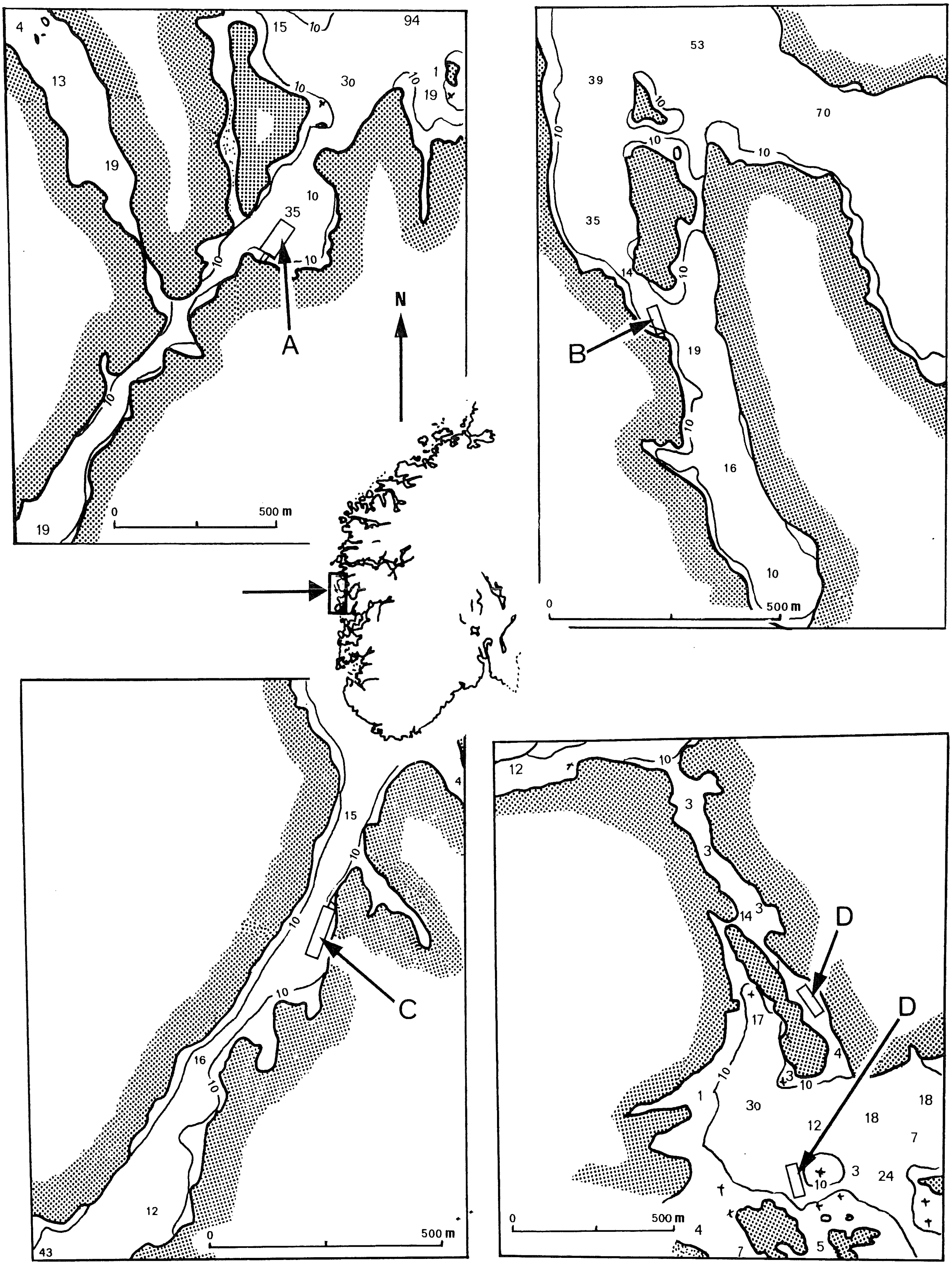


Figure 1 Bottom topography and localization of the different farm sites.

