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Migration and survival of farmed Atlantic salmon (*Salmo salar* L.) released from two Norwegian fish farms

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Many salmon escape from fish farms during autumn and winter, making the migratory pattern and survival to sexual maturity of these fish an interesting topic of study. This study aimed to assess the migration and survival of large farmed salmon released from fish farms at different times during autumn and winter. Farmed salmon were individually tagged with external tags and released from two fish farms, one in southern Norway and the other in northern Norway. Salmon released in autumn one year before attaining sexual maturity appeared to survive poorly to sexual maturation, whereas salmon escaping later in winter showed greater survival. The released salmon appeared to move with the current and appeared to have a very weak homing instinct, if any. Based on the results of the tagging experiments, the direction and speed of ocean currents, and information about the abundance of fish farm escapees in salmon fisheries and stocks in several countries in the Northeast Atlantic, two hypotheses are advanced: first, salmon that escape during early autumn the year before they become sexually mature are transported with the currents to Arctic areas and subsequently do not survive the winter; second, large salmon escaping from fish farms in Ireland, Scotland, the Faroe Islands, and Norway during winter and spring move with the current and, during the following summer or autumn, may enter homewater fisheries and spawning populations far away from the site of escape, when they become sexually mature.

Keywords: dispersal, escaped farmed salmon, migration, ocean currents, survival.

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Introduction

Farming of Atlantic salmon (*Salmo salar* L.) in the Northeast Atlantic has developed rapidly during the past 25 years. Currently, approximately 800 000 t of farmed salmon are produced in the North Atlantic area, with Norway and Scotland accounting for most of this production (ICES, 2005). In comparison, the total nominal annual landings of salmon in fisheries in the North Atlantic varied from 2000 to 3000 t during the last decade (ICES, 2005). These landings include a small proportion of salmon released as smolts for ranching or for stock enhancement and escapees from fish farms.

Salmon escape from fish farms at all life stages, and they are caught in oceanic, coastal, and freshwater fisheries. The escapees spawn in fresh water (e.g. Hansen *et al.*, 1987, 1999; Gausen and Moen, 1991; Lund *et al.*, 1991; Webb and Youngson, 1992; Youngson *et al.*, 1997; Crozier, 1998; Butler *et al.*, 2005), but their reproductive success is less than that of wild salmon (Fleming *et al.*, 2000).

The occurrence of escaped farmed salmon in areas of the North Atlantic, where wild salmon are present, raises several concerns. First, assessment and management of salmon fisheries and wild salmon stocks will be complicated in the presence of large numbers of farmed salmon; it is important, therefore, to identify farmed fish and adjust catch records accordingly. Second, interbreeding between farmed and wild salmon may reduce the fitness of the wild stocks (McGinnity *et al.*, 2003). Third, escaped farmed salmon may be vectors for transferring diseases and parasites to wild salmon.

Wild Atlantic salmon smolts leave fresh water in spring and move quickly into the ocean. The main feeding areas for Norwegian salmon are in the Norwegian Sea (Holm *et al.*, 2000; Hansen and Jacobsen, 2002). After living in the ocean for 1–4 years, the majority of adults return to spawn in the rivers they left as smolts (Hansen *et al.*, 1993). Most adult wild salmon enter Norwegian coastal waters between May and September. Marine survival of wild salmon is highly variable among years and stocks, and in

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the Northeast Atlantic, survival rates of wild salmon of 1–30% have been observed (ICES, 2005).

Information on the survival and migratory pattern of the escaped farmed salmon is sparse, but Hansen *et al.* (1987) demonstrated that farmed salmon tagged and released in Norway during summer were apparently "homeless", and some of the immature fish were captured north of the Faroe Islands. Farmed salmon caught in the Faroese longline fishery and tagged before release have been recaptured in Norway (Hansen and Jacobsen, 2003). Furthermore, Hansen and Jonsson (1989, 1991) observed interannual variation in migration pattern and survival of tagged hatchery-reared salmon post-smolts held in saltwater and released sequentially for one year, with poor survival of the groups released during late summer and autumn and poor homing precision of fish released during winter.

Many salmon escape from fish farms during autumn and winter, making the migratory pattern and survival to sexual maturity of farmed fish escaping at this time of the year an interesting topic of study. The purpose of this study was first, to test if large farmed salmon released from fish farms return to the release area or whether they are "homeless", and second, to test the null hypothesis that the survival of large farmed salmon is independent of the time of release. These hypotheses were tested by releasing approximately 4500 individually tagged farmed salmon from two fish farms in sequence during autumn and winter/spring and, subsequently, examining the distribution pattern and recapture rate of tagged fish based on the reported tag recoveries.

