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RANCHING OF ATLANTIC SALMON IN THE RIVER IMSA, NORWAY

by

Lars P. Hansen and Bror Jonsson

Norwegian Institute for Nature Research
Tungasletta 2, 7004 Trondheim, Norway

ABSTRACT

Research on life history of Atlantic salmon, salmon ranching and salmon fishery have been carried out at the NINA Research Station at Ims since 1976. The Research Station consists of hatchery and rearing facilities and a research river, the River Imsa with trapping facilities both for ascending and descending fish. The station is especially designed for research in salmon life history and salmon culture. The first hatchery-reared smolts were released in 1981. The present paper presents a summary of knowledge gained until present with hatchery-reared and wild salmon. We discuss life history of hatchery-reared and wild salmon and present results from a salmon ranching programme. We emphazize migration, survival and harvest of ranched salmon and discuss potential environmental problems as a result of ranching. Finally we suggest a strategy to maximize benefits and minimize environmental problems in sea ranching with Atlantic salmon.

INTRODUCTION

The first artificial crossings of eggs and milt in salmonids was documented from the mid 1700s. In Norway the first hatchery was built in 1855, and soon after it became very popular to release artificially hatched alevins and fry in lakes and rivers. The technique to produce salmon smolts was developed during the 1890s.

The first systematic releases of hatchery-reared Atlantic salmon Salmo salar smolts were carried out in Swedish rivers draining into the Baltic Sea in the 1940s. In Norway similar releases commenced about 10 years later. These smolts were released to compensate for losses of spawning and rearing grounds, due to damages caused by river regulations in order to produce hydropower. Since then, large release programmes have been developed both in Pacific and Atlantic drainages to enhance the wild salmon stocks and to increase the production of salmon protein for human consumption.

Salmon ranching can be defined as the release of artificially reared smolts with a view to harvest the entire crop of returning adults. The interest for ranching has increased during the last decades (e.g. Thorpe 1980, Eriksson et al. 1983, Isaksson 1988), and results have been promising with Pacific salmon in some areas, especially in Japan and Alaska. A high recapture-rate of ranched Atlantic salmon has been reported from the Baltic (e.g. Larsson 1980). The majority of the harvest of ranched fish, however, is taken in oceanic and coastal mixed stock fisheries. In Norway due to a heavy marine salmon exploitation on mixed stocks (Hansen 1986, 1988a), salmon ranching has still not been established other than as compensatory smolt releases in regulated rivers or as a research activity, although it has been shown that ranching may be profitable for the country (Hansen & Jonsson 1989a).

Farming of Atlantic salmon commenced around 1970, and has developed into an enormous industry. At present the total production of farmed salmon in the Atlantic is more than ten times of the production of wild salmon. In 1990 the total production of farmed salmon in the Atlantic was 224,000 tonnes, whereas the total nominal catch of salmon in the Atlantic was 4,500 tonnes (Anon. 1991). Of this, 158 000 and 910 tonnes of farmed and wild salmon respectively, were reported from Norway.

The salmon market is now crowded with farmed salmon, and the first sale value per unit of weight is low. The potential cost/benefit ratio in salmon ranching is therefore also increasing. To compensate for this, the return-rate and fish size must be improved, and the costs of producing smolts reduced. In 1974 the Norwegian Authorities started to build a research station especially designed to carry out reseach to gain further knowledge in salmon ranching. This research station is situated at Ims, near Stavanger, SW Norway where the first reared smolts were released in 1981. The wild salmon stock in the river is functioning as a control of the ranching programme.

The present paper summarizes knowledge gained during the first ten years of research at Ims. The main emphasis is put on fundamental biological and practical aspects of salmon ranching in particular related to Norwegian conditions. Furthermore, we discuss different ranching models in relation to benefit and potential environmental problems.

THE IMS RESEARCH STATION

The Research Station, NINA was located to Ims because of: (1) favourable climatic conditions in south-west Norway, (2) excellent water quality in the river (pH = 6.7-6.8), (3) the water supply is satisfactory all year around (annual mean = 5.1 m3s-1) and about 12% of the catchment is lake surface which moderate sudden floods, (4) a permanent trap catching all ascending and descending fish could be built near the outlet in the river, (5) Ims has a reasonably central position near the cities of Sandnes and Stavanger.

The Research Station consists of a hatchery with rearing facilities and fish traps in the River Imsa. Supplies of fresh and salt water to the hatchery is good and the water temperature can be regulated by heat exchangers and a heat pump. Annual smolt rearing capacity is at present ca. 100,000 smolts. The River Imsa running from Lake Liavatn to the sea, a distance of 1 km, is a part of the Research Station (Fig. 1). The traps are situated ca 100 m above the river mouth. The trap catching downstream migrating fish is a Wolf trap (inclination 10%, apertures 10 mm). The upstream trap is a fish ladder of 3 steps where the fish are caught in the uppermost chamber. The natural salmon stock in the river is small, consisting of mainly grilse and some 2-sw salmon. Salmon of the local stock are the only fish to get access to the spawning grounds upstream the trap.

LIFE HISTORY OF ATLANTIC SALMON

Atlantic salmon spawn in rivers in the autumn, and the alevins hatch the following spring. After spending two to six years in the river (parr stage) the juveniles transform and migrate to the sea as smolts in the spring, earlier in the southern than the northern part of the distribution area of Atlantic salmon (e.g. Power 1969, Baglinière 1976, Nordeng 1977, Hesthagen & Garnås 1986). In the River Imsa, the main smolt run occurs in May (Jonsson & Ruud-Hansen 1985, Hansen 1987).

Salmon originating from Norwegian rivers feed in the northern Norwegian Sea during one to four years, and are caught in the mixed stock long-line fisheries north of the Faroe Islands and to a small extent in the west Greenland drift net fisheries. Salmon return to the rivers they left as smolts in order to spawn (e.g Hasler 1966, Harden Jones 1968, Carlin 1969). Dependent on the sea-age, their size vary from one to 30 kg. The survival from smolt to adult vary between 10 and 30 %, and is highest in grilse. Many fish survive spawning and leave the rivers as kelts. Few fish spawn a second time (< 25%) but the survival to a second spawning is higher for females than for males, and higher in small than large fish (N. Jonsson et al. 1991a).

Many factors determine the survival and return of ranched salmon, although many of them are poorly known (e.g. Saunders 1982). The parr-smolt transformation (smolting) and the post-smolt stage (the period just after the smolts have left the rivers) is of particular interest in salmon ranching, because this period is critical for survival in the sea (Browne et al. 1982).

Smolting in salmonids is under hormonal control and is characterised by a number of physiological and behavioural changes which preadapt the young fish for sea life, while still in fresh water (e.g. Thorpe et al. 1985, Hansen et al. 1989b). The downstream smolt migration is probably synchronized by changing day-length, whereas water temperature and water flow seem to be key factors initiating the migration (Thorpe & Morgan 1978, Ruggles 1980, Jonsson & Ruud Hansen 1985, Hesthagen & Garnås 1986). Smolt migration usually takes place during the darkest period of the night, but towards the end of the smolt migration period migrating smolts are also observed at day-time (Österdahl 1969, Thorpe & Morgan 1978).

Atlantic salmon home with high precision to the stream they leave as smolts (Hasler 1966). Moreover, salmon released as smolts at a sea locality return to the same area in the sea when sexually mature (Carlin 1969, Sutterlin et al. 1982, Hansen et al. 1989a). Recent studies from the River Imsa (Hansen et al. 1987, 1989a, B. Jonsson et al. 1990) support the sequential learning hypothesis (Harden Jones 1968), i.e. that outward emigrating smolts learn a continuous set of cues and use this information during the return migration to the home river. As a consequence, cultured smolts may return to the site of release, as do ranched salmon.