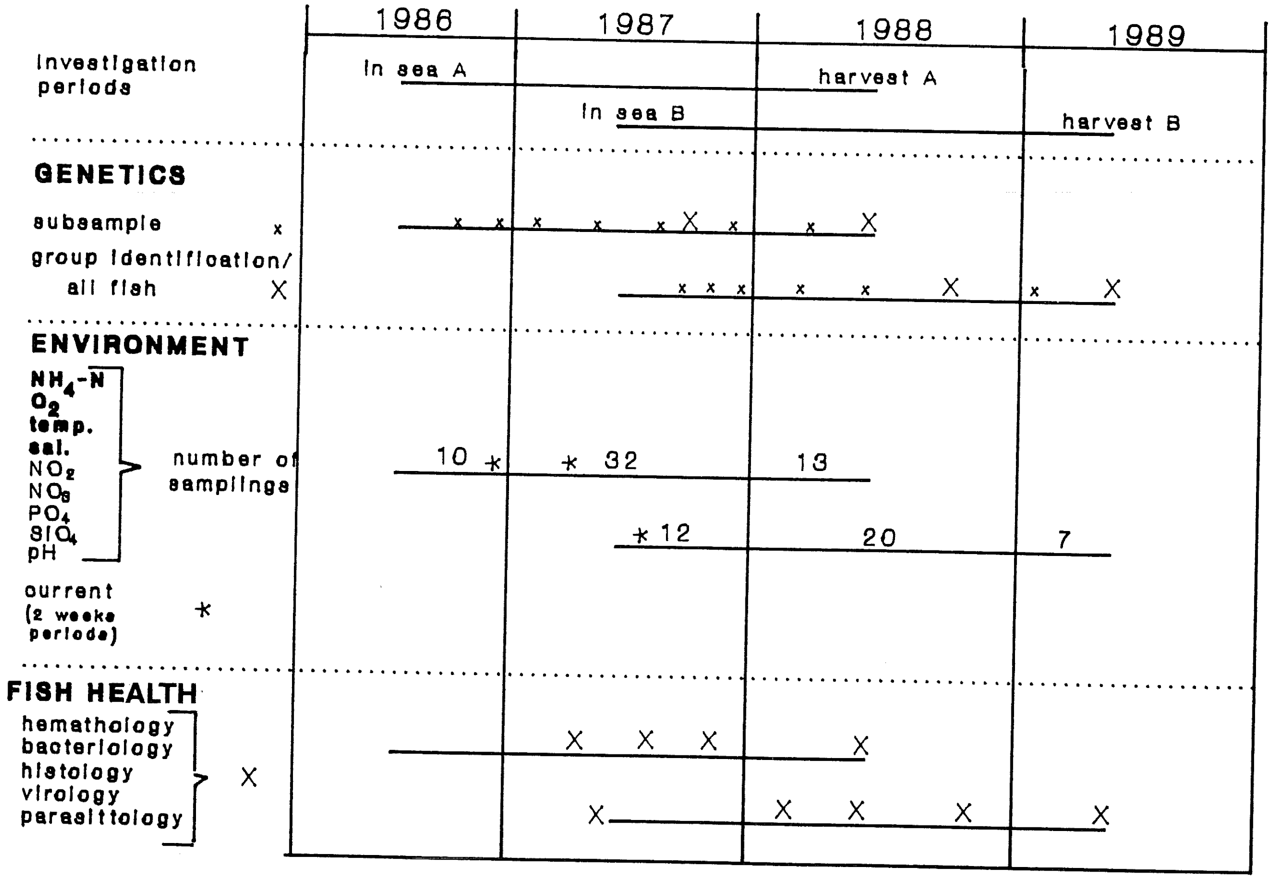


Figure 2 Investigation periods and sampling programs for estimation of environmental parameters, growth performance and fish health status.