Material and methods

Groups of Atlantic salmon produced at two Norwegian fish farms were released during autumn and winter of 1993/1994. The farms are situated at Bersagel in Høgsfjord, southwest Norway, and at Meløy in mid-Norway (Figure 1). The total age of the fish was 2+ years, and they were stocked into the marine cages as 1-year-old smolts in spring 1992. The strain of salmon farmed at Bersagel originates from Norsk Lakseavl (genotypically selected over four generations for growth and late maturity by a combination of family and within-family selection) (Gjedrem *et al.*, 1991) and at Meløy from MOWI (phenotypically selected for growth and late maturity by individual selection) (T. Gjedrem, pers. comm.).

The fish were anaesthetized with chlorobutanol, tagged individually with numbered external tags (Lea tags), measured (mm; total length), and released in batches of about 500 individuals directly from the sea cages. At Meløy, four batches, 1996 fish in all, were released between 3 November 1993 and 23 March 1994 (Table 1). The mean lengths of the salmon released varied between 701 and 764 mm. At Bersagel, 2499 fish were released in five batches between 12 November 1993 and 26 April 1994. The mean lengths of these fish varied between 683 and 738 mm. All fish were immature in autumn 1993, but most were expected to mature in autumn 1994. Recaptures of tagged fish were reported by commercial fishers and anglers.

Figure 1. The geographical distribution of recaptures of tagged farmed salmon released at Bersagel. Grey and black dots are river and sea recaptures, respectively.

Results

In all, 92 (4.6%) and 116 (4.6%) of the tagged salmon released at Meløy and Bersagel, respectively, were reported to have been recaptured (Table 2). Salmon recaptured within the first 60 days after release were caught in areas close to the release sites as bycatch in fishing gear set to catch marine fish. The exception to this was the group of salmon released at Bersagel on 25 April 1994. In this case, fish recaptured 31–60 days after release were taken in gear intended to catch salmon during the legal salmon

Table 1. Details of the salmon tagged and released at the different sites.

Site	Date	Number released	Mean length in mm (s.d.)	Strain
Meløy	03 Nov 1993	500	701 (54)	MOWI
Meløy	16 Dec 1993	499	728 (58)	MOWI
Meløy	02 Feb 1994	499	747 (56)	MOWI
Meløy	23 Mar 1994	498	764 (46)	MOWI
Bersagel	12 Nov 1993	500	697 (48)	LAKSEAVL
Bersagel	17 Dec 1993	500	683 (43)	LAKSEAVL
Bersagel	18 Feb 1994	499	706 (49)	LAKSEAVL
Bersagel	25 Mar 1994	500	724 (50)	LAKSEAVL
Bersagel	26 Apr 1994	500	738 (50)	LAKSEAVL

Table 2. The number of recaptures of tagged salmon in relation to the time of release and the time period from release to recapture.

Date of release	Number of recaptures 0–30 days after release	Number of recaptures 31–60 days after release	Number of recaptures more than 60 days after release	Total number of recaptures
Meløy				
03 Nov 1993	24	1	1	26
16 Dec 1993	3	0	4	7
02 Feb 1994	17	1	9	27
23 Mar 1994	4	1	27	32
Bersagel				
12 Nov 1993	8	1	1	10
17 Dec 1993	2	0	7	9
18 Feb 1994	21	1	6	28
25 Mar 1994	22	0	18	40
26 Apr 1994	7	8	14	29

fishing season. In all other release groups, fish recaptured more than 60 days after release were taken in the commercial salmon fishery on the coast or by anglers in fresh water. The commercial marine net fishery for salmon in Norway in 1994 operated from 1 June to 5 August, and the angling season in most rivers ran from 1 June to 1 September. Fish recovered during this period are assumed to provide the most reliable information on survival and migration because of the intensity of the directed fishery for salmon at that time.

From the experiment at Meløy, 34 salmon were recaptured in commercial marine salmon nets during the salmon fishing season, and seven fish were recaptured by anglers in fresh water. Of the fish released at Bersagel, 37 were recaptured in marine nets and 17 by anglers. In general, the recapture rates were low and were extremely low for fish released in November from both farms (0.2%). The recapture rate increased with the date of release, reaching 5.5% and 3.8% for fish released in March at Meløy and Bersagel, respectively. The April release at Bersagel resulted in a recapture rate of 4.5% (Figure 2).