The precise homing explains why salmon are subdivided into discrete stocks localized to specific rivers, tributaries or parts of rivers (e.g. Ståhl 1987, Hindar et al. 1991a). Salmon are probably adapted through natural selection to the prevailing environmental conditions they encounter in the river and at sea. The result of this is that salmon populations vary in life history traits like growth-rate, adult size, age at sexual maturity, migration pattern and seasonal timing of their return, frequency of mature male parr, resistance against diseases and parasites, survival-rate in freshwater and at sea, time of spawning, frequencies of isozymes (e.g Saunders 1981, Heggberget

1988, Bakke et al. 1990, Hansen & Jonsson 1991a, Hindar et al. 1991a).

Some fish in a salmon population mature sexually as parr in the river. These fish are chiefly males (Jones 1959), although mature female parr have been described (Baglinière & Maisse 1985, Hindar & Nordland 1989). Under rearing conditions, parr maturity is also common, and advanced developmental rates seem to increase the frequency of mature fish (Thorpe 1989). In mature parr, the probability of later smolting is reduced, but maturation does not rule out a later smolting completely (Saunders et al. 1982, Hansen et al. 1989c, Berglund et al. 1991).

Atlantic salmon are subjected to heavy mortality as post-smolts due to predation by different animals. Important predators are different species of birds like gulls, cormorants, herons and mergansers (Reitan et al. 1987, Shearer et al. 1987, Kennedy et al. 1988), and fishes like Atlantic cod, saithe, pollack and sea trout (Hvidsten & Møkkelgjerd 1987, Hvidsten & Lund 1988).

Density dependent mortality in the sea due to lack of food is not likely to occur due to the small numbers of post-smolts, compared with the amount of food organisms in the area (Dragesund 1982).

As post-smolts, Atlantic salmon feed on surface insects (unpublished data), crustaceans and small fish like sand-eel (Morgan et al. 1986). Later, salmon feed on various invertebrates like krill and hyperid amphipodes, squid and pelagic and mesopelagic fishes (Templeman 1967, Lear 1972, 1980, Thurow 1973, Hislop & Youngson 1984, Hansen & Pethon 1985, Reddin 1985).

Salmon enter rivers in summer and autumn, the oldest individuals ascend before younger ones. In small rivers water flow limits the ascent of in particular larger salmon. In such cases salmon may enter rivers late in the season and small fish may come before the larger ones (N. Jonsson et al. 1990). In general, small rivers harbour only small salmon, whereas large rivers support both small and large fish (N. Jonsson et al. 1991a).

Salmon that survive spawning migrate to sea either in late autumn/early winter or in spring. Males tend to descend earlier than females. Survivers return for spawning in subsequent years; small salmon are annual spawners whereas large fish spawn biennially (N. Jonsson et al. 1990, 1991a).

Spawning behaviour of Atlantic salmon has been described by Jones (1959) and is presently being studied at Ims. The ascending adults congregate in pools in the river close to the area where they later are going to spawn. Males start to fight for dominance, and local hierarchies are soon formed with the largest male as the dominant one. The dominant male will later spawn with most of the females within the territory. At first females rest along the bottom, but at the time of ovulation they select their spawning area and start digging nests in gravel bottom. The digging females defend their nest against other females. The females are courted by a number of males, also other than the dominant ones. Females appear to select their partner by being aggressive against subordinate males. Most females are monogamous and spawn with the dominant male in the local hierarchy, but in some cases one female spawn with different males. Females spawning with several males simultaneously occur from time to time. The female covers the fertilized eggs in the substratum soon after spawning. When the nest is covered, the female finds a new site to spawn her next portion of eggs. Very often the new nest is formed right in front of the first one, but sometimes she selects a completely new site for spawning. The same males may be reproductively active for up to two months, whereas most females spawn their eggs during one week in up to ten portions. After the eggs are buried, females leave the nests and no further nest defense is observed.

During spawning, males are more frequently wounded than females, and their woundings are ususally larger, which may also be reflected in the higher mortality-rate among male spawners (B. Jonsson et al. 1990, N. Jonsson et al. 1990). However males and females appear to invest the same amount of energy into spawning, at Ims ca.50% of their total energy when ascending (N. Jonsson et al. 1991b). Females allocate more energy into gonadal production (28%) than males (5%). The somatic effort is highest among males.

Preliminary results from Ims suggest that 1-2% of the egg deposition survive until smolting (personal observations).

SMOLT PRODUCTION

When juvenile salmon are physiologically adapted for a sea life they are called smolts. During smolting a number of morphological, physiological and behavioural characters are changed (e.g. Hoar 1976, Thorpe 1989). The hatchery environment influences the development of the smolts through its rearing temperature, photoperiod, salinity, feeding intensity, rearing facilities etc. Biological factors such as heredity and developmental rate together with health status are also important during smolt production. If these factors are not controlled, it is difficult to predict the outcome of a sea ranching programme.

It is important to select the most suitable brood stock for each ranching locality. In nature partners are selected through dominance and ability to defend spawning territories. In a sea ranching programme the brood stock selection depends on the goals and physical limitations set by the ranching site. If the fish is to be harvested in fresh water, the main physical limitation is the water discharge of the river which affects timing of ascent and the size of the upstream migrating fish (Fig. 2, N. Jonsson et al. 1990). If the fish are to be harvested in marine fisheries, survival and adult size are very important. Both survival, growth-rate and sea age at maturity depend on heredity as well as environment (e.g Gjedrem 1983, Thorpe 1991). The key factors when selecting brood stock are size and sea age at maturity and the genetic origin of the stock.

The selection of stocks will affect the recapture pattern of the returning salmon. The total yield will vary considerably among stocks and years (Fig. 3, Hansen & Jonsson 1989a). Large salmon will give the highest yield to high seas fisheries, whereas grilse will give the highest yield in a small river like the Imsa (Hansen & Jonsson 1989a). Salmon returning late in the season have poor quality for human consumption, and ranched salmon should therefore be harvested early in the season when the quality is better. Experiments carried out at Ims have demonstrated that the seasonal return pattern varies among stocks (Fig. 4, Hansen & Jonsson 1991a).

The most beneficial way to rear the fish depends on a trade-off between smolt price, survival in nature and return to the site of release. It is possible to produce cheap smolts by the release of alevins, fry and parr in rivers where space and food resources are available. However, such natural rearing grounds will always be limited and can only be a small supplement if sea ranching is to be developed on an industrial basis. In Norway there are a number of small lakes and ponds which may be used for smolt rearing. A lake rearing experiment with 0+ parr in the River Imsa gave good growth and 9,4 % survival to migrating smolts (Hansen 1987). However, the timing of the smolt migration differed from that of wild smolts in that fish descended during all months of the year. This may be because the lake-reared smolts where delayed when migrating downstream. The delay was probably caused by the low flow through the system. This delay reduced the survival and return of adults. However in lakes with high through-flow the result may be better. It is also possible that some salmon stocks are adapted to migrate through lakes.

The large smolt production potential is the artificial rearing of salmon in hatcheries. Under such conditions environmental variables can be controlled, and there is no limit to the number of smolts that can be produced. In hatcheries, the growth is excellent, survival from egg to smolt high, and the developmental rate is high. Through knowledge gained by the fish farming industry, the smolt production methods are well developed. However, one may easily produce smolts with low survival when released in nature. Experiments carried out in the River Imsa show that the average survival-rate of hatchery-reared smolts is only half of that in wild fish (B. Jonsson et al. 1991). This difference may both be due to different selection pressures in hatcheries and nature, to differences in smolt quality (e.g. physical condition) and release methods.