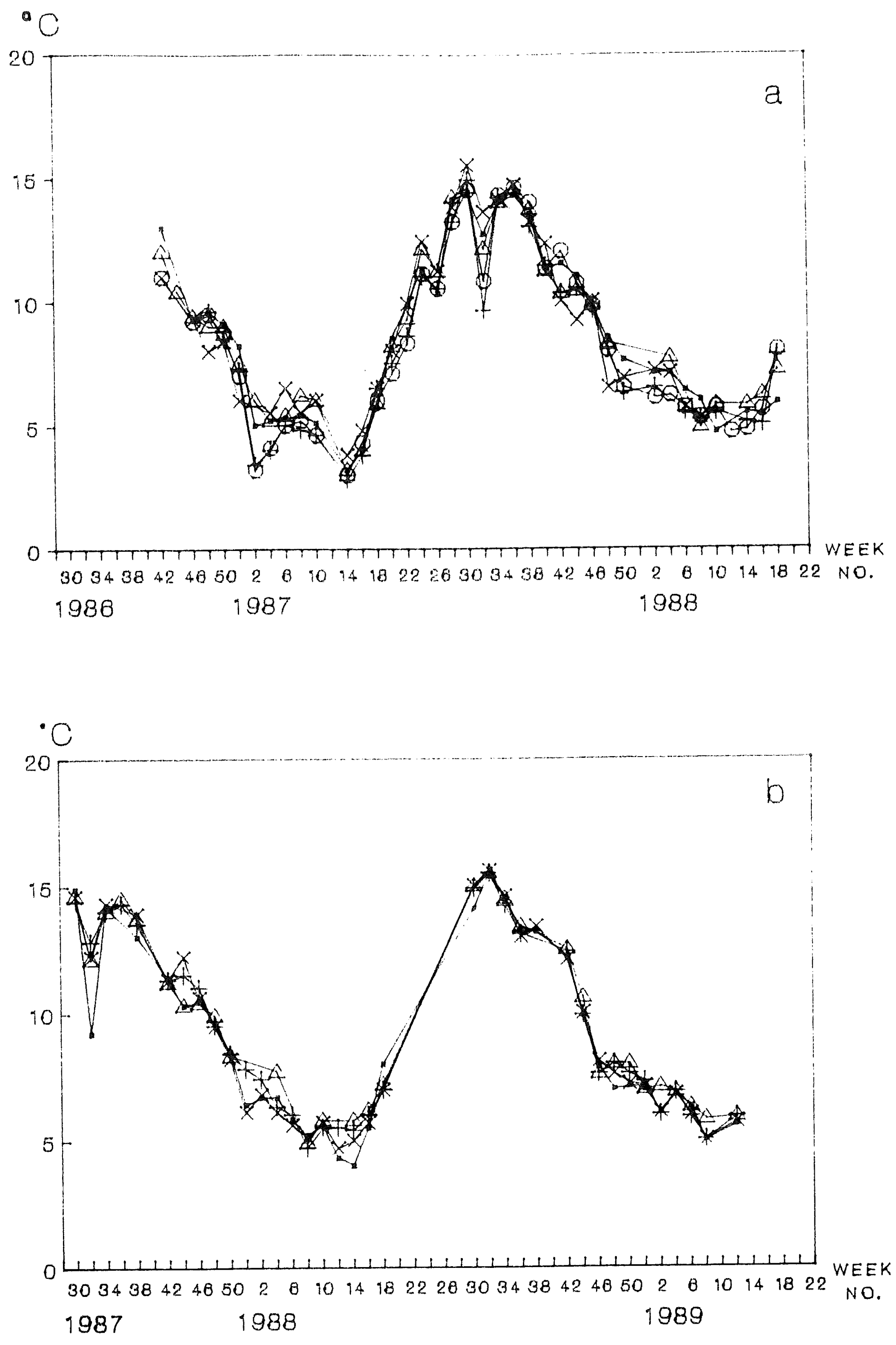


Figure 3 Temperature in the experimental pens at different farms and the reference station.

a: 1985 yearclass; **b**: 1986 yearclass.
reference: △ ; farm A: + ; farm B: ○ ; farm C: x ; farm D: ▪ .

