Published on paper: 1990. Published online: 2024-10-20.
ISSN 1502-4873 (paper). ISSN 1891-5396 (electronic).
doi: https://doi.org/10.5324/fn.v11i0.6061.

Migration pattern of Atlantic salmon smolts *Salmo salar* L. released at different sites in the River Drammenselv, SE Norway

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Pethon, P. & Hansen, L. P. 1990. Migration pattern of Atlantic salmon smolts *Salmo salar* L. released at different sites in the River Drammenselv, SE Norway. *Fauna norv. ser. A 11:* 17—22.

Hatchery-reared smolts of Atlantic salmon *Salmo salar* L. of the River Drammenselv stock were released at four different sites in the River Drammenselv system; (1) at Gol, (2) at Kaggefoss, (3) at Hellefoss and (4) in the estuary at Svelvik. All smolts were individually tagged with Carlin tags. Based on tag returns the first two months after release, it became evident that the great majority of the smolts descended the river and migrated to sea. The smolts released at Gol descended the river with average speeds between 4.3 and 5.4 km day-1, whereas the smolts released at Hellefoss and Kaggefoss descended on average 13.4 km of the river per day. The speed of descent decreased when the smolts reached the fjord, but seemed to increase when the fish reached the coastal current. This migration pattern is discussed in relation to the current system both in the river, the estuary and the sea.

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INTRODUCTION

Atlantic salmon smolts, *Salmo salar* L., migrate from freshwater to the sea in the spring — early summer (e.g. Jones 1959, Österdahl 1969), earliest in the southern part of the distribution range of salmon. This timing seems to be crucial for survival and return as adult fish (Larsson 1977, Cross & Piggins 1982, Hansen 1987, Hansen & Jonsson 1989), and is probably a result of adaptation to the prevailing environmental conditions in the local area (Hansen 1990a). The period after the smolts leave freshwater (post-smolt stage) has been suggested to be the most critical period for the marine survival of Atlantic salmon (Doubleday et al. 1979, Browne et al. 1982).

In salmon ranching programmes (salmon ranching: the release of articially raised salmon smolts and the subsequent harvesting of the returning adults) it is important to maximize the survival and return of adult fish. There is, however, very little information of migration and feeding of post-smolts in estuaries and fjords draining into the Atlantic (see Hansen 1986, Morgan et al. 1986, Reddin & Short 1989). Some data are, however, available on predation of post-smolts, although they are limited to estuaries (e.g. Hvidsten & Møkkelgjerd 1987, Reitan et al. 1987, Shearer et al. 1987, Ritter 1989).

In the River Drammenselv, salmon smolts of the local stock have been released since 1984, as a part of a programme to restore and increase the salmon stock (Hansen et al. 1986, Hansen 1990b). In 1987 the parasitic fluke *Gyrodactylus salaris* infected the salmon population and has caused a heavy decrease of naturally produced salmon parr in the system (Eken & Garnås 1990). In order to maintain the salmon stock in the future, the presence of this parasite has probably made the salmon stock completely dependent on stocking of salmon parr upstream the *G. salaris* infected area and smolts in the main river.

The aim of this study is to describe the migratory pattern of hatchery-reared smolts released at different sites in the river and estuary and to estimate their migration speed.

STUDY AREA

The River Drammenselv system drains large areas, i.e. 17 140 km² of south east Norway. An important tributary is the River Hallingdalselv, where some of the experiments were carried out. This system is heavily affected by regulation for the generation of hydroelectric power, and a number of dams and weirs has been built. At the release site at Gol the annual average water discharge is about 20 $m^3s.^{-1}$, while during spring flood the water discharge may reach 50—100 $m^3s.^{-1}$. About 20 km downstream Gol, the water running out from the power plants again joins the river. From here and to Lake Krøderen, about 64 km downstream Gol, the river forms a series of smaller lakes where the current velocity of the water is reduced. Lake Krøderen is 38 km long with a regulated water level amplitude of 2.6 m, and is characterized as a flow through basin. The River Snarumselv with an annual average water discharge of about 110 m^3s^{-1}, and a very pronounced spring flood, is the river that runs out of Lake Krøderen. This river empties into the River Drammenselv which runs out of the Lake Tyrifjord, about 35km downstream the lake Krøderen. From this point the distance to the Drammensfjord where the river meets saline water is about 35 km.

The Hellefoss waterfall, utilized to generate hydroelectric power, is located about 19 km upstream the estuary. Here the average annual water discharge is about 225 m^3s^{-1}, but during the spring flood the discharge may exceed 1500 m^3s^{-1}.

