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Growth, migration and survival of lake reared juvenile anadromous Atlantic salmon *Salmo salar* L.

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A release of 16.741 underyearlings of Atlantic salmon *Salmo salar* in Lake Storevatnet in the River Imsa system resulted in a downstream migration of 1.580 smolts. Most of the smolts were 2 years of age, but there was also a significant proportion of one year old smolts. Growth of the lake reared smolts was excellent, but they migrated downstream over a much longer period than naturally produced smolts which descended mainly in May. In total 0,7% of Carlin-tagged lake reared smolts were recaptured as adults compared with 15,4% of the naturally produced smolts. It is suggested that the low survival of lake reared smolts is mainly due to their irregular migration time.

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INTRODUCTION

Since the discovery of artificial hatching and feeding techniques of salmonids, the most popular method of salmon stock enhancement has been the release of fry, underyearlings and smolts in rivers.

The idea of using lakes and ponds as rearing grounds for salmon is old, and a number of different experiments have been carried out. Reviews by Harris (1973, 1978) and Pedley & Jones (1978) conclude that stocking salmon fry may give high survival to smolt stage, and excellent growth, in particular when fry are stocked in fishless lakes. This has also been reported from Northern Norway (Berg 1967). The main problem which may limit the usefulness of this rearing technique has been the reluctance of some smolts to migrate from the rearing lakes (Munro 1965, Frantsi et al. 1972, Harris 1973).

There is little information on the survival and return of adults from lake reared smolts. Recently Pepper et al. (1985) reported from Newfoundland that marine survival of lake reared smolts was comparable to that for smolt from riverine habitat.

In Norwegian coastal areas there are thousands of lakes and ponds inhabited by stunted populations of brown trout *Salmo trutta* L. and Arctic charr *Salvelinus alpinus* (L.), and the question has been asked if those lakes could be efficient salmon smolt producers and thus benefit the local salmon fisheries.

This study presents results from a lake rearing experiment with anadromous Atlantic salmon in the River Imsa watercourse, SW Norway, with particular reference to growth, survival and migration.

STUDY AREA

The Imsa-Lutsi watercourse is situated near Stavanger in south-western Norway (Fig. 1). The catchment area of the river system is 128 km^2, of which 12% is lake surface. The river near the mouth is c. 10 m wide, the yearly average water discharge is 4.5 $m^3 s^{-1}$. A Wolf trap (inclination 1:10, apertures 10 mm) 100 m above the river mouth catches all descending fish larger than c. 10 cm at water discharges less than 30 $m^3 s^{-1}$. The reared smolts used were produced at the Research Station for Freshwater Fish, situated at the mouth of the Imsa-Lutsi watercourse. The hatchery water flows directly into the estuary.

Apart from Atlantic salmon, dense populations of brown trout, Arctic charr, whitefish *Coregonus lavaretus,* Atlantic eel *Anguilla anguilla* and three-spined stickleback *Gasterosteus aculeatus* are present in the watercourse. Escaped rainbow trout *Salmo gairdneri* from nearby fish farms also ascend the river to spawn, but no stock is established. The salmon spawning areas are found in the river between the mouth and the first lake, a distance of 1 km. In the years 1975—1986 the natural production of salmon smolts va-

