Fol. 41 F

ICES 1990 PAPER C.M.1990/F:64
Mariculture Committee

SMOLTIFICATION OF ATLANTIC SALMON IN DIFFERENT WATER QUALITIES AND SUBSEQUENT GROWTH IN SEA WATER, FOLLOWING DISTINCT TRANSFER STRATEGIES FROM FRESHWATER

by

Ragnar Nortvedt[1], Tom Hansen[2], Trygve Lunde[3] and Steinar Skybakmoen[3]

[1]Institute of Marine Research, Div. of Aquaculture, P.O.Box 1870, N-5024 Bergen - Nordnes, Norway
[2]Institute of Marine Research, Div. of Aquaculture, Matre Aquaculture Reasearch Station, N-5198 Matredal, Norway
[3]Norwegian Hydrotechnical Laboratory, SINTEF Group, Klæbuveien 153, N-7034 Trondheim - NTH, Norway

ABSTRACT

Atlantic salmon parr were kept in four different fresh water qualities for seven months before smoltification, which was characterized by plasma chloride content after sea water challenge tests. Three groups were transferred directly to sea water, together with three comparable subgroups, which had stayed the last seven weeks in a tank with increased water flow and fish density. Growth and mortality of all groups were thereafter followed for six months in sea water.

Groups from fresh water with highest oxygen content and water exchange rate increased their biomass 5-6 times in sea water, whereas fresh water groups with low oxygen content and low water exchange rate only increased biomass 2-3 times in sea water. Mortality explained most of the differences in biomass. This emphasizes the importance of fresh water quality for the following success in sea water. Transference to new environmental conditions with increased fish density, water flow and exchange rate seven weeks ahead of release into sea water, had negative influence on the subsequent success in sea water. Smoltification in oxygen supersaturated (118 %) water had no negative influence on smolt quality.

INTRODUCTION

Smolt production capacity in Norway today is in surplus. Intensive rearing of Atlantic salmon parr to reduce costs in Norwegian smolt production has concequently become crucial to survive as farmer. Intensive rearing may include manipulation with light (Saunders and Henderson 1970, Stefansson *et al.* 1990) and temperature (Wagner 1974).

Adequate water supply may represent a bottleneck to many producers during intensive rearing under high temperature. In short time oxygenation has become a widely used rearing method to improve production, both as security and as means of reducing water transport costs within the production area. Addition of oxygen may also improve the ability to benefit from periods of high temperature. Better growth has consequently resulted from properly use of oxygenation methods (Colt and Watten 1988). However, oxygenation will also make influence on water flow and water exchange rates in tanks, and sustained excercise is important to salmonids (Christiansen *et al.* 1989).

When new methods are introduced with some documentation of immediate positive effects, there should always be questions about possible negative long-term effects. Some producers of adult salmon may ask if intensive smolt production with surplus amounts of oxygen will cause negative influence on subsequent success in sea water. The aim of the present investigation was to answer that question, and also to find out how changing fresh water flow during smoltification could influence performance in sea water.

MATERIAL AND METHODS

The experiment in fresh water was carried out at the Matre Aquaculture Research Station from November 16, 1988 to June 29, 1989. The salmon were transported to Austevoll Aquaculture Research Station June 30, and the experiment were continued in sea water until December 21, 1989. The experimental part in fresh water was conducted in five grey, covered fibreglass tanks with water volume 1.000 litres. The salmon received continuous light from Nov. 16, 1988 to Jan. 31, 1989 and simulated natural photoperiod from Feb. 1. The fish were fed calculated rations, according to size and temperature (Austreng *et al.* 1987), from automatic feeders during the illumination period. The experimental part in sea water was conducted in a net pen (125 m^3). The salmon were handfed to satiation 2-3 times the day. All the fish were deloused in July and August with Nuvan.

Fish

Atlantic salmon parrs of mixed genetic origin were placed in their respective tanks November 16, 1988. Their mean size were 14.3 g, and represented the smallest graded subgroup from a large population.

Experimental design in fresh water

Three salmon groups B, C, D were reared in separate tanks, supplied with oxygenated water from an oxygen cone. Cooling water from Matre Hydroelectrical Power Plant ($temp_{mean}$ = 6.0 °C, $temp_{sem}$ = 0.2 °C) and oxygen from AGA Norgas were mixed under a constant pressure of 4 bars. Oxygenated inlet water to the tanks had a mean O_2 content of 17.9 $mg*l^{-1}$, whereas O_2 content in outlet water was regulated according to the experimental setup. It varied from 6.7 to 14.5 $mg*l^{-1}$ in tanks B, C and D (Figure 1), and was regulated by the flow of oxygenated water, which served as main supply. The flow varied between mean values of 3.2 and 11,7 $l*min^{-1}$. Biomass was regulated monthly to about 25 $kg*m^{-3}$.