Of the fish tagged at Bersagel, most of the recoveries were scattered along the Norwegian coast north of the release site, and one fish tagged and released in December was recaptured in a Russian river (Figure 1). From the Bersagel tagging, there were also several recaptures to the southeast of the tagging site. These fish were mainly tagged in March. One of these fish was recaptured in a net on the Swedish west coast. There was no indication of homing behaviour in the fish released at Bersagel, with salmon released from this farm recaptured in marine commercial fisheries over large areas of the coast; most tagged fish that had entered fresh water to spawn were recaptured in rivers distant from the release site (Figure 1). The recaptures of tagged fish released at Meløy were reported close to, or north of, the tagging site (Figure 3). Of the recaptures in fresh water of fish released at Meløy, three salmon were

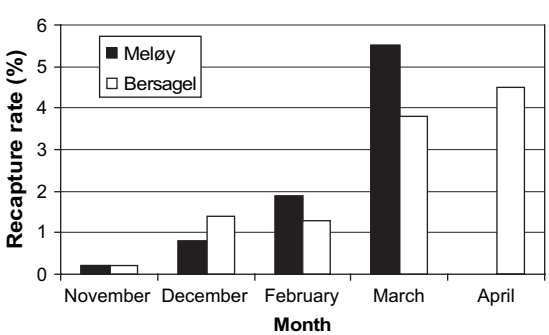

Figure 2. Recapture rates of farmed salmon released from two fish farms in Norway.

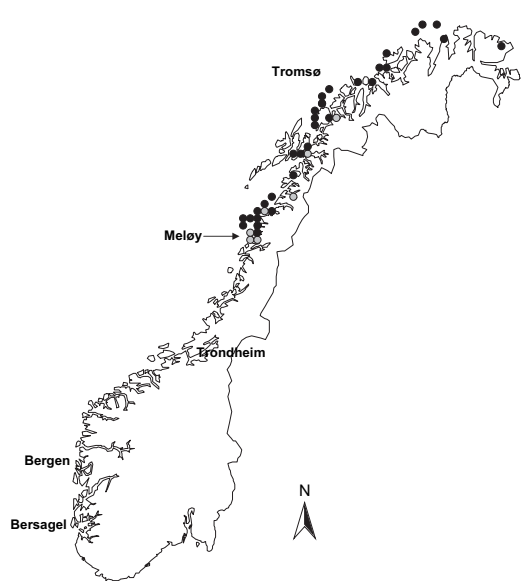

Figure 3. The geographical distribution of recaptures of tagged farmed salmon released at Meløy. Grey and black dots are river and sea recaptures, respectively.

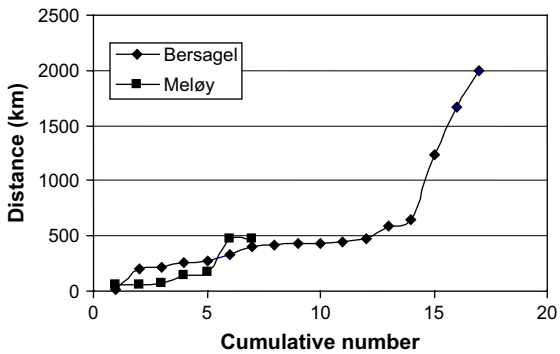

Figure 4. Distance from the site of release to rivers of recapture for tagged farmed salmon.

recaptured in rivers relatively close to the release site and four fish in more distant areas north of Meløy. Most salmon released at Bersagel were recaptured in rivers more than 250 km away, with one individual recaptured 2000 km north of the release site (Figure 4). The salmon released at Meløy were recaptured in rivers up to 500 km away (Figure 4).

The main ocean currents in the Northeast Atlantic are shown in Figure 5 (redrawn from Aure *et al.*, 1999). There is a strong current along the west coast of Ireland and Scotland moving northeastwards towards the Norwegian coast and running northwards with branches into the Norwegian Sea and the Barents Sea. There is also a branch moving towards the Skagerrak. When the distribution of tag recoveries is compared with the direction of these currents, it appears that the currents are the factors determining the dispersal and movement of the released salmon.