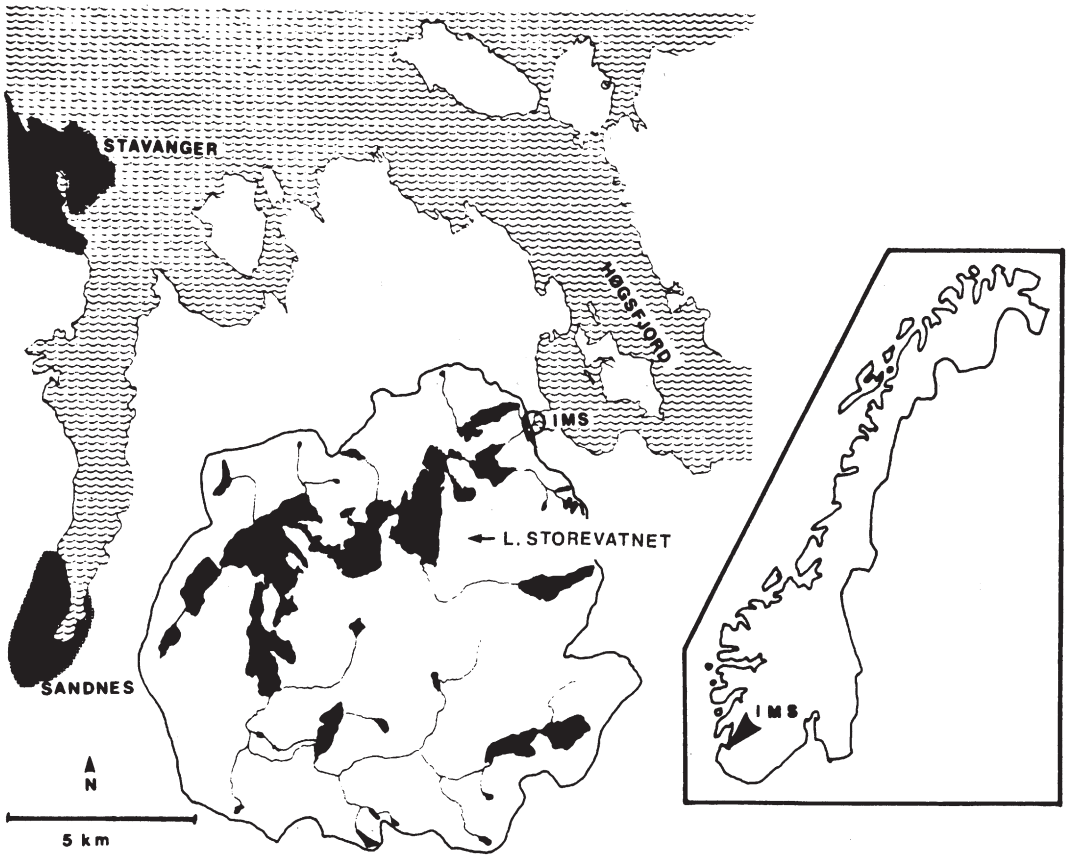

Fig. 1. The River Imsa system.

ried between 675 and 3144. The number of ascending mature salmon in the same period was between 15 and 119. Most naturally produced smolts are 2 and a few 3 years of age.

MATERIAL AND METHODS

In September 1980 16.741 autumn fingerlings of Atlantic salmon were released in the 2.5 km² large Lake Storevatnet (Fig. 1).

Table 1. Number of naturally produced and lake reared Atlantic salmon smolt caught in the smolt trap.

Year	1981	1982	1983	Total
Natural	2751	656	1451	4858
Lake reared	539	945	96	1580
Total	3290	1601	1547	6438

Mean total length and weight of the fish were 6 cm and 2.5 g, respectively. The parent fish were wild salmon ascending River Imsa. About a week before release the fish were anaesthetized in MS 222 and the adipose fins were removed. The fingerlings were carefully spread along the lake shores. Downstream migrating fish were captured in the trap which worked very well, except between 24 November 1981 and 4 April 1982 when it was partly out of order. The migrating smolts were measured (total length), weighed, Carlin-tagged (Carlin 1955) under MS 222 anaesthesia, and released in the river below the trap. In 1981 and 1982 a total of 3241 naturally produced and 1080 lake reared smolts were tagged.