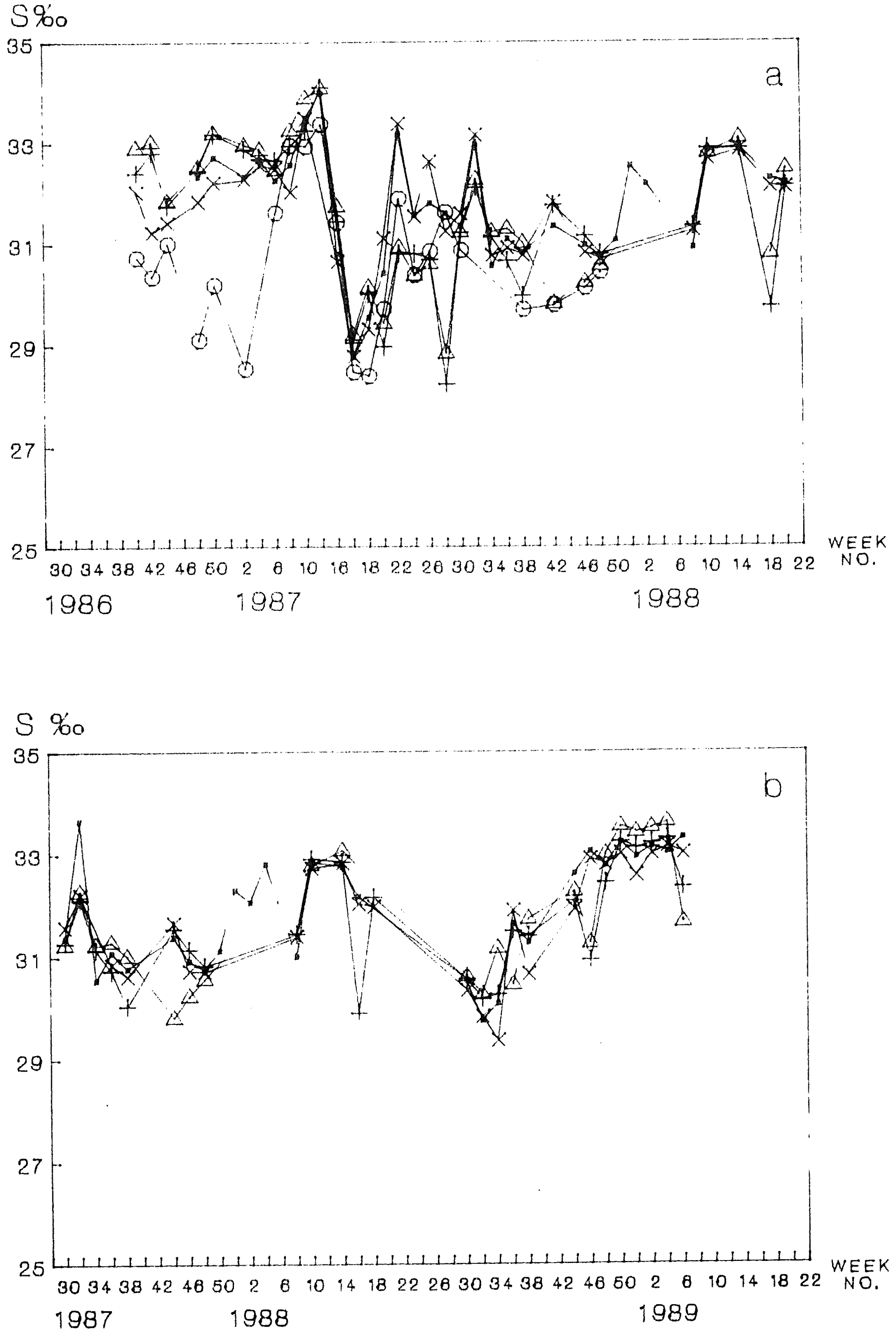
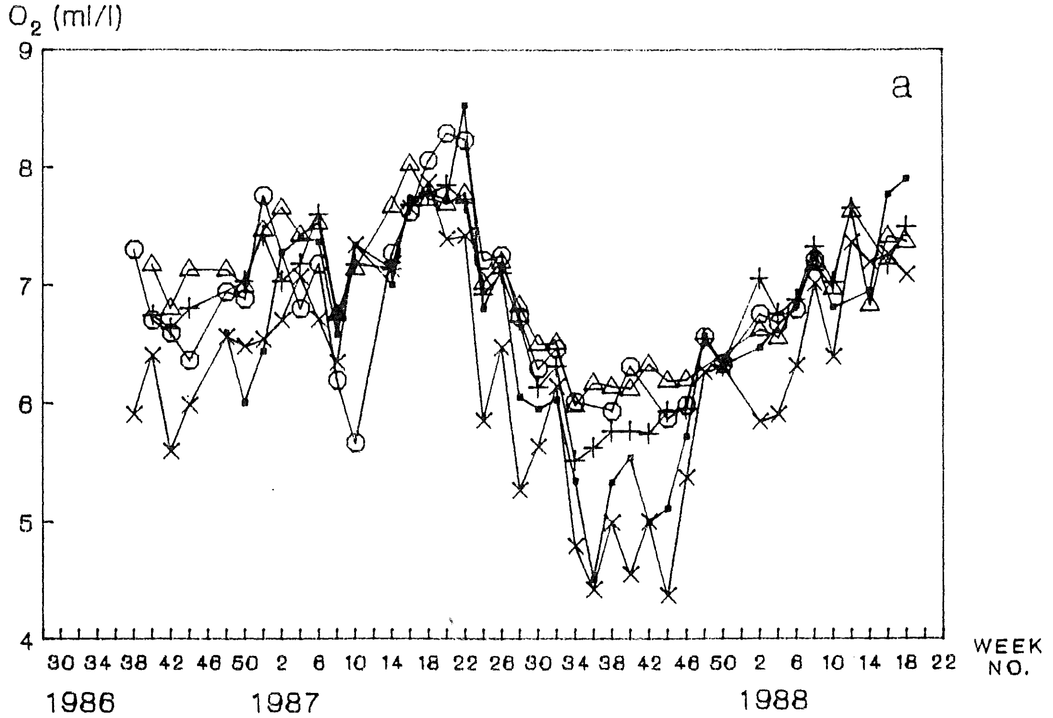


Figure 4 Salinity in the experimental fish pens at different farms and the reference station.

a: 1985 yearclass; **b**: 1986 yearclass.
reference: △ ; farm A: + ; farm B: ○ ; farm C: x ; farm D: ▪ .