The fourth salmon group A were supplied with normal water from the power plant. O_2 content in the outlet was regulated by flow (23 $l*min^{-1}$) to a comparable level (7 $mg*l^{-1}$) as in group B. Biomass was kept between 50-70 $kg*m^{-3}$ to ensure high flow and rapid exchange rate of water (mean residence time was 43.5 minutes). A small additional supply of salt well water from the ground was added to ensure a satisfactory conductivity in all tanks. Salinity was regulated to 2 ppt and increased during spring to 8 ppt in June 20.

After six months, 68 to 94 fish from each mother group B, C and D were fin clipped, freeze branded and transferred as subgroups B_2, C_2 and D_2, respectively, to a common temporary tank (Figure 1), to test the effect of a change in water flow and O_2 content on subsequent success in sea water. Oxygenated water was supplied to this tank, and water flow (6.2 $l*min^{-1}$) and biomass (50 $kg*m^{-3}$) were controlled to ensure 6.5 mg O_2*l^{-1} outlet water. The salmon were kept in the temporary tank from May 9 to June 20, whereafter it was pooled with 99 to 117 marked salmon from each of the groups A, B and C in an outside holding tank. The salinity in the holding tank was gradually increased from 10 ppt to 28 ppt before transportation to the net pen i sea water (29.5 ppt).

Sea water challenge tests

Sea water (35 ppt) tolerance of the salmon (n = 12) from groups A, B and C were tested monthly from January to June, 1989 for 24 hours in separate tanks. Tests were performed in unexchanged, aerated water. Blood samples were collected from the caudal vein. Sampled fish were anaesthized in benzocaine. Plasma was freezed as standard procedure after blood sentrifugation in 10 minutes. Chloride content in plasma was analyzed by $AgNO_3$-titration. Plasma chloride in untreated fish from the same groups were also sampled as control in May and June.