RESULTS

Most of the fin-clipped smolts produced from lake reared underyearlings descended as 2 +, but there were also a substantial proportion

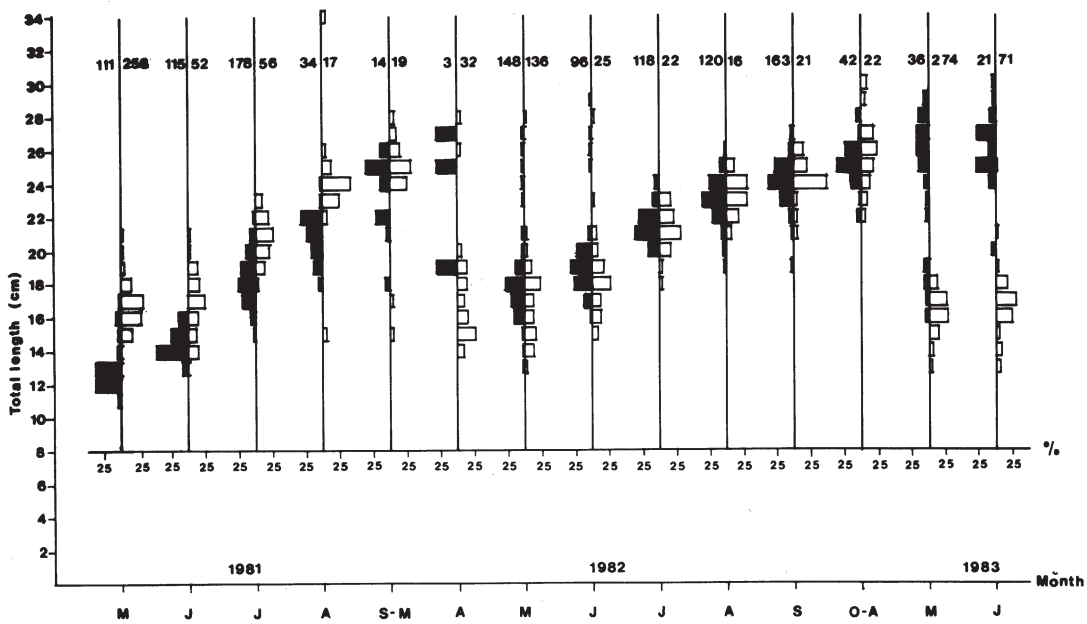

Fig. 2. Length distribution of migrating lake reared (black columns) and naturally produced smolts (white columns) caught in the smolt trap from May 1981 to June 1983. The figures give the number of observations.

of 1 + smolts (Table 1). In 1983 only a few 3 + smolts descended. In total 1.580 smolts descended which is 9.4% of the underyearlings released. In addition 8 fin-clipped parr descended during the same period.

Figure 2 shows length distribution of random samples of fin-clipped and naturally produced smolt caught in the smolt trap. The samples from September 1981 to March 1982 and October 1982 to April 1983 were small and are pooled. As early as in May 1982, 9 months after release, the first fin-clipped smolts appeared in the trap. The mean length of this group at that time was about 13 cm compared to 17 cm for the natural smolt. Both groups had very rapid growth during the summer, and in August 1981 their mean lengths were about 21 and 24 cm, respectively. In 1982 there was no difference in size between the two groups, but in 1983 the stocked fish were significantly larger than the naturally produced salmon ($p<0.01$). Among the lake reared fish the migrating yearlings grew faster than the fish remaining in the lake for a further year.

The main downstream migration of naturally produced smolts took place in May in all three years (Fig. 3). That was not the case with the lake reared fish which descended in relatively large numbers during the whole summers of 1981 and 1982.

In total 15.4% of the naturally produced smolts were recaptured as adults, while during the same period only 0.7% recaptured adults were reported from the lake reared smolts (Table 2).

DISCUSSION

The observed rate of smolt descent into the trap is a minimum figure of survival. There is a net and rod fishery for brown trout, Arctic charr and whitefish in the lake and many of the larger smolts were probably caught in this fishery. Despite the dense populations of brown trout, Arctic charr and whitefish in Lake Storevatn the stocked underyearlings survived in relatively large numbers to smolt stage. Even though the lake is not a normal habitat for Atlantic salmon parr, this indicates that salmon may compete efficiently with the other fish species in the exposed Lake Storevatn.