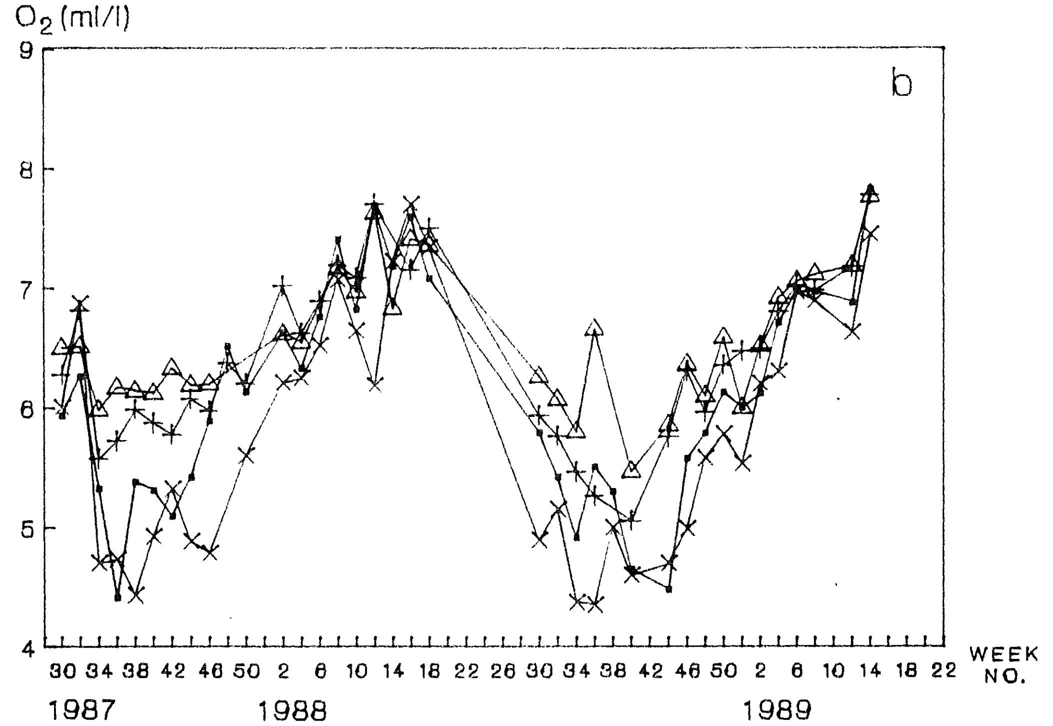
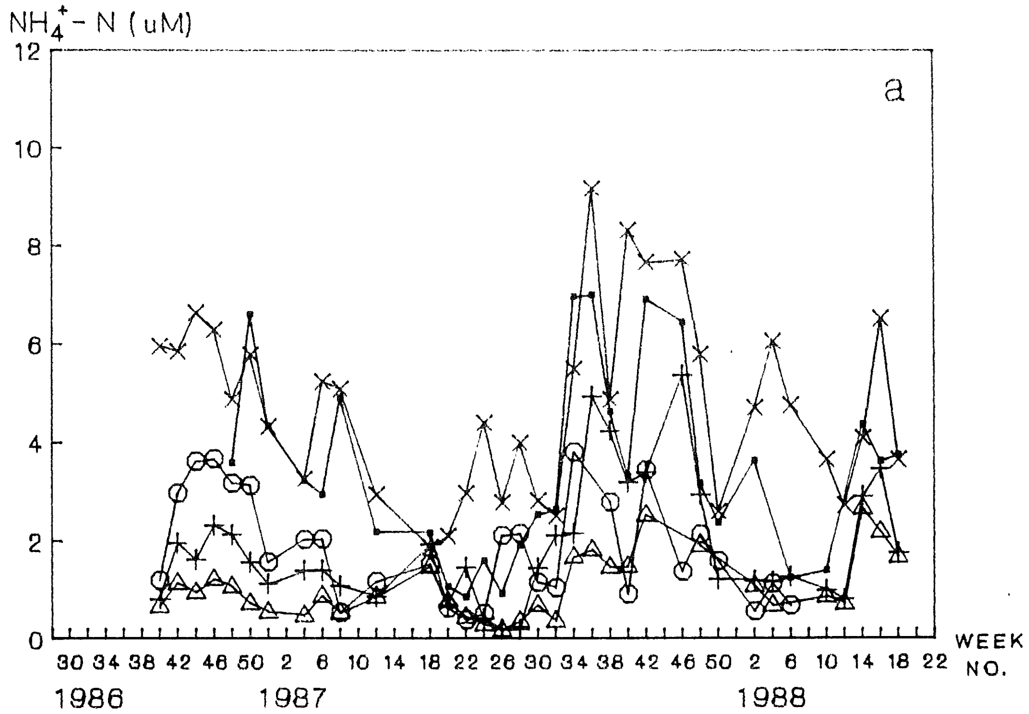


Figure 5 Oxygen content in the experimental pens at different farms and the reference station.

a: 1985 yearclass; **b**: 1986 yearclass.
reference: △; farm A: +; farm B: ○; farm C: x ; farm D: ▪ .