Smolting and parr maturation are competing processes (Saunders 1982, Thorpe 1986). Under accelerated development regimes of hatcheries it is common to find high proportions of males maturing as parr (Leyzerovich 1973, Saunders et al. 1982). Sexual maturity of parr reduces the probability of a future seaward migration. Experiments at Ims revealed a 30% reduction in the proportion of migrants, compared with corresponding immatures (Hansen et al. 1989c). However, it is possible to increase the proportion of the mature males that will migrate by keeping them in heated water during winter (Tab. 1, Berglund et al. 1991). A similar effect may be achieved by stripping the mature parr in the autumn (Hansen et al. 1989c). In general, survival of smolts improves with increased smolt size. There also seems to be higher survival of two than one year old smolts of the same size (Hansen & Lea 1982, and personal observations at Ims). On the other hand, the proportion of grilse versus older salmon is higher for two than one year old smolts (Isaksson 1983, Saunders et al. 1983).

MIGRATION OF SEA RANCHED SALMON

All smolts released must be free of diseases and should be released within the peak of the smolting period, or shortly before. When released in the spring at the normal time of smolt migration, reared smolts will start the descent immediately, and move faster than wild smolts (Hansen et al. 1984). Typically, smolts move downstream at night. However, when released in large numbers at day-time, the hatchery-reared smolts will school and also descend during the day, but they will move more slowly than fish released in the evening (Hansen & Jonsson 1985). The release of larger groups of hatchery-reared smolts at day-time could also induce a migration of wild smolts during the day.

In salmon ranching experiments in the Baltic, it has been observed that smolts released during spring moved further south in the Baltic than those retained in sea-cages for some months and released in the autumn (Eriksson 1988). This different pattern was partly explained by the influence of an annual time programme on salmon migratory behaviour. This hypothesis, however, remains to be tested in the Atlantic.

The water current is a vector that transport smolts downstream (Thorpe 1982). However, when smolts were released in the River Imsa they migrated more slowly than the current velocity of the river, indicating that they were holding back against the current. The smolts migrated more quickly at high than low waterflow (Youngson et al. 1989). The smolts appear to move actively out into the main current of the river to avoid being caught in sloughs and backwater (Hansen & Jonsson 1985). Thus, the descent is not passive.

After the smolts leave the River Imsa, they move with the current out the Høgsfjord into the coastal current. The precise migration route is depending on the current set up by wind and tidal changes (Holm et al. 1982).

Two year old smolts migrated more quickly and at a higher rate than 1+ smolts (Hansen & Jonsson 1985), as was also the case when considering immature fish only (Hansen et al. 1989c). This could be caused by the fact that 2+ smolts were larger than the 1+ smolts, as larger fish among the 2+ smolts migrated faster than smaller ones. The faster movement of large fish may also be connected with a more advanced stage of smolting. It appears to be a general feature that older individuals show circannual developmental changes earlier than younger ones (Gwinner 1986), and this seems to be applicable to Atlantic salmon smolting and time of migration (N. Jonsson et al. 1990).

Ranched and wild salmon from the River Imsa seem to migrate the same routes to the feeding grounds and exploit the same areas in the sea. Furthermore ranched and wild salmon are both harvested in oceanic and coastal fisheries (Hansen 1988b). When released at Ims and the River Akerselv, Norway salmon from the River Neva (draining to the Baltic Sea) differed in migratory pattern as the 2+ Neva smolts migrated shorter than other stocks released in the same localities. Most 2+ Neva fish seemed to stay in the fjord outside Ims (Hansen & Jonsson 1991b).

Sea ranched salmon return towards the area of release as maturing adults, whether released at sea or in fresh water (Sutterlin et al. 1982, Hansen et al. 1989a). However, the precision varies with site of release, stock and time of release.

The homing prescision increases with increased waterflow in the rivers (Hindar et al. 1991b). The homing precision is higher when the fish are released in the river than at the river mouth, and is even further reduced when smolts are released in the fjord (Gunnerød et al. 1988, Hansen et al. 1989a, B. Jonsson et al. 1991). In small rivers straying is higher for large than small salmon probably due to lack of water (unpublished data). The fish appear to learn the way when moving to the feeding area at sea, and use this knowledge when returning one or more years later. However, when juveniles are released in the winter they appear unable to learn the way to the site of release (Hansen & Jonsson 1991c).

SURVIVAL

Handling, transport and the use of anaesthesia prior to release are known to stress salmonids (Soivio et al. 1977, Barton et al. 1980, Pickering et al. 1982, Soivio & Virtanen 1984), and migrating salmon smolts in particular are vulnerable (Saunders & Allen 1967). In experiments with wild Atlantic salmon smolts in the River Imsa it was demonstrated that smolts suffered from high mortality when caught in a smolt trap, anaestetized with tricane (MS 222-Sandoz), tagged with Carlin tags and subsequently released back into the stream (Hansen 1988a). Tests of effects of dip-netting, chlorobutanol anaesthesia and transport of hatchery-reared smolts, revealed that all these treatments added an extra mortality to 1+ smolts, whereas only effects of anaestetation on survival were detected among the 2+ smolts (Hansen & Jonsson 1988). When both age groups were kept in tanks after the different treatments, no mortality was observed. The difference observed between the two age groups is probably explained by the stress added to the smolts, and this stress makes 1+ fish more vulnerable to predators than the larger 2+ smolts.

Jensen (1979) suggested that survival of Atlantic salmon smolts could be improved if the smolts were kept in brackish water a short time prior to release. Reasons for this may be that such treatment speeds up the ability to osmoregulate (Reite & Staurnes 1986), and that smolts will leave the estuary and fjord faster than non-acclimated fish. This may reduce the predation which is probably smaller in the open ocean than in the estuary and fjord. Groups of smolts acclimated to brackish and salt water for 2 weeks and longer were released outside the River Imsa. There was no significant difference in recapture-rate between smolts kept in brackish or salt water for two weeks and the controls (Hansen & Jonsson 1986, 1989b). However, the recapture-rate of smolts kept four weeks or longer in brackish or salt water decreased significantly compared with the control groups. The observations that salt water acclimated smolts delayed for 4 weeks or more showed reduced survival were probably a result of release when the "migration window" had started to close.

The timing of smolt releases seems to be crucial for survival and return of the salmon (Larsson 1977, Cross & Piggins 1982, Hansen 1987, Hansen & Jonsson 1989b), hence this timing may be a result of adaptation to the prevailing environmental conditions in the local area. When salmon smolts are retained in fresh water, they will desmolt, and males will tend to mature the coming autumn (Lundqvist & Fridberg 1982). However, when retained in seawater, these fish will survive poorly when released in late summer and autumn, despite their larger size at release (Hansen & Jonsson 1986,1989b). This is not the case in the Baltic where experiments with delayed release have demonstrated that these fish survive better than those released in spring (Eriksson 1988). This difference between the Atlantic and the Baltic is at present difficult to explain. There is, however, great difference between the two environments with regard to the salinity, smolt predator species and food conditions (e.g. Larsson 1984, Hansen & Jonsson 1986, Eriksson 1988).

It is well known that the physiological state of smolts and post-smolts changes with time, and in particular when smolts are retained in freshwater. However, the mechanisms behind the observations that there is an optimal time for smolt migration ("migration window") are less understood, but predators, diseases, parasite abundance and food conditions may be factors causing the mortality.

In several Norwegian rivers it has been observed that released smolts of Atlantic salmon could be heavily preyed upon by different birds (Reitan et al. 1987) and fish, especially Atlantic cod, saithe, pollack and sea trout (Hvidsten & Møkkelgjerd 1987, Hvidsten & Lund 1988). Some of these predators are dependent on vision to search for their prey. It has therefore been speculated whether predation pressure on released salmon smolts is smaller when they are released at dark than during daylight. Experimental releases of salmon smolts at Ims gave no significant difference in return rate of smolts released in the morning and smolts released in the evening (Hansen & Jonsson 1986). It is, however, important to note that there may be great differences between localities regarding types and numbers of predators, their seasonal occurence and behaviour, and hence there will be local variations in predation pressure on smolts and post-smolts.