Predation is probably a very important mortality factor, especially the first days after stocking. Pedley & Jones (1978) who relea-

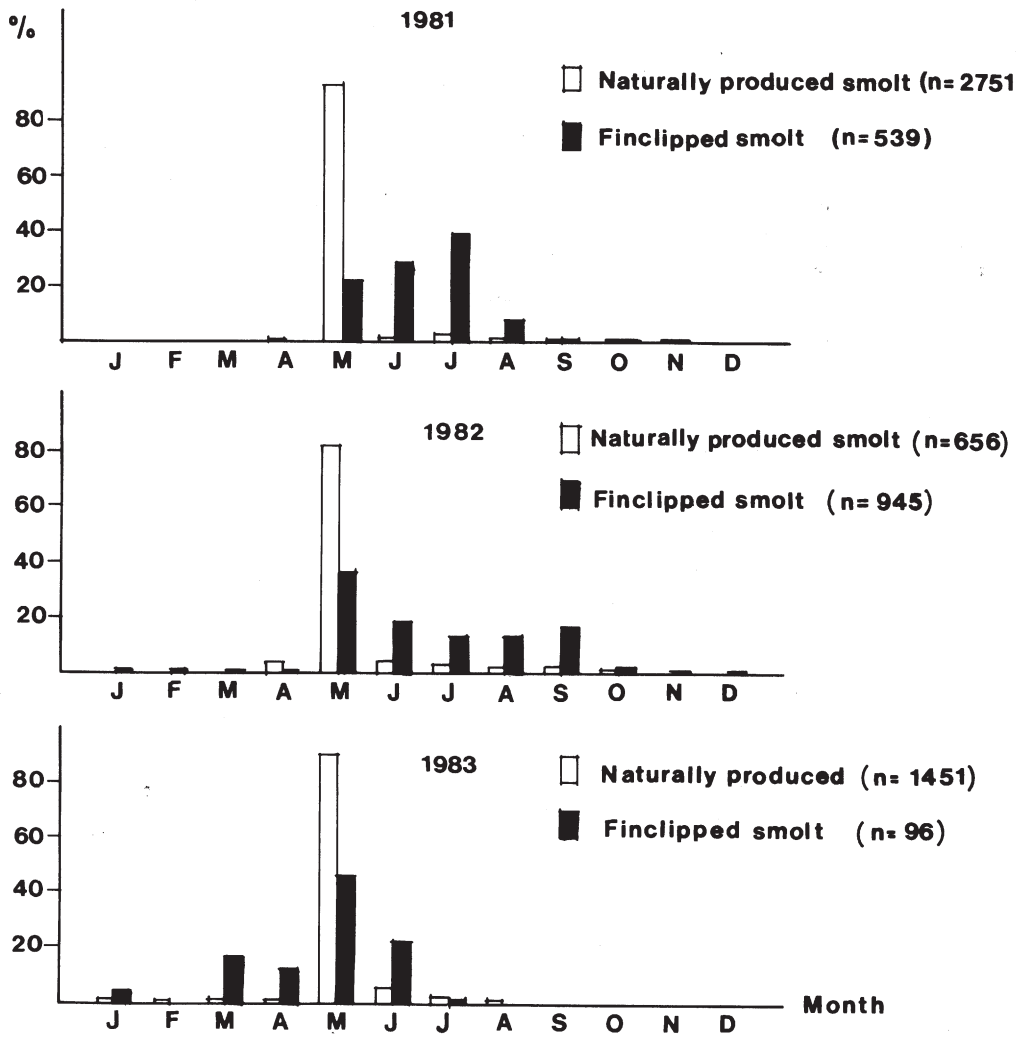

Fig. 3. Monthly migration of lake reared and naturally produced smolts. n = total number of smolts observed in the smolt trap.