At Svelvik the Drammen Fjord is naturally narrowed and forms the entrance of the fjord. This entrance is the functional estuary of the river in spring and early summer, due to the fact that the river flood creates a sharp halocline at 10 m depth all over the fjord with freshwater (Beyer 1976, Pethon 1987). Within the freshwater above the halocline a considerable, but narrow current is present southwards to the fjord entrance. This current is, however, tidal impacted. The salinity outside the entrance is about 5 o/oo in spring and increases to about 10 o/oo at the bay opening 8 km further out.

The Atlantic salmon in the River Drammenselv is a typical multi-sea-winter salmon stock spending 1—4 winters in the sea, and the majority of the adult salmon ascending the river vary between 2 and 20 kgs in size.

Table 1. Number of tagged Atlantic salmon smolts released at the different sites in the River Drammenselv system, and the number of post-smolts recaptured. 1= Gol; 2= Kaggefoss; 3= Hellefoss; 4= Svelvik, 5= Svelvik, floated in a net-pen from Hellefoss.

Site of release	Date of Smolt release age	No. released	No recaptured
1	7 May 86 1+	2982	14
1	19 May 87 2+	976	6
2	10 May 89 2+	1878	3
3	7 May 84 1+	1472	1
3	7 May 84 2+	984	3
3	6 May 86 2+	1437	2
3	10 May 89 2+	1676	1
4	9 May 84 2+	995	4
4	6 May 86 1+	2965	2
4	19 May 87 2+	985	3
5	19 May 87 1+	962	1
5	19 May 87 2+	990	2

MATERIAL AND METHODS

In May 1984—1989 1+ and 2+ smolts of the local stock were released at four localities within the River Drammenselv system, and the groups from which post-smolts were recaptured are shown in Tab. 1. The smolts released in 1984, 1985 and 1986 were reared at the Research Station for Freshwaterfish at Ims, SW Norway. The smolts released in 1987 were reared at Ims, at Hovet in Hallingdal and at the hatchery at Åmot, while the smolts released in 1989 were reared in the local hatcheries at Hellefoss and Åmot. More than two weeks before release, the smolts were anaestethetized with chlorobutanol and individually tagged with Carlin tags (Carlin 1955). The fish were transported by truck from the rearing sites to the different places of release, and put directly into the river, except for a group towed for 14 hrs in a floating pen from Hellefoss to Svelvik and subsequenly released. Recaptures were reported by fishermen and anglers, and speed of migration was estimated based on shortest distance traveled from point of release to recapture site in relation to number of days between release and recapture.

RESULTS

Of the 42 smolts reported recaptured (pooled material), three fish obviously became resident. One individual released at Gol was re-

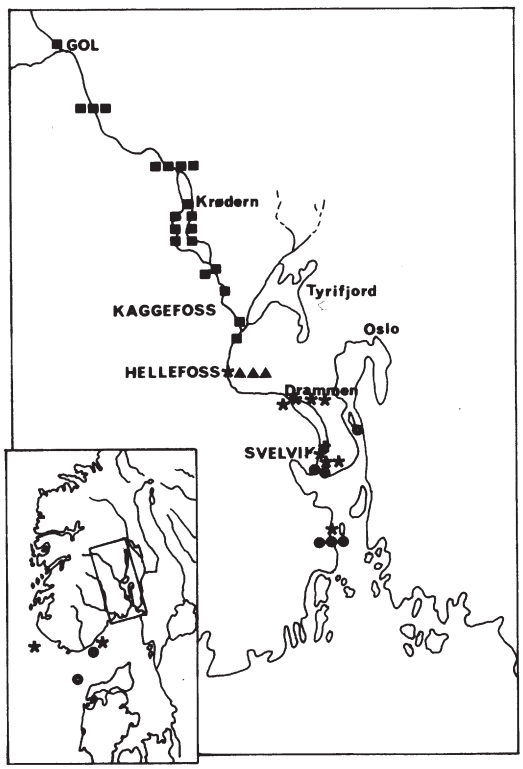


Fig. 1. Geographical distribution of recaptured smolts and post-smolts of Atlantic salmon released as smolts at Gol (■), Kaggefoss (▲), Hellefoss (★) and Svelvik (●).

captured after 61 days in the lower part of the tributary River Hemsil, about 1 km upstream the point of release (Fig. 1). Of the smolts released at Hellefoss one was caught at the same site after 101 days. Furthermore, one fish released at Svelvik was recovered there 49 days later. The other recaptured fish behaved like migrating smolts, althoug several were recaptured at fairly short distances from the point of release. Except for two individuals released at Hellefoss and Svelvik and caught at the site of release after 1 and 3 days respectively, the distance between site of release and site of recapture varied between 20 and 470 km.