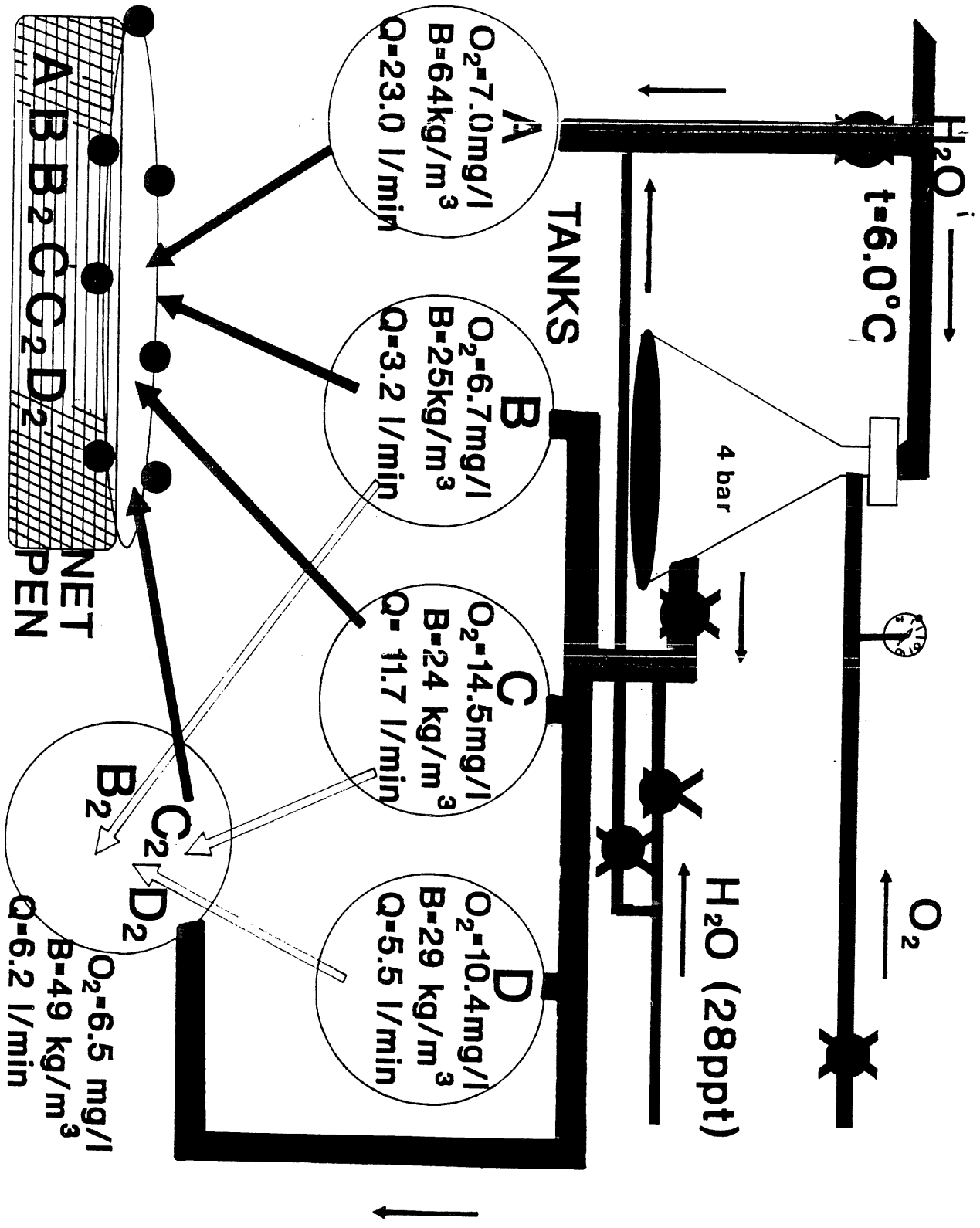

Figure 1: **Experimental design.** All fresh water groups, except group A, received oxygenated water (17.9 mg O_2*l^{-1}) from an oxygen cone. A minor supply of salt water was added to ensure water quality in all fresh water tanks. Salmon parrs were reared in fresh water tanks A, B, C, D from Nov.16, 1988 to June 20, 1989. Three subgroups of salmon B_2, C_2, D_2 were kept in a temporary fresh water tank from May 9 to June 20, 1989. Groups A, B, C, B_2, C_2, D_2 were transferred to sea water June 30, and reared in a net pen until December 21, 1989.

Continuation in sea water

Growth and mortality of smolts from groups A, B, C, B_2, C_2 and D_2 were registered for six months in sea. Sampled fish were anaesthized in metomidate. Weight was measured individually on all fish. Daily specific growth rate were calculated as:

$$SGR\ (\%) = ((\exp((\ln W_2 - \ln W_1)*(T_2 - T_1)^{*-1}) - 1) * 100)$$

W_1 and W_2 denote mean weights at sampling time T_1 and T_2, respectively. Cange in biomass were calculated according to mortality and mean weight. Increase in biomass until $date_a$ was related to biomass at $date_1$ (June 20), according to: $B_a * B_1^{-1}$.

RESULTS

Sea water challenge tests

Plasma chloride content after sea water challenge tests showed a general increase from 160-180 μM in January until March in groups A and B, and thereafter a decrease to about 140 μM in June 20 (Fig.2). Group C started at 144 μM in January and increased to a peak value in April, followed by a decrease to the same level as the other groups in June. Plasma chloride from control groups showed a constant level of 125-138 μM from May 12 until June 20. Salinity in control groups increased from 3 to 8 ppt in the same period. Plasma chloride from group C and its control group showed the highest variabilty during the experimental period.

Environmental conditions in sea

Temperature and salinity were measured at 2 m depth (Table 1). Temperature decreased from a mean value of 13.9 °C during summer to 8.2 °C in December. Salinity was less variable than temperature, and increased from a mean value of 29.5 ppt during summer to 31.5 ppt in December.

Table 1: Temperature and salinity at 2 m. depth in sea from June 30 to December 21 1989. Mean values (X) are presented with standard error of mean (SEM).

PERIOD	TEMPERATURE °C		SALINITY ppt	
	X	SEM	X	SEM
30.06 - 30.08.89	13,9	0,1	29,5	0,2
31.08 - 13.10.89	13,0	0,2	28,6	0,2
14.10 - 24.11.89	10,0	0,2	30,4	0,2
25.11 - 21.12.89	8,2	0,2	31,5	0,2

Growth

Daily specific growth rate (SGR) was generally low in all groups during summer, and varied between 0.5 % (group D_2) and 0.9 % (group B)(Table 3). However, biomass increased more in groups A and C (1.7 times), related to biomass in June 20, than in the other groups (1.4 times) in the same period (Figure 3, Table 3).