Table 2. Number of naturally produced and lake reared salmon tagged as smolts and total number of adults recaptured in the sea fisheries and in the trap in River Imsa.

Year of tagging	1981		1982		Total	
Smolt type	Natural	Lake reared	Natural	Lake reared	Natural	Lake reared
No of smolts tagged	2681	395	560	685	3241	1080
No of adults recaptured	451	1	37	7	498	8
Recaptured rate (%)	16.8	0.3	6.6	1.0	15.4	0.7

sed salmon fry in a small lake in North Wales had low survival to smolts (0.01%). The main reason for this was predation by brown trout shortly after release. But they improved survival by stocking underyearlings in the autumn 1974 which produced a survival rate of 3.8% by autumn 1976.

A review of some lake rearing experiments of salmon fry in the British Isles and Ireland (Pedley & Jones 1978) demonstrated higher survival rates in lakes without interspecific competition. Stocking of fry in lakes containing other fish species gave highly variable results. In spite of some methodical problems Berg (1967) showed a high survival rate to smolts of fry stocked in a fish-free lake in Northern Norway.

Frantsi et al. (1972) reported a 76% survival to two year smolts from a release of 12.770 1 + parr in a 1.4 ha pond in Eastern Canada. Predator and competitor fish had been eliminated from the lake by poisoning with rotenone prior to stocking. Artificial food was supplied during the summer months.

Survival and growth rate of lake reared salmon are highly dependent on stocking density, and competitors and predators present in the system (e.g. Harris 1973). In the present experiment the lake reared fish grew faster than did the natural smolts in the main river. The observation that the migrating yearlings grew faster than the fish remaining in the system for a further year is consistent with the results of Pedley & Jones (1978).

The lake reared smolt showed irregular timing of migration compared with the natural smolts. The reason for this is suggested to be the very small water through-flow in Lake Storevatnet. Munro (1965), Berg (1967), Frantsi et al. (1972) and Harris (1973) reported that a high proportion of lake reared smolts did not leave the lakes at all or left the lake outside the normal smolt migration period.

Tracking experiments with salmon smolts through a Scottish loch showed that the direction and speed of the smolt movement was approximately the same as that of the surface water (Thorpe et al. 1981). Release experiments with tagged wild and hatchery reared smolts above and in the lakes in the River Imsa system demonstrated that these smolts were considerably delayed in their downstream migration compared to smolts released in the main river downstream the lake (Hansen et al. 1984).

Smolts of lacustrine salmonids such as sockeye salmon *Oncorhynchus nerka* (Groot) 1965) and Arctic charr (B. Jonsson, pers. obs.) migrate actively through lakes faster than the downstream current velocity. There is little evidence for active migration through lakes in Atlantic salmon (Thorpe 1983). The existence of such behaviour in other anadromous salmonids leads to the assumption that local adaptations in this trait may occur in Atlantic salmon stocks reproducing above lakes.

The irregular timing of migration of lake reared smolts is probably the main factor for the very poor survival of these fish to adults. Based on successive smolt plantings in the River Indalselv, Sweden, Larsson (1977) showed that the optimal time of release was a short period at the end of May, beginning of June. In the Burrishole system in Ireland Cross & Piggins (1982) reported a very low return of wild salmon from the 1980 smolt year class compared to returns of reared smolts. They suggested that the main reason was a delay in the wild smolt migration. In salmon ranching experiments in the River Imsa Hansen & Jonsson (1986) observed a significantly lower survival of smolts retained for one month or more in sea water than control smolts released at normal time.

Lake reared smolts are delayed when leaving lakes or ponds with a small water through flow. This delay reduces survival and return of adults, probably except in cases where there is a natural salmon production above the lakes or when ponds and lakes are naturally utilized by salmon parr as described from Newfoundland by Pepper et al. (1985).

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