The predation on salmon smolts and post-smolts is suggested to be most significant in estuaries and fjords, just after the smolts have left freshwater. In the estuaries of the River Surna and River Orkla, mid-Norway heavy predation of fish, mainly cod, has been observed on both reelased hatchery-reared and wild smolts (Hvidsten & Møkkelgjerd 1987, Hvidsten & Lund 1988). A significantly improved survival of hatcery-reared smolts was obtained when smolts were transported by a well-boat and subsequently released in the ocean outside the River Surna (Gunnerød et al. 1988), but straying of the returning adults increased considerably.

In Norwegian rivers draining areas with high snow fall, the current velocity increases considerably during snow melt, and the water turbidity of the water increases. Both in the River Gaula and River Surna hatchery-reared smolts improved their survival significantly when they were released at high water discharge within the normal period of migration (Hvidsten & Hansen 1988), as was also observed in rivers in Maine, USA (Hosmer et al. (1979). Reasons for this may be that because smolts move close to the water surface (Holm et al. 1982) and descend more quickly at high current velocity (Youngson et al. 1989), they may be less vulnerable to predation from marine fish species in the estuary at high than at low water flow. The high turbidity may also make the smolts less visible for the predators.

HARVEST AND ECONOMY

Ranched salmon can be harvested in the traditional salmon fisheries in the ocean, on the coast, in the fjords and rivers. At the feeding grounds in the ocean, salmon are exploited by drift-nets (west Greenland) and long-lines (Faroes). Until 1989 salmon were exploited in the coastal current along Norway with drift-nets. This fishery is now banned. In the fjords the main legal salmon gear is at present bag-nets. There is also a restricted bend-net fishery. With few exceptions angling is the only legal fishing method in fresh water. An increased ranching effort will benefit all fisheries. Although marine salmon fishing effort in Norway has been significantly reduced during recent years, still a relatively small proportion of the ranched salmon will return to the site of release.

A simple way to exploit ranched salmon is by traps in the river, and in some cases also in estuaries. When using these methods the size of the river will influence the results significantly. Large salmon hesitate in entering small rivers, and do not ascend before autumn freshets, or just prior to spawning when the quality of the flesh is poor. Many salmon will also stray to other rivers. In large rivers, however, even large salmon will enter soon after arriving from the ocean and the straying rate is small.

The profitability of a salmon ranching programme is dependent on several factors. Among these are: smolt production prices, survival and return of adult fish, first sale value, size of salmon, costs at harvest, sport fishing licenses, recreational values as well as a number of spin off activities. A preliminary evaluation of cost/benefit of the sea ranching at Ims (Hansen & Jonsson 1989a) concluded that salmon ranching as a private enterprise was unprofitable. However, in many cases the first sale value of the total salmon flesh harvested more than balanced the costs of smolt production. In order to develop profitable salmon ranching the ways to increase the benefit is to ranch fast growing and late maturing salmon stocks in large rivers and harvest the fish in a combined sport and commercial fishery in the river.

ENVIRONMENTAL PROBLEMS

Concerns have been expressed about the potential impacts of accidentially as well as intentionally released fish on wild salmon stocks (e.g. Egidius et al. 1991, Hindar et al. 1991a, Saunders 1991). Sea ranching with non-indiginous stocks or based on releases from marine localities and small rivers correspond to mass escapes of smolts from fish farms. Managed inappropiately, salmon ranching is a potential threat to wild salmon stocks.

One of the most serious problems is straying of ranched salmon into other rivers. The strays will interfere with the wild fish on the spawning grounds and may produce offspring with decreased viability relative to locally adapted salmon. Ranched males will compete with wild males for females, and ranched females will compete with wild females for spawning territories (unpublished). The ranched fish seem to have lower reproductive success in competition with wild salmon. This is most pronounced in males (Tab. 2, B. Jonsson et al. 1990, 1991). Even when ranched females loose in spawning competition with wild females, they may spawn later and superimpose the nests of wild females and thereby dig up eggs. There is little direct knowledge about the fate of the offspring of sea ranched, or hybrids between ranched and wild salmon. However, in a recent review of the literature on genetic effects of cultured fish on natural fish populations Hindar et al. (1991a) concluded that when genetic effects on performance traits have been documented, they always appear to be negative in comparison with unaffected native populations.

Contagious diseases are one of the largest and most serious problem in the fish farming industry (Egidius et al. 1991, Håstein & Lindstad 1991). Although diseases also occur in wild fish, it can usually be seen as a phenomenon, rather than a problem, and they existed long before the commencement of fish farming (Håstein & Lindstad 1991). Releases of hatchery smolts are a potential way of spreading infectious diseases and parasites that are harmful to wild stocks. Movement of fish between localities increases the risk, in particular when moved over large distances to drainages isolated and very different from where they were evolved and became coadapted with the host. Examples of infectious diseases/parasites spread in Norway is the introduction of furunculoses from Scotland (Egidius 1987) and the parasitic fluke Gyrodactylus salaris from the Baltic sea (Johnsen & Jensen 1986, 1991, Bakke et al. 1990).

Massive releases of hatchery smolts will increase the amount of salmon available for harvest in all fisheries. When caught in the sea, hatchery fish will be exploited side by side with wild salmon. If the effort in such mixed stock fisheries, as a result of higher abundance of fish, is increased, wild stocks may suffer from unintended overexploitation.

CONCLUSIONS

The salmon ranching experiments in the River Imsa have improved our knowledge of salmon life history. Furthermore we have learnt that there is a potential for a beneficial salmon ranching in Norway, and that survival and return can be improved when paying attention to a number of biological and environmental factors during rearing and release. Salmon ranching requires (1) a smolt production strategy, (2) a release strategy and (3) a harvesting strategy. These strategies should ensure maximum survival, return and harvest, that ranched salmon do not interfere with natural salmon stocks, and that ranching is economically feasible. In order to obtain the highest possible harvest as well as minimizing straying to other rivers, preferably all returns of ranched fish should be harvested. Moreover, ranched salmon should be harvested separately from wild fish, as increased fishing effort in mixed stock fisheries will increase the level of exploitation on wild salmon.

If only partly harvested, ranched salmon will interfere with wild salmon in rivers and spawn there. The benefit/cost ratio of salmon ranching will be highest and the negative environmental impact lowest in large rivers. Here, successful ranching can be performed with large, valuable salmon and the fish will ascend estuaries and rivers early in the season when the quality of the flesh is still good. Straying-rate to other rivers will be low. Ranching in small rivers should be carried out with grilse stocks which are less sensitive to low water flow. However, straying will be higher, and in years with low summer flow the fish will ascend late in the season. Releases directly in the sea should be avoided because of high straying rates and difficulties in harvest of the entire crop. Care must be taken not to release fish infected with contagious diseases. The economy in salmon ranching can be considerably improved when the fish are harvested in a sport fishery.

REFERENCES

Anon. 1991. Report of the working group on north Atlantic salmon. ICES C.M. 1991/Assess:12, 157 pp.

Baglinière, J.L. 1976. Etude des populations de saumon Atlantique (Salmo salar L., 1766) en Bretagne - Basse-Normandie. II.- Activite de devalaison des smolts sur l'Elle. Ann. Hydrobiol. 7: 159-177.

Baglinière, J.L. and G. Maisse 1985. Precocious maturation and smoltification in wild Atlantic salmon in the American massif, France. Aquaculture 45: 249-263.

Bakke, T.A., P.A. Jansen & L.P. Hansen 1990: Differences in the host resistance of Atlantic salmon (Salmo salar) stocks to the monogenean Gyrodactylus salaris Malmberg, 1957. J. Fish Biol. 37: 577-587.