A sharp increase in SGR was observed in all groups (1.7-2.2 %) during the early autumn, although biomass did not increase at the same expected rate. Differences in biomass were now accelerated between groups A, C (20-22 kg) and the other groups (5-11 kg)(Figure 3).

From mid October until termination of the experiment, SGR decreased sharply to 0.3-0.5 % in December among all groups. Group A increased its biomass 5.8 times in sea, group C 5.3 times, and the other groups 2.4-3.6 times. The lowest biomass in December was found in group B_2 (7 kg) with a mean weight of 290.5 g (Table 2), whereas the highest was found in group A (34 kg) with a mean weight of 321.6 g. Groups B_2 and particularly C_2 showed a significantly lower increase in biomass than their mother groups B and C, respectively.

Table 2: Mean weight of all groups 10 days before transference to sea water and at termination of experiment.

DATE	MEAN WEIGHT (g) OF GROUPS					
	A	B	C	B_2	C_2	D_2
20.06.89	49,6	41,6	54,9	43,3	49,3	50,5
21.12.89	321,6	319,7	316,2	290,5	295,3	295,0

Table 3: Specific growth rate, SGR (%) and rate of biomass increase B_a/B_1, where SGR is calculated from $date_{a-1}$ to $_a$ and biomass B_a at $date_a$ is related to biomass B_1 10 days ahead of transference to sea water (30.06.89).

DATE	GROUPS											
	A		B		C		B_2		C_2		D_2	
(a)	SGR	$B_{a/1}$	SGR	$B_{a/1}$	SGR	$B_{a/1}$	SGR	$B_{a/1}$	SGR	$B_{a/1}$	SGR	$B_{a/1}$
30.08.89	0,8	1,7	0,9	1,4	0,8	1,7	0,7	1,4	0,6	1,4	0,5	1,4
13.10.89	2,0	3,8	2,1	2,2	1,7	3,6	2,2	1,8	2,0	2,3	2,2	2,2
24.11.89	0,9	5,4	0,9	2,8	0,8	5,0	0,9	2,4	1,0	3,3	0,7	3,0
21.12.89	0,3	5,8	0,4	2,9	0,3	5,3	0,3	2,4	0,3	3,6	0,5	3,4