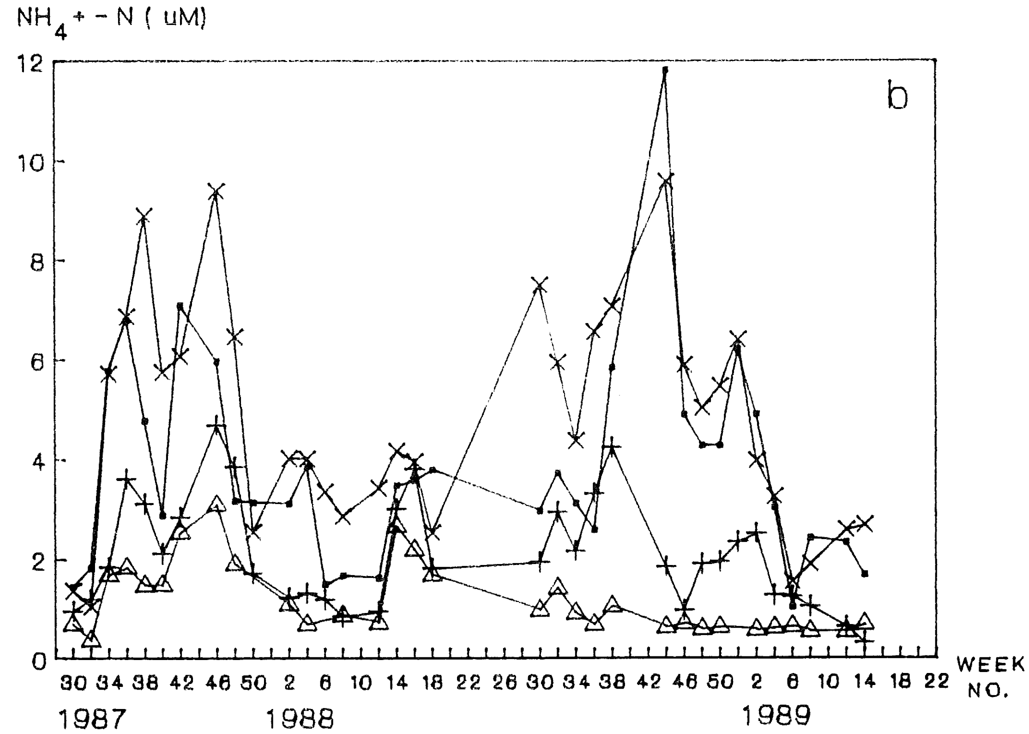


Figure 6 Total ammonium in the experimental pens at different farms and the reference station.

a: 1985 yearclass; **b**: 1986 yearclass.
reference: △; farm A: +; farm B: ○; farm C: x; farm D: ▪.