Barton, B.A., R.E. Peter and C.R. Paulencu 1980. Plasma cortisol levels of fingerling rainbow trout (Salmo gairdneri) at rest, and subjected to handling, confinement, transport and stocking. Can. J. Fish. Aquat. Sci. 37: 805-811.

Berglund, I., L.P. Hansen, H. Lundqvist, B. Jonsson, T. Eriksson, J.E. Thorpe & L.O. Eriksson 1991: Effects of elevated winter temperature on seawater adaptability, sexual rematuration, and downstream migratory behaviour in mature male Atlantic salmon parr (Salmo salar). Can. J. Fish. Aquat. Sci. 48: 1041-1047.

Browne, J., C. Eriksson, L.P. Hansen, P.O. Larsson, J. Lecompte, D.J. Piggins, P. Prouzet, A. Ramos, O. Sumari, J.E. Thorpe and J. Toivonen 1983. COST 46/4, Ocean Ranching of Atlantic salmon. Action COST 46, Mariculture. XII/1199/82, E.E.C. Brussels, 94 pp.

Carlin, B. 1955. Tagging of salmon smolts in the River Lagan. Rep. Inst. Freshwat. Res. Drottningholm 36: 57-74.

Carlin, B. 1969. Salmon conservation in Sweden, salmon tagging experiments, the migration of salmon. Series of lectures. Montreal: The Atlantic Salmon Association, 22 pp.

Cross, T.F. and D.J. Piggins 1982. The effect of abnormal climate conditions on the smolt run of 1980 and subsequent returns of Atlantic salmon and sea trout. I.C.E.S. C.M. 1982/M: 26, 8 pp.

Dragesund, O. 1982. Ressursgrunnlaget for storstilet utsetting av laksefisk. Proc. Symp. Kulturbetinget fiske etter laksefisk, Bergen. Direktoratet for Naturforvaltning (in Norwegian).

Egidius, E. 1987. Import of furunculoses to Norway with Atlantic salmon smolts from Scotland. ICES C.M. 1987/F:8, 7pp.

Egidius, E., L.P. Hansen, B. Jonsson & G. Nævdal 1991: Mutual impact of wild and cultured Atlantic salmon in Norway. J. Cons. int. Explor. Mer. 47: 404-410.

Eriksson, T. 1988. Migratory behaviour of Baltic salmon (Salmo salar L.); adaptive significance of annual cycles. Ph.D. thesis, Umeå University, Umeå, Sweden, 86 pp.

Eriksson, C., M.P. Ferranti and P.O. Larsson (eds.) 1983. Sea ranching of Atlantic salmon. COST 46/4 Workshop, Lisbon October 1982. E.E.C. Brussels.

Gjedrem, T. 1983. Genetic variation in quantitative traits and selective breeding in fish and shellfish. Aquaculture 33: 51-72.

Gunnerød, T.B., N.A. Hvidsten and T.B. Heggberget 1988. Open sea releases of Atlantic salmon smolts, Salmo salar, in central Norway, 1973-83. Can. J. Fish. Aquat. Sci. 45: 1340-1345.

Gwinner, E. 1986. Circannual rhythms. Springer, Berlin.

Hansen, L.P. 1986. The salmon catch data available for analysis in Norway. In: Jenkins, D. and W.M. Shearer (eds.). The status of Atlantic salmon in Scotland. I.T.E. Symp. 15: 79-83.

Hansen, L.P. 1987. Growth, migration and survival of lake reared juvenile anadromous Atlantic salmon Salmo salar L. Fauna norv. Ser. A 8: 29-34.

Hansen, L.P. 1988a. Effects of Carlin tagging and fin clipping on survival of Atlantic salmon (Salmo salar) released as smolts. Aquaculture 70: 391-394.

Hansen, L.P. 1988b. Status of exploitation of Atlantic salmon in Norway. In: Mills, D.H. and D.J. Piggins (eds.). Atlantic salmon: Planning for the future. Croom Helm, London & Sydney. Timber Press, Portland, Oregon, pp. 143-161.

Hansen, L.P. and B. Jonsson 1985. Downstream migration of hatchery-reared smolts of Atlantic salmon (Salmo salar L.) in the River Imsa. Aquaculture 45: 237-248.

Hansen, L.P. and B. Jonsson 1986. Salmon ranching experiments in the River Imsa: Effects of day and night release and of sea-water adaptation on recapture-rates of adults. Rep. Inst. Freshwat. Res. Drottningholm 63: 47-51.

Hansen, L.P. and B. Jonsson 1988. Salmon ranching experiments in the River Imsa: Effects of dip-netting, transport and chlorobutanol anaesthesia on survival. Aquaculture 75: 301-305.

Hansen, L.P. and B. Jonsson 1989a. Salmon ranching experimets in the River Imsa: Returns of different stocks to the fishery and the River Imsa. In: De Pauw, N., E. Jaspers, H. Ackefors and N. Wilkins (eds.). Aquaculture - a biotechnology in progress. European Aquaculture Society, Bredene, Belgium, pp. 445-452.

Hansen, L.P. and B. Jonsson 1989b. Salmon ranching experiments in the River Imsa: Effect of timing of Atlantic salmon (Salmo salar) smolt migration on survival to adults. Aquaculture 82: 367-373.

Hansen, L.P. & B. Jonsson 1991a: Evidence of a genetic component in the seasonal return pattern of Atlantic salmon (Salmo salar L.). J. Fish Biol. 38: 251-258.

Hansen, L.P. & B. Jonsson 1991b: The effect of smolt age on the migratory behaviour of Baltic salmon (Salmo salar L.), transplanted to the east Atlantic. Aquacult. Fish. Manage. 22: 357-362.

Hansen, L.P. & B. Jonsson 1991c: The effect of timing of Atlantic salmon smolt and post-smolt release on the distribution of adult return. Aquaculture 98: 00-00. (In press).

Hansen, L.P. & T.B. Lea 1982: Tagging and release of Atlantic salmon smolts Salmo salar L. in the River Rana, Northern Norway. Rep. Inst. Freshw. Res. Drottningholm. 60: 31-38.

Hansen, L.P. & P. Pethon 1985: The food of Atlantic salmon, Salmo salar L. caught by long-line in Northern Norwegian waters. J. Fish Biol. 26: 553-562.

Hansen, L.P., B. Jonsson and K.B. Døving 1984. Migration of wild and hatchery reared smolts of Atlantic salmon, Salmo salar L., through lakes. J. Fish Biol. 25: 617-623.

Hansen, L.P., K.B. Døving & B. Jonsson 1987: Migration of farmed adult Atlantic salmon with and without olfactory sense, released on the Norwegian coast. J. Fish Biol. 30: 713-721.

Hansen, L.P., B. Jonsson and R. Andersen 1989a. Salmon ranching experiments in the River Imsa: Is homing dependent on sequential imprinting of the smolts? In: Brannon, E. and B. Jonsson (eds.). Proc. of the salmonid migration and distribution symposium. School of Fisheries, University of Washington, Seattle, USA. NINA, Trondheim, Norway, pp. 19-29.

Hansen, L.P., W.C. Clarke, R.L. Saunders and J.E. Thorpe (eds.) 1989b. Salmonid smoltification III. Aquaculture 82: 1-390.

Hansen, L.P., B. Jonsson, R.I.G. Morgan and J.E. Thorpe 1989c. Influence of parr maturity on emigration of smolting Atlantic salmon (Salmo salar). Can. J. Fish. Aquat. Sci. 46: 410-415.

Harden Jones, F.R. 1968. Fish migration. Edward Arnold, London, 325 pp.

Hasler, A.D. 1966. Underwater guideposts: homing of salmon. Madison, Wisconsin, University of Wisconsin Press, 155 pp.

Heggberget, T.G. 1988. Reproduction in Atlantic salmon (Salmo salar): aspects of spawning, incubation, early life history and population structure. Dr. philos. thesis, University of Trondheim.