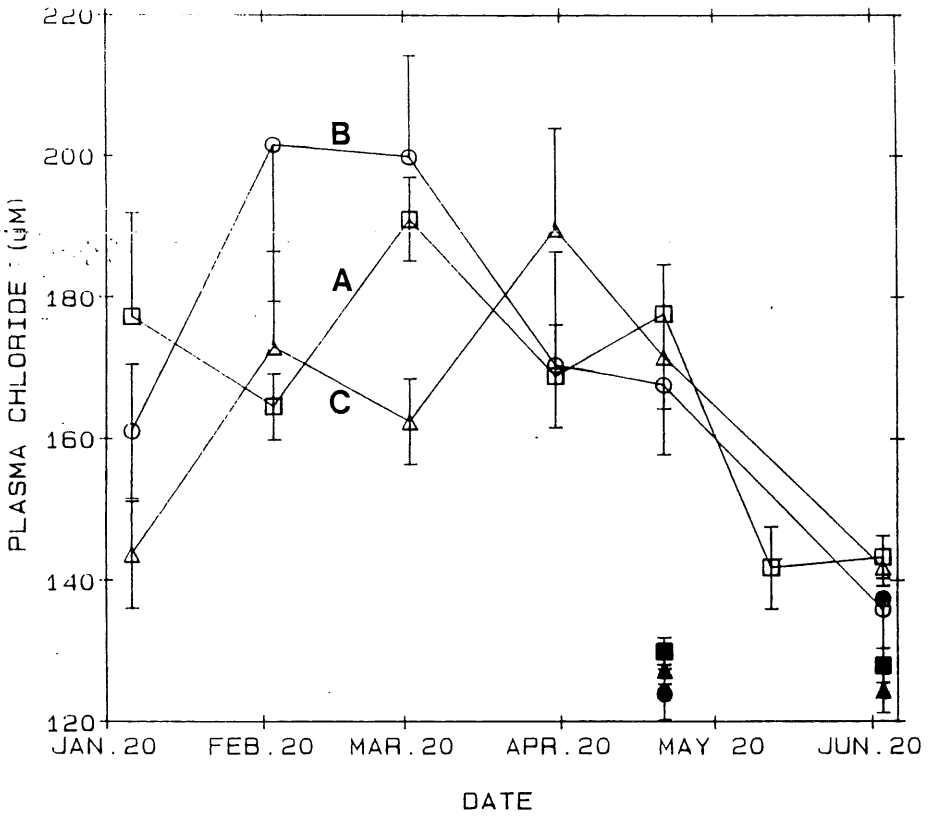

Figure 2: Plasma chloride after sea water (35 ppt.) challenge tests (24 h.) from January to June 1989 in three groups, which were transferred to sea water June 30. Capital letters indicate groups. Square denotes group A, circle denotes group B and triangle denotes group C. Filled symbols indicate the respective control groups.

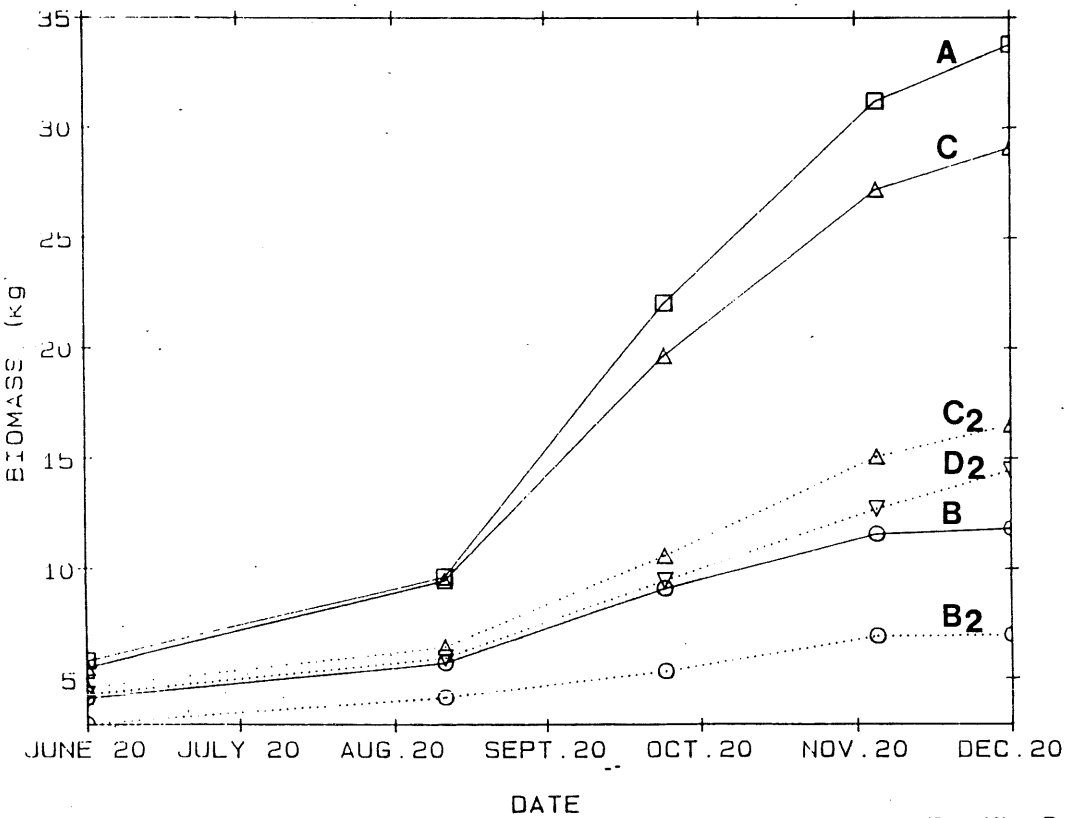

Figure 3: Biomass of all groups as function of time from 10 days ahead of transference to sea water (June 30) to December 21, 1989. Single lines indicate original groups, whereas dotted lines indicate subgroups$_2$ with a temporary stay in a common fresh water tank with increased fish density from May 9. Squares denote group A, circles denote groups B and B_2, triangles denote groups C and C_2, and inverse triangles denote group D_2.

DISCUSSION

Plasma chloride levels in the present investigation generally increased during winter and peaked in March and April. The increase is probably related to the change in light regime. The parrs received continous light until February 1, 1989, and were consequently in a physiological status in step with the summer situation. The abrupt change in day length influenced their osmoregulatory ability. This is a generally accepted theory (Stefansson, pers.comm.). Salmon from group C managed to osmoregulate better than group B from January to March. This could be as concequence of better water quality and improved physiological status.