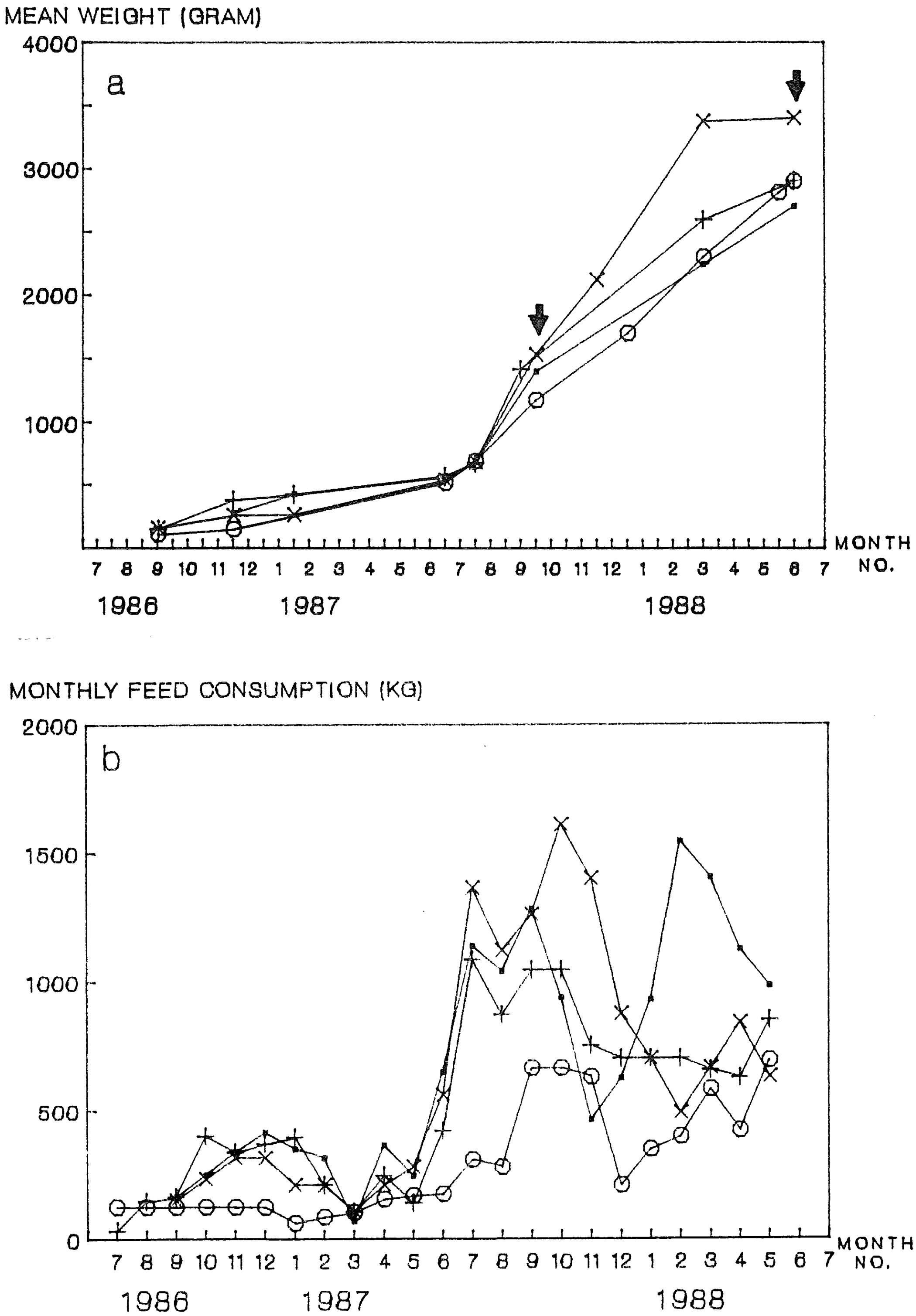


Figure 7 Mean weight of the fish (a) and monthly feed consumption (b) at different farms during the 1985 yearclass experiment. The growth estimates are based on measurements of subsamples and the whole population. (The last indicated by arrows).

Estimates of feed conversion factors:

	total period	86-87	87-88
farm A +	1.32	1.17	1.97
farm B ○	0.88	0.65	1.92
farm C X	1.20	1.04	1.58
farm D ▪	1.53	1.08	2.11

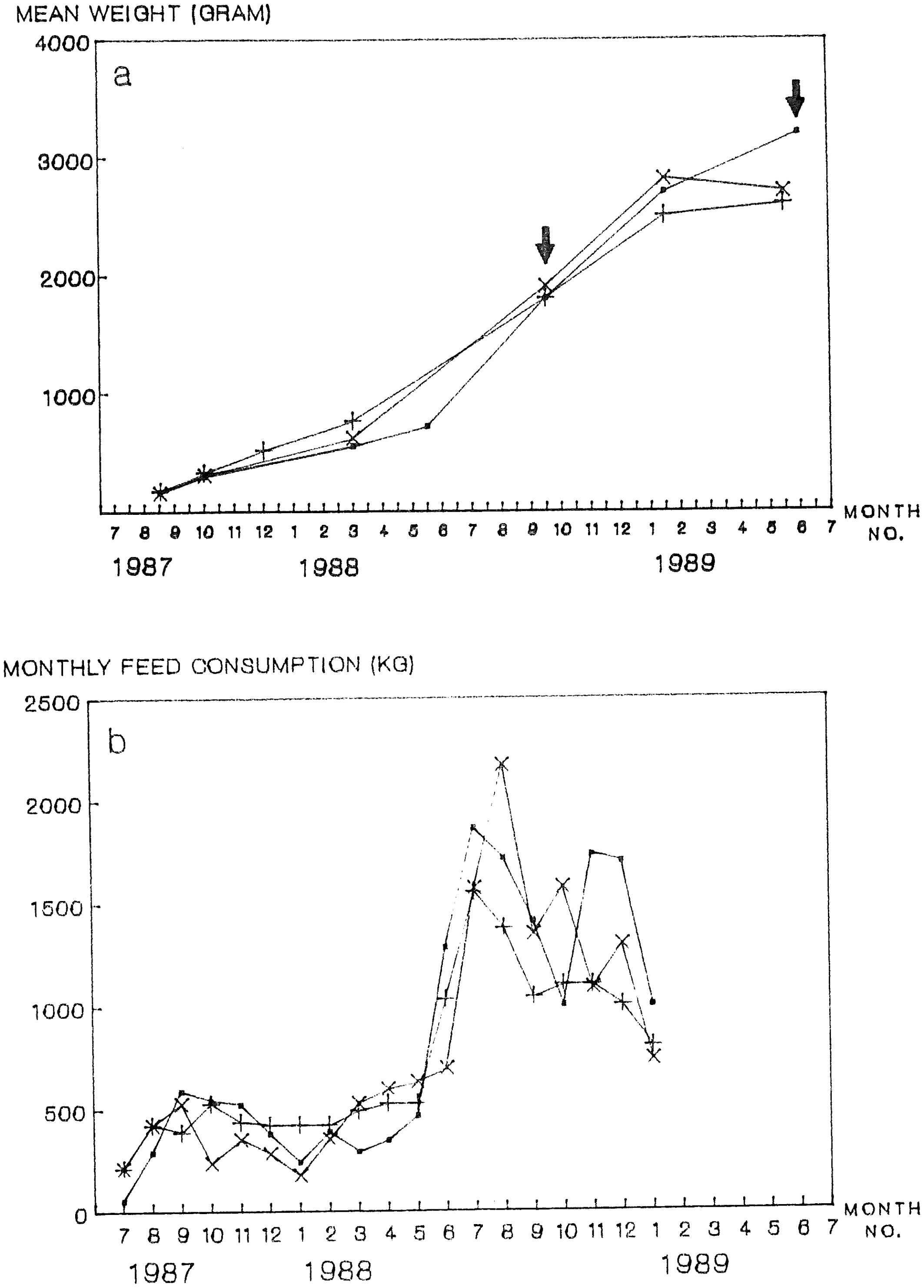


Figure 8 Mean weight of the fish (a) and monthly feed consumption (b) at different farms during the 1986 yearclass experiment. The growth estimates are based on measurements of subsamples and the whole population.(The last indicated by arrows).