Hesthagen, T. and E. Garnås 1986. Migration of Atlantic salmon smolts in River Orkla, central Norway in relation to management of a hydroelectric station. N. Am. J. Fish. Manage. 6: 376-382.

Hindar, K. and J. Nordland 1989. A female Atlantic salmon, Salmo salar L., maturing sexually in the parr stage. J.Fish Biol. 35: 461-463.

Hindar, K., N. Ryman and F. Utter 1991a. Genetic effects of cultured fish on natural fish populations. Can. J. Fish. Aquat. Sci. 48: 945-957.

Hindar, K., S. Engen, Ø. Bakke, L.P. Hansen & B. Jonsson 1991b: Straying in salmonid fishes. Manuscript submitted for publication.

Hislop, J.R. and A. Youngson 1984. A note on the stomach contents of salmon caught by longline north of the Faroe Islands in March, 1983. ICES C.M. 1984/M:17, 4pp.

Hoar, W.S. 1976. Smolt transformation: evolution, behaviour and physiology. J. Fish. Res. Bd. Can. 33: 1234-1252.

Holm, M., I. Huse, E. Waatevik, K.B. Døving and J. Aure 1982. Behaviour of Atlantic salmon smolts during seaward migration. I. Preliminary report on ultrasonic tracking in a Norwegian fjord system. ICES C.M. 1982/M:7, 17 pp.

Hosmer, M.J., J.G. Stanley and R.W. Hatch 1979. Effects of hatchery procedures on later return of Atlantic salmon to rivers of Maine. Progr. Fish Cult. 41: 115-119.

Hvidsten, N.A. and L.P. Hansen 1988. Increased recapture rate of adult Atlantic salmon Salmo salar L., stocked at high water discharge. J. Fish Biol. 32: 153-154.

Hvidsten, N.A. and R.A. Lund 1988. Predation on hatchery-reared and wild smolts of Atlantic salmon, Salmo salar L., in the estuary of River Orkla, Norway. J. Fish Biol. 33: 121-126.

Hvidsten, N.A. and P.I. Møkkelgjerd 1987. Predation on salmon smolts (Salmo salar L.) in the estuary of the River Surna, Norway. J.Fish Biol. 30: 273-280.

Håstein, T. and T. Lindstad 1991. Diseases in wild and cultured salmon: possible interaction. Aquaculture 98: 00-00 (in press).

Isaksson 1983. Salmon ranching in Iceland In: Eriksson, C., M.P. Ferranti and P.O. Larsson (eds.) 1983. Sea ranching of Atlantic salmon. COST 46/4 Workshop, Lisbon October 1982. E.E.C. Brussels, pp. 23-42.

Isaksson, A. 1988. Salmon ranching: a world review. Aquaculture 75: 1-33.

Jensen, K.W. 1979. Saltwater releases and saltwater adaption of smolts of Atlantic salmon. ICES C.M. 1979/M:8, 10 pp.

Jones, J.W. 1959. The salmon. Collins, London.

Johnsen, B.O. and A.J. Jensen 1986. Infestation of Atlantic salmon, Salmo salar, by Gyrodactylus salaris in Norwegian rivers. J. Fish Biol. 29: 233-241.

Johnsen, B.O. and A.J. Jensen 1991. The Gyrodactylus story in Norway. Aquaculture 98: 00-00 (in press).

Jonsson, B. and J. Ruud-Hansen 1985. Water temperature as the primary influence on timing of seaward migrations of Atlantic salmon (Salmo salar) smolts. Can. J. Fish. Aquat. Sci. 42: 593-595.

Jonsson, B., N. Jonsson & L.P. Hansen 1990: Does juvenile experience affect migration and spawning of adult Atlantic salmon? Behav. Ecol. Sociobiol. 26: 225-230.

Jonsson, B., N. Jonsson & L.P. Hansen 1991: Differences in life history and migratory behaviour between wild and hatchery reared Atlantic salmon in nature. Aquaculture 98: 00-00 (in press).

Jonsson, N., B. Jonsson and L.P. Hansen 1990. Partial segregation in timing of migration of different aged Atlantic salmon. Anim. Behav. 40: 313-321.

Jonsson, N., L.P. Hansen & B. Jonsson 1991a: Variation in age, size and repeat spawning of adult Atlantic salmon in relation to river discharge. J. Anim. Ecol. 60: 00-00 (in press).

Jonsson, N., B. Jonsson & L.P. Hansen 1991b: The energetic cost of spawning in Atlantic salmon. J. Fish Biol. 39: 00-00 (in press).

Kennedy, G.J.A. and J.E. Greer 1988. Predation by cormorants, Phalacrocorax carbo (L.), on the salmonid population of an Irish river. Aquaculture and Fish. Manage. 19: 159-170.

Larsson, P.-O. 1977. The importance of time and place of release of salmon on the results of stocking. I.C.E.S. C.M. 1977/M: 42, 4 pp.

Larsson, P.-O. 1980. Smolt rearing and the Baltic salmon fishery. In: Thorpe, J.E. (ed.) 1980. Salmon ranching. Academic Press, London. pp. 157-186.

Larsson, P.-O. 1984. Some characteristics of the Baltic salmon, _Salmo salar_ L. population. Ph.D. thesis, University of Stockholm, Stockholm, Sweden, 80 pp.

Lear, W.H. 1972. Food and feeding of Atlantic salmon in coastal areas and over oceanic depths. Res. Bull. int. Comm. NW Atlant. Fish. 9: 27-39.

Lear, W.H. 1980. Food of Atlantic salmon in the West Greenland-Laborador Sea area. Rapp. P.-v. Reun. Cons. int. Explor. Mer. 176: 55-59.

Leyzerovitch, K.A. 1973. Dwarf males in hatchery propagation of the Atlantic salmon (_Salmo salar_). J. Ichthyol. 13: 382-391.

Lundqvist, H. and G. Fridberg 1982. Sexual maturation versus immaturity: different tactics with adaptive values in Baltic salmon (_Salmo salar_) male smolts. Can. J. Zool. 60: 1822-1827.

Morgan, R.I.G., Greenstreet, S.P.R. and Thorpe, J.E. 1986. First observations on distribution, food and fish predators of post-smolt Atlantic salmon, _Salmo salar_, in the outer firth of Clyde. _ICES C.M. 1986/M:27,_ 1-12.

Nordeng, H. 1977. A pheromone hypothesis for homeward migration in anadromous salmonids. Oikos 28: 155-159.

Österdahl, L. 1969. The smolt run of a small Swedish river. In: Northcote, T.G. (ed.). Salmon and trout in streams. H.R. MacMillan lectures in fisheries, University of British Columbia, Vancouver, B.C., pp. 205-215.

Pickering, A.D., T.G. Pottinger and P. Christie 1982. Recovery of brown trout, _Salmo trutta_ L., from acute handling stress: a time-course study. J. Fish Biol. 20: 229-244.

Power, G. 1969. The salmon of Ungava Bay. Arct. Inst. N. Am. Tech. Pap. 22: 1-77.

Reddin, D.G. 1985. Atlantic salmon (_Salmo salar_) on the east of the Grand Bank. J. Northwest Atl. Fish. Sci. 6: 157-164.

Reitan, O., N.A. Hvidsten and L.P. Hansen 1987. Bird predation on hatchery reared Atlantic salmon smolts, _Salmo salar_ L., released in the River Eira, Norway. Fauna Norv. Ser. A. 8: 35-38.

Reite, O.B. and M. Staurnes 1986. Osmoregulation in salmonids in culture. Norsk Vet. Tidskr. 98: 787-792 (In Norwegian with English summary).

Ruggles, C.P. 1980. A review of the downstream migration of Atlantic salmon. Can. Tech. Rep. Fish: Aquat. Sci. 952: 1-39.