The average smolt migration speed varied considerably between groups released at the different sites, and apparently dependent on where they were recovered (Table 2). The smolts released at Gol were all recaptured within the river system, and the average speed of fish recaptured at three pooled areas; river Hallingdalselv, Lake Krøderen and river Snarumselv, was very similar. The relatively short journey down the main river, from the Kaggefoss/Hellefoss release sites is on average fullfilled in about 2 days, i.e. with an average speed of 13.4 km day^{-1}. The passage along the Drammen Fjord to the spring estuary of Svelvik seems to be very variable with an estimated mean speed of 3.7 km day^{-1}. Within the Oslofjord area 5 post-smolts have been recaptured, 39 to 59 days after release. One was released at Hellefoss and four at Svelvik. Their average migration speed was 0.9 km day^{-1}. Only four post-smolts were caught offshore in the Skagerak; two released at Hellefoss and two at Svelvik. Their speed of migration averaged 16.7 km day^{-1}.

DISCUSSION

The great majority of the hatchery-reared smolts released at the four sites in the river descended soon after release, only 3 of the 42 recaptures (7.1%) were assumed residents.

Table 2. Average migration speed (km day-1) and duration (as average time of days travelled from the point of release to site of recapture) of smolts released at different sites.

Site of release	Recapture area	Nos. recaptured	Migration		
			Speed ($\bar{x}$)	Speed range	Duration ($\bar{x}$)
Gol	R. Hallingdal	7	5.1	2.6—6.2	12.0
Gol	L. Krøderen	7	4.3	1.2—7.3	25.1
Gol	Below L. Krøderen	5	5.4	2.6—12.7	32.6
Hellef.	R. Drammenselv	7	13.4	6.0—20.0	2.1
Kaggef.	Drammensfjord	4	3.7	0.7—10.5	27.7
Hellef.	Oslofjord	5	0.9	0.5—1.5	47.8
Svelvik	Skagerak	4	16.7	10.6—20.5	23.5

All individuals in a salmon population do not smolt and migrate to sea. Resident mature males are common in wild populations (Jones 1959), and under hatchery conditions parr maturity is also common and advanced developmental rates seem to give higher frequencies of early maturity (e.g. Thorpe 1989). From experiments carried out in the River Imsa it has been demonstrated that sexual maturity of parr reduces the probability of a future seaward migration (Hansen et al. 1989). This is probably the most plausible explanation why some «smolts» do not migrate to sea after release.

It has been suggested that smolt migration is a result of a passive displacement (Tytler et al. 1979, Thorpe et al. 1981), although it has been argued that this migration is partly active (Thorpe & Morgan 1978, Solomon 1978, Kennedy et al. 1984, Burgeois & O' Connell 1988). In the River Imsa Hansen & Jonsson (1985) suggested that smolts move actively into the main current of the stream to avoid being caught in backwater and sloughs. However, it was also observed that smolt descended more slowly than the current velocity of the river, but the smolts moved more quickly downstream at high waterflow than at low (Youngson et al. 1989).

The estimated speed of migration of the smolts released at Gol were remarkably consistent, when comparing the recaptures reported from the three different sections of the river. We expected that the 38 km long Lake Krøderen would reduce their speed of descent, since it has been observed in the River Imsa that hatchery-reared smolts released above lakes with small through flow of water were considerably delayed (Hansen et al. 1984). In the River Imsa smolt group released in the river, about 1 km upstream the smolt trap descended with average speeds between 2.2 and 5.3 km day^{-1}, which are in the same order of magnitude than observed in the present study. The comparable groups of smolts released in lakes farther upstream migrated with average speeds of between 0.2 and 1.3 km day^{-1} (Hansen et al. 1984). Although no data of water current speed in the lake Krøderen are available, this lake is different from the lakes in the River Imsa system, and characterized as very narrow and vertically stratified.