Generally decreased plasma chloride levels during the spring reflected the increased osmoregulatory ability of the smoltifying salmon. 140 μM chloride in plasma after sea water tests in 35 ppt is known as an acceptable level for smolts. This level was also close to the plasma chloride level in the control groups.The salmon were consequently physiologically adapted to a continued life in the sea in June.

Growth during the summer period in sea was not correlated with the temperature of 13.9 °C. The growth depression could be due to large numbers of salmon lice (**Lepeophtheirus salmonis**), which is known to cause severe problems and heavy loss of salmon (Egidius 1985). Moreover, most of the small sized smolts died after the delousing procedures in July and August.

Minor differences in SGR between salmon from the groups A, B and C indicated equal growth potential. Even lower SGR in the B_2, C_2 and D_2 groups during summer could reflect the disadvantage of being transferred to a new environment during smoltification in fresh water, which probably represented a severe stress with long-term effects. The depressed growth among these groups during summer is partly compensated by the highest SGR in the next sampling period. However, increased mean SGR could just be a result of loss of many small fish in the late summer.

Although minor differences in SGR (Table 3), major differences in growth of total biomass were observed (Table 3, Figure 3). This is mostly explained by differences in mortality. Because of low rate of biomass increase in groups B_2, C_2 and D_2, we conclude that transference of salmon between different environments during smoltification is not recommended, even if water flow is increased within the tested levels. This does not imply that strong current is to any disadvantage to smolts. In fact, Jobling *et al.*(1989) and Christiansen *et al.*(1989) have shown that sustained excercise had positive effects on growth and body composition of salmonids. But the environmental conditions should not be varied to much during this important period.

Both high fresh water flow with normal oxygen conditions (group A) and low water flow with an oxygen saturation of 118 % in outlet water (group C), resulted in nearly equal growth of biomass in sea water. SGR in these groups were at the same level as other performance studies in the sea (Skilbrei 1990). Oxygenation of fresh water within the limits in the present investigation is consequently not harmful to smolt quality.

ACKNOWLEDGEMENTS

We would like to thank Laila Eikefet at Matre Aquaculture Research Station and Stian Morken at Austevoll Aquaculture Research Station for their skilled assistance during the experiment. We would also like to thank Terje Svåsand for helpful criticism of the manuscript. This study was financed by NFFR and NTNF.

LIST OF REFERENCES

Austreng, E., T. Storebakken and **T. Åsgård**, 1987. Growth rate estimates for cultured Atlantic salmon and rainbow trout. **Aquaculture**, 60: 57-60.

Christiansen, J.S., E. Ringø and **M. Jobling**, 1989. Effects of sustained exercise on growth and body composition of first-feeding fry of Arctic charr, **Salvelinus alpinus** (L.), **Aquaculture**, 79: 329-335.

Colt, J. and **B. Watten**, 1988. Applications of pure oxygen in fish culture. **Aquacultural Engineering**, 7: 397-441.

Egidius, E., 1985. Salmon lice - **Lepeophtheirus salmonis**. In: **Fiches d'identification des maladies et parasites des poissons, crustacés et mollusques. Copenhagen: International Council Exploration of the Sea**, C.J. Sindermann (ed.).

Jobling, M., E.H. Jørgensen and **J.S. Christiansen**, 1989. Why bother to monitor food intake ? **NFA-Symposium, Ethology in Aquaculture: Application of Behavioural Studies in Aquaculture, Trondheim (Oct. 20-22, 1989), ISBN-8274450051**, p. 30-41.

Saunders, R.L. and **E.B. Henderson**, 1970. Influence of photoperiod on smolt development and growth of Atlantic salmon (**Salmo salar**). **J. Fish. Res. Board Can.**, 27: 1295-1311.

Skilbrei, O.T., 1990. Influences of different light and temperature regimes on growth and maturation of Atlantic salmon (**Salmo salar**) in freshwater and subsequent performance in seawater. **Manuscript submitted for Dr.thesis, Dep. of Fisheries Biology, University of Bergen**, 24 p.

Stefansson, S.O., R. Nortvedt, T.J. Hansen and **G.L. Taranger**, 1990. First feeding of Atlantic salmon, **Salmo salar** L., under different photoperiods and light intensities. **Aquaculture and Fisheries Management**, 21: 000-000 (accepted).

Wagner, H.A., 1974. Photoperiod and temperature regulation of smolting in steelhead trout (**Salmo gairdneri**). **Can. J. Zool.**, 52: 219-234.