Saunders, R.L. 1981. Atlantic salmon (Salmo salar) stocks and management implications in the Canadian Atlantic provinces and New England, USA. Can. J. Fish. Aquat. Sci. 38: 1612-1625.

Saunders, R.L. 1983. Sea ranching of Atlantic salmon in Canada. In: Eriksson, C., M.P. Ferranti and P.O. Larsson (eds.) 1982. Sea ranching of Atlantic salmon. COST 46/4 Workshop, Lisbon October 1982. E.E.C. Brussels, pp. 5-21.

Saunders, R.L. 1991. Potential interaction between cultured and wild Atlantic salmon. Aquaculture 98: 00-00 (in press).

Saunders, R.L. and K.R. Allen 1967. Effects of tagging and fin-clipping on the survival and growth of Atlantic salmon between smolt and adult stages. J. Fish. Res. Board Can. 24: 2595-2611.

Saunders, R.L., E.B. Henderson and B.D. Glebe 1982. Precocious sexual maturation and smoltification in male Atlantic salmon (Salmo salar). Aquaculture 28: 211-229.

Saunders, R.L., E.B. Henderson, B.D. Glebe, and E.J. Loudenslager 1983. Evidence of a major environmental component in determination of the grilse: large salmon ratio in Atlantic salmon (Salmo salar). Aquaculture 33: 107-118.

Shearer, W.M., R.M. Cook, D.A. Dunkley, J.A. MacLean and R.G.J. Shelton 1987. A model to assess the effect of predation by sawbill ducks on the salmon stock of the River North Esk. Scot. Fish. Res. Rep. 37: 1-12.

Soivio, A. and E. Virtanen 1984. Physiological effects of stocking stress on Baltic salmon (Salmo salar). E.I.F.A.C. H/C.E.C.P.I./T42 (suppl.), Vol. 1, pp. 217-226.

Soivio, A., K. Nyholm and M. Huhti 1977. Effects of anaesthesia with MS 222, neutralized MS 222 and benzocaine on the blodd constituens of rainbow trout, Salmo gairdneri. J. Fish Biol. 10: 91-101.

Ståhl, G. 1987. Genetic population structure of Atlantic salmon. In: Ryman, N. & F. Utter (eds.)Population genetics and fishery management. University of Washington Press, Seattle, WA, pp. 121-140.

Sutterlin, A.M., R.L. Saunders, E.B. Henderson and P.R. Harmon 1982. The homing of Atlantic salmon (Salmo salar) to a marine site. Can. Tech. Rep. Fish. Aquat. Sci. 1058: 1-6.

Templeman, W. 1967. Atlantic salmon from the Laborador Sea and off West Greenland, taken during "A.T. Cameron" cruise July-August 1965. Res. Bull. int. Comm. NW Atlant. Fish. 5: 5-40.

Thorpe, J.E. (ed.) 1980. Salmon ranching. Academic Press, London.

Thorpe, J.E. 1982. Migrations in salmonids, with special reference to juveniles in freshwater. In: Brannon, E.L. and E.O. Salo (eds.). Proc of the salmon and trout migratory symposium, University of Washington, Seattle, pp. 86-97.

Thorpe, J.E. 1986. Age at first maturity in Atlantic salmon, Salmo salar: freshwater period influences and conflict with with smolting. In: D.J. Meerburg (ed.). Salmonid age at maturity. Can. Spec Publ. Fish. Aquat. Sci. 89: 7-14.

Thorpe, J.E. 1989. Downstream migration of young salmon: recent findings, with special reference to Atlantic salmon, Salmo salar L. In: Brannon, E.L. and B. Jonsson (eds.). Proc. of the salmonid migration and distribution symposium. University of Washington, Seattle; NINA, Trondheim, pp. 81-86.

Thorpe, J.E. 1991. Acceleration and decleration effects of hatchery rearing on salmonid development, and their consequences for wild stocks. Aquaculture 98: 00-00 (in press).

Thorpe, J.E and R.I.G. Morgan 1978. Periodicity in Atlantic salmon, Salmo salar L. smolt migration. J. Fish Biol. 12: 541-548.

Thorpe, J.E., H.A. Bern, R.L. Saunders and A. Soivio (eds.) 1985. Salmonid smoltification II. Aquaculture 45: 1-404.

Thurow, F. 1973. Research vessel fishing on salmon off Norway. Arch. Fisch. Wiss. 24: 253-260.

Youngson, A.F., L.P. Hansen, B. Jonsson and T.F. Næsje 1989. Effects of exogenous thyroxine or prior exposure to raised water flow on the downstream movement of hatchery-reared Atlantic salmon smolts. J. Fish Biol. 34: 791-797.

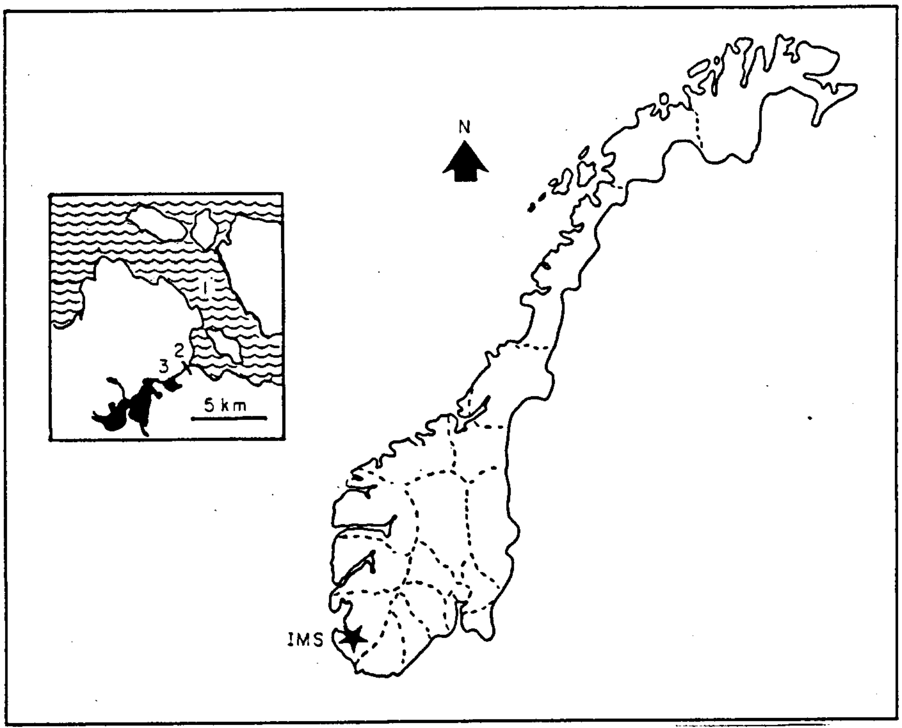

Fig. 1. The River Imsa drainage. (1) Høgsfjord; (2) the fish traps; (3) Lake Liavatn.

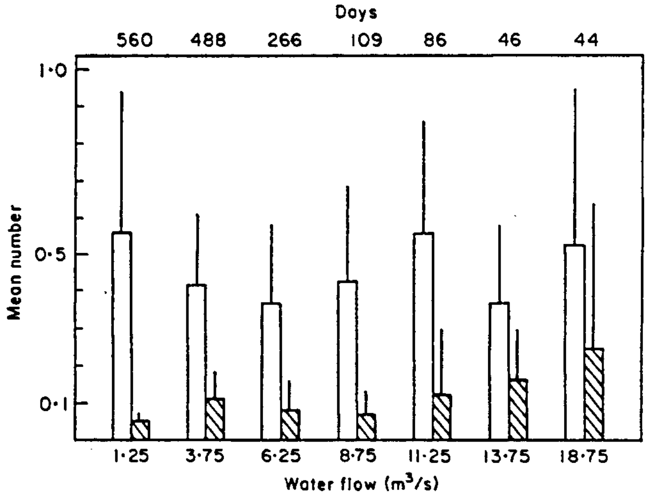

Fig. 2. Annual mean number of Atlantic salmon that spent one (□; N=668) or more (▨; N=133) winters at sea ascending into the fish trap at the outlet of the River Imsa per day at different water discharges during June-October 1976-1988. Vertical lines give 95% confidence limits of the annual means (N. Jonsson et al. 1990).