The recaptures of the smolts released from the closely located Kaggefoss and Hellefoss, indicated that the fish moved relatively fast downstream the main river to the fjord. The migration speed in the Drammen Fjord was considerably lower, however, and about the same as observed for smolts released at Gol and recaptured in Lake Krøderen. This is interesting since a pronounced outward current above the halocline is present in this fjord, however with varying strength and localization dependent om the tide. A possible explanation for the observed delay in migration within this fjord may be that the rising tide creates both current displacements and eddies (Beyer 1976) to an extent that bring the migratory smolts off track, i.e. the fjord in fact equalizes a lake within a river system.

The post-smolts recaptured from the Oslofjord area all showed a delayed migration pattern with an estimated migration speed of less than 0.9 km day^{-1}. McCleave (1978), Tytler et al. (1978) and LaBar et al. (1980) tracking post-smolts in estuaries observed a close relationship between direction of tidal currents and the direction of post-smolt movement. Holm et al. (1982), however, tracking smolts in the estuary and fjord outside the River Imsa, where the tidal currents are negligible, observed that the movement of surface water due to winds and effect of the local coastal current also affected the pattern of movement.

In the Oslo Fjord outside the Drøbak Sound currents are mainly weak, with direction and strength largely dependent on wind direction and air pressure and less on tide (Braarud & Ruud 1937, Anon. 1987). This creates quite unpredictable current systems in the fjord which are supposed to cause the delayed pattern of migration observed in the present study. From observations of post-smolts recaptured after release in River Akerselv (Hansen 1986), an average migration speed of approximately 6 km day^{-1} can be estimated based on eight of the recoveries, while the remaining six were probably resident. Compared with the data in the present study the higher migration speed of the migrants released in the River Akerselv could be explained by more tidal dependent currents inside the very narrow and shallow Drøbak Sound giving the post-smolts in the inner part of the fjord a more consistent track to follow than in the middle and outer parts.

The relatively high migration speed of the post-smolts recaptured offshore on the Skagerak partly depend on the Norwegian coastal current. This current flows along the coast

with a speed of 1 to 2 knots hr^{-1} (Anon. 1987), which equals 45—90 km day^{-1}. Although the present observations indicate the Drammen Fjord as an area where migrating post-smolts are delayed, it seems reasonable to suggest that the main bottleneck for the migration post-smolts from the River Drammenselv is the Oslo Fjord due to its weak and unpredictable current system.

When releasing hatchery-reared smolts in rivers the timing of release is of great importance to the future performance of the fish. It has been observed that smolts have to leave freshwater during a short period in the spring-early summer to give maximum survival and return as adults (Larsson 1977, Cross & Piggins 1982, Hansen 1987), and even so for smolts released from saltwater (Hansen & Jonsson 1989). The optimal time for the smolts to leave the River Drammenselv system is probably during the same period when the wild smolts leave the river, which is in May (Rosseland 1965). It is likely that the smolts released at Gol will enter the sea when the survival window has closed, and the extreme low survival to the adult of smolts released at Gol suggested by provisional results (L.P. Hansen in prep.) lend support to this.

ACKNOWLEDGEMENTS

We are most grateful to Erik Fagerlid Olsen, Øyvind Fladaas, the members of Østsiden and Åmot & Omegn Angling Clubs, the staff at the Research Station for Freshwaterfish at Ims and Berit Larsen for valuable help at different stages of this project.

REFERENCES

Anon. 1987. *Den norske los IIA.* Norsk Sjøkartverk, 188 pp.

Beyer, F. 1976. Influence of freshwater outflow on the hydrography of the Dramsfjord in Southern Norway, pp. 75—87 in: Skreslet, S., Leinebø, R., Matthews, J. & Sakshaug, E. (eds.). *Freshwater on the sea.* Norske Havforskeres Forening, Oslo.

Braarud, T. & Ruud, J. T. 1937. The hydrographic conditions and aeration of the Oslofjord 1933—1934. *Hvalrådets Skr. 15,* 1—56.

Browne, J., Eriksson, E., Hansen, L. P., Larsson, P. O., Lecompte, J., Piggins, D. J., Prouzet, P., Ramos, A., Sumari, O., Thorpe, J. E. & Toivonen, J. 1982. *Ocean ranching of Atlantic salmon.* Action COST 46, Mariculture. KII/1199/82, EEC, Brussels.

Burgeois, C. E. & O, Connell, M. F. 1988. Observations on the seaward migration of Atlantic salmon *(Salmo salar* L.) smolts through a large lake as determined by radiotelemetry and Carlin tagging studies. *Can. J. Zool. 66,* 685—691.

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

Cross, T. F. & Piggins, D. J. 1982. The effect of abnormal climatic conditions on the smolt run of 1980 and subsequent returns of Atlantic salmon and sea trout. *ICES C.M. 1982/M:26,* 1—8.