Estimates of feed conversion factors:

	total period	**87-88**	**88-89**
farm A +	1.34	1.12	2.04
farm C X	1.30	1.04	1.96
farm D ▪	1.15	1.10	1.26

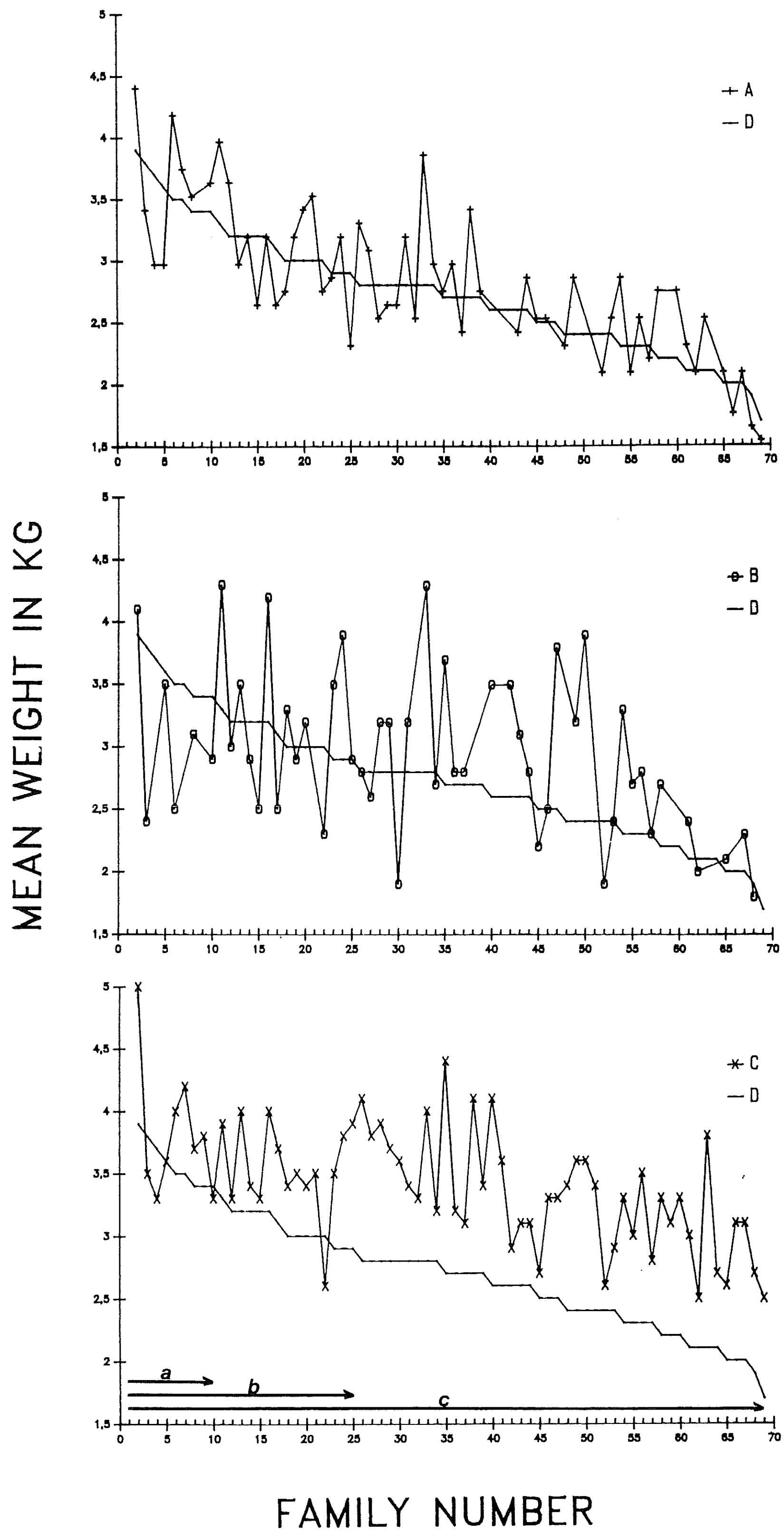


Figure 9 Comparisons of mean weights of the 1985 yearclass salmon sib groups measured at different farms. The ranking profile obtained at farm D is used as a reference.

Family ranking groups: a → 1-10; b → 1-25; c → 1-69.