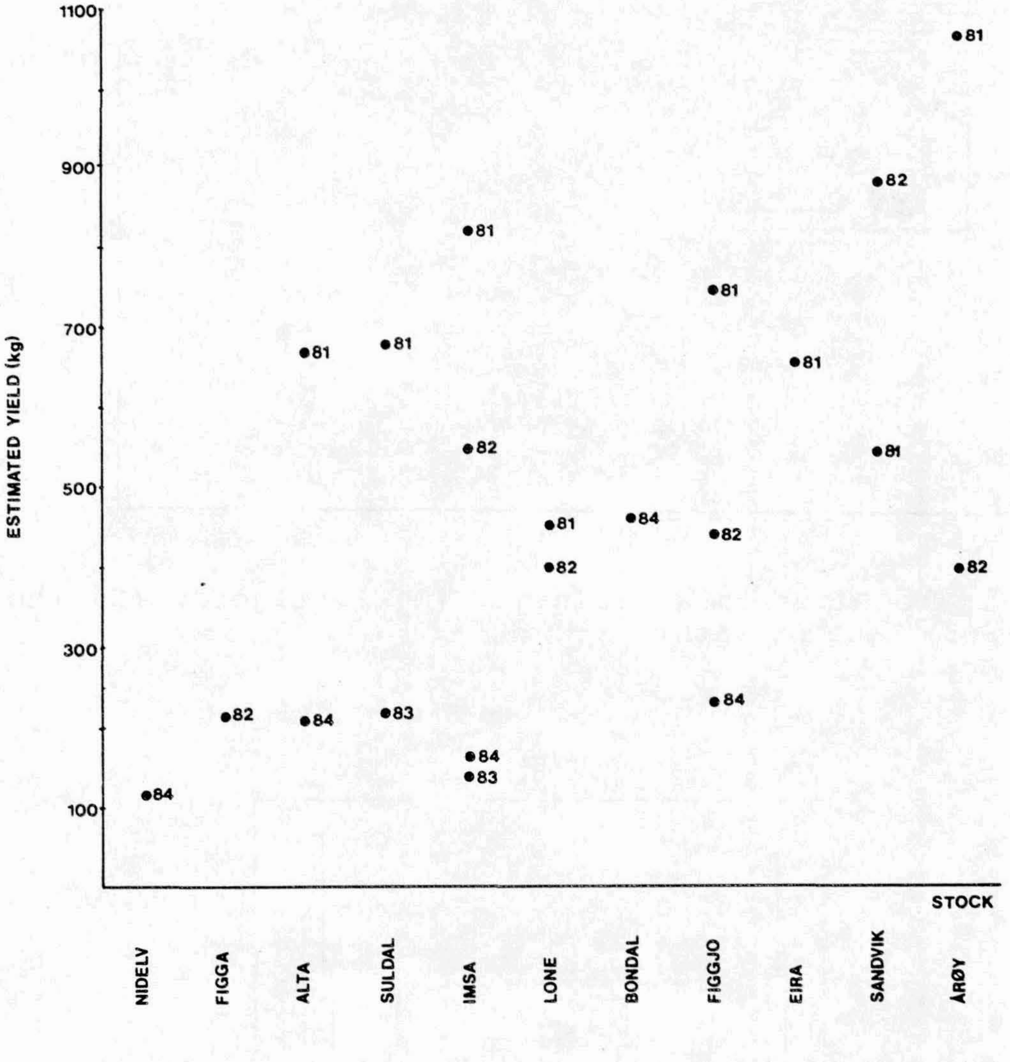

Fig 3. Estimated total yield of adult Atlantic salmon released as 2-year-old smolts at Imsa. The figures besides the dots are the year of release (Hansen & Jonsson 1989a).

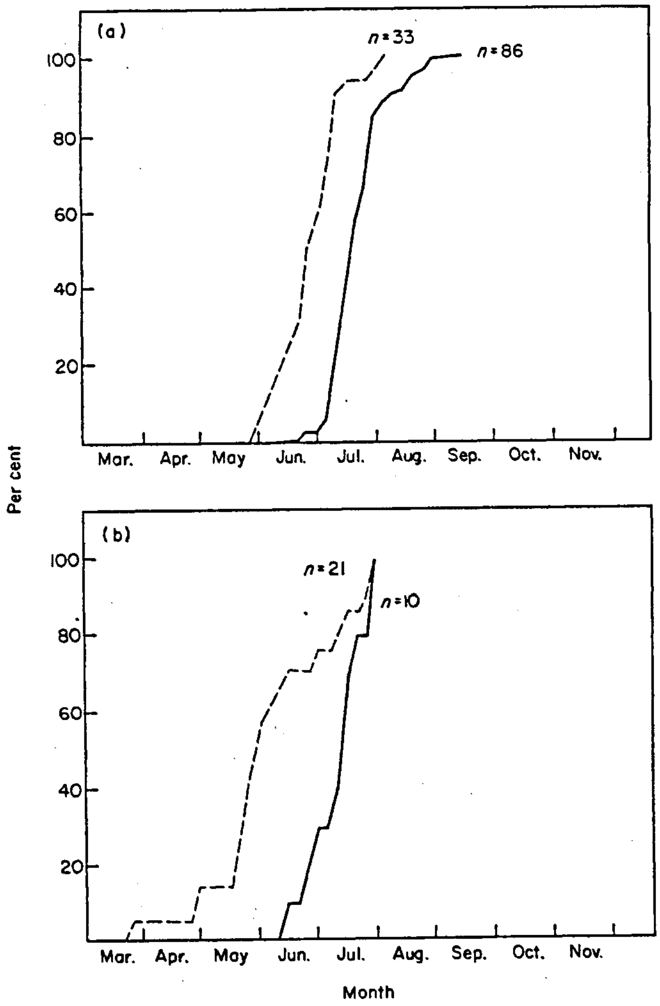

Fig. 4. Cumulative recaptures of (a) one-sea-winter and (b) two-sea-winter salmon in Norwegian coastal fisheries of smolts released in the River Imsa 1981. ----, R. Figga stock; ——, R. Imsa stock.

Group		No. released	No. migrants	Migrants(%)
Heated	M	210	171	81.4
Ambient	M	210	122	58.1
Heated	I	239	206	86.2
Ambient	I	235	207	88.1

Tab. 1. Number of released and migrant smolts from immature parr (I) and mature male parr (M). Prior to release on 9 May the fish had been kept in ambient temperature or heated water (4-7 centigrades above ambient) from 17 December to 12 April. The fish were released 1000 m above the smolt trap in River Imsa (Berglund et al. 1991).

Trait	Sex	Wild	Hatchery	Significance
Time of 50% cumulative return to coastal Norway	B	6 July	11 July	ns
Time of 50% cumulative river ascent	M	5 october	17 October	**
	F	11 September	11 October	**
Time of 50% cumulative river descent	M	4 January	20 December	*
	F	17 February	23 January	*
Descending without having spawned (%)	M	3.8	36.7%	***
	F	0	13.5%	***
Passed the trap more than once in each direction during the same season (%)	B	1.0	21.2	***
Injuring during spawning (%)	M	30.2	55.7	***
	F	3.9	9.0	***

Tab. 2. Behavioural differences between wild and hatchery-reared salmon of the River Imsa stock. B= both sexes, M= males, F= females (B. Jonsson et al. 1990, 1991).