Doubleday, W. G., Ritter, J. A. & Vickers, K. U. 1979. Natural mortality rate estimates for north Atlantic salmon in the sea. *ICES C.M. 1979/M:26,* 1—15.

Eken, M. & Garnås, E. 1990. Overvåking av lakseparasitten *Gyrodactylus salaris* på Østlandet 1989. Fylkesmannen i Buskerud Miljøvernavdelingen, Rapport 7, 1—47.

Hansen, L. P. 1986. Introduction of Atlantic salmon *Salmo salar* L. to the River Akerselv, Oslo. *Fauna norv. Ser. A 7,* 27—32.

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. 1990a. *Salmon ranching experiments; migration and survival of Atlantic salmon smolts (Salmo salar L.)* Dr. Philos. Thesis, University of Oslo.

Hansen, L. P. 1990b. Exploitation of Atlantic salmon *(Salmo salar* L.) from the River Drammenselv, SE Norway. *Fish Res.* (in press).

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

Hansen, L. P. & Jonsson, B. 1989. 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., Jonsson, 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., Næsje, T. F. & Garnås, E. 1986. Stock assessment and exploitation of Atlantic salmon *Salmo salar* L. in the River Drammenselv. *Fauna norv. Ser. A 7,* 23—26.

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

Holm, M., Huse, I., Waatevik, E., Døving, K. B. & Aure, J. 1982. Behaviour of Atlantic salmon smolts during seaward migration. I: Preliminary report on ultrasonic tracking in a Norwe-

gian fjord system. *ICES C.M. 1982/M:7,* 1—17.

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

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

Kennedy, G. J. A., Strange, C. D., Andersen, R. J. D. & Johnston, P. M. 1984. Experiments on the descent and feeding of hatchery-reared salmon smolts *(Salmo salar* L.) in the River Bush. *Fish. Manage. 15,* 15—25.

LaBar, G. W., McCleave, J. D. & Fried, S. M. 1978. Seaward migration of hatchery-reared Atlantic salmon *(Salmo salar)* smolts in the Penobscot river estuary, Maine: open-water movements. *J. Cons. int. Explor. Mer. 38,* 257—269.

Larsson, P. O. 1977. The importance of time and place of release of salmon on the results of stocking. *ICES C.M. 1977/M:42,* 1—4.

McCleave, J. D. 1978. Rhytmic aspects of estuarine migration of hatchery-reared Atlantic salmon *(Salmo salar)* smolts. *J. Fish Biol. 12,* 559—570.

Morgan, R. I. G., Greenstreet, S. P. R. & 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.

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

Pethon, P. 1987. Salinitetsmålinger i Drammensfjorden og Oslofjorden høsten 1987. *Direktoratet for Naturforvaltning, Forskningsavdelingen. Teknisk Notat 1,* 1—16.

Reddin, D. G. & Short, P. B. 1989. Post-smolt Atlantic salmon in the Labrador Sea. *ICES C.M. 1989/M:9,* 1—10.

Reitan, O., Hvidsten, N. A. & Hansen, L. P. 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.

Ritter, J. A. 1989. Marine migration and natural mortality of North American Atlantic salmon *(Salmo salar* L.). *Can. MS Rep. Fish. Aquat. Sci. 2041,* 1—136.

Rosseland, L. 1965. Rapport om utførte lakseundersøkelser mv. Vedlegg til Fiskeriinspektørens årsmelding for årene 1951—1962. Landbruksdepartementet, Oslo, 78 pp.

Shearer, W.M., Cook, R. M., Dunkley, D. A., MacLean, J. A. & Shelton, R. G. J. 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.

Solomon, D. J. 1978. Some observations on salmon smolt migration in a chalkstream. *J. Fish Biol. 12,* 571—574.

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

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

Thorpe, J. E., Ross, L. G., Struthers, G. & Watts, W. 1981. Tracking Atlantic salmon smolts, *Salmo salar* L., through Loch Voil, Scotland. *J. Fish Biol. 19,* 519—537.

Tytler, P., Thorpe, J. E. & Shearer, W. M. 1979. Ultrasonic tracking of the movements of Atlantic salmon smolts *(Salmo salar* L.) in the estuary of two Scottish rivers. *J. Fish Biol. 12,* 575—586.

Youngson, A. F., Hansen, L. P., Jonsson, B. & Næsje, T. F. 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.

Received 15 Oct. 1990.