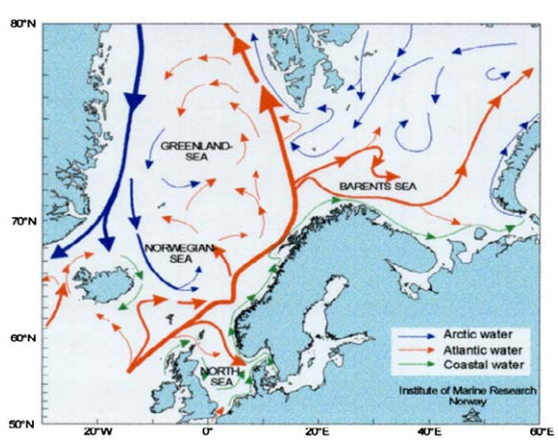

Figure 5. The dominant surface currents in the study area. Current directions, strength, and water types are represented by arrows of different width (the wider the arrow, the stronger the current) and appearance. Data from the Institute of Marine Research, redrawn from Aure *et al.* (1999).

Discussion

Farmed salmon occur in large numbers in Norwegian coastal commercial salmon fisheries. The abundance is relatively low in fisheries in fjords and fresh water, but higher in spawning populations (Fiske *et al.*, 2006). It has been suggested that these differences reflect the failure of the farmed salmon to home, and because the fish have no home rivers, they have no motivation to enter fjords and fresh water until later in summer, when they approach sexual maturity (Lund *et al.*, 1991). The incidence of escaped farmed salmon in the Norwegian Sea north of the Faroe Islands can be high (Hansen *et al.*, 1999), and tagging experiments have demonstrated that farmed salmon released in Norway can be found in this area (Hansen *et al.*, 1987). Results from the monitoring of salmon fisheries in Scotland, Ireland, and Northern Ireland have suggested a much lower proportion of farmed salmon in catches than has been found in Norway (Webb and Youngson, 1992; Youngson *et al.*, 1997; Crozier, 1998; ICES, 2000; Butler *et al.*, 2005). The proportion of escaped farmed salmon in relation to nominal salmon catches in several countries is shown in Table 3 (ICES, 2000). It should be noted, however, that the different monitoring methods used and the different geographical locations of the farms relative to salmon rivers may make it difficult to compare the data between countries.

Salmon that were released at Bersagel were recaptured along the coast in marine fisheries and rivers, both to the north and to the southeast of the release site. One fish was captured in the Russian River Tuloma, approximately 2000 km away. Based on the results of the experiment at Bersagel, the hypothesis that large salmon, escaping from fish farms during winter, return to the area from which they escaped is rejected because the salmon appeared to be "homeless". This conclusion is supported by the geographical distribution of recaptures during summer and autumn in both marine and fresh water and by the considerable distances from the release site to the rivers

Table 3. Proportion of escaped farmed salmon in fisheries in different countries in relation to nominal salmon catch (ICES, 2000).

Year	Norway	Faroes	Ireland	N. Ireland	Scotland
1989	22				
1990	23				
1991	22	42	0.4	1.8	3.0
1992	23	34	0.6	1.2	5.2
1993	23	27	0.4	0.2	5.7
1994	21	17	0.3	0.5	0.8
1995	22	20	0.1	1.8	0.3
1996	28	20	0.2		0.2
1997	31		0.2	0.1	0.3
1998	28		0.3	0.0	0.4
1999	24		0.4	1.3	0.5

in which the fish were recaptured. All recaptures of fish released at Meløy were north of the release site. There was no consistent evidence that salmon were homing to rivers close to the release sites, although three of the seven tagged salmon recaptured in rivers were reported relatively close to Meløy. The distances travelled by the seven salmon released at Meløy and recaptured in rivers were similar to the seven shortest distances travelled by fish released at Bersagel. That several salmon released at Bersagel were recaptured farther from the release site than fish released at Meløy may be explained, in part, by the greater length of coastline to the north of Bersagel, along which there are directed fisheries for salmon. An alternative explanation may be that not all the fish released at Meløy left the fjord areas, or they left at different times. This could explain the recaptures relatively close to the release sites. Fiske *et al.* (2006) observed a significant relationship between fish farming activity and the abundance of farmed fish in nearby rivers, which appears contrary to the findings presented here. However, the transfer of smolts to marine cages often results in escapes. Farmed salmon escaping at the smolt stage tend to home to the coastal area from which they escaped and enter nearby rivers (Hansen *et al.*, 1989; Hansen and Jonsson, 1991), which may explain the observations by Fiske *et al.* (2006).

Wild salmon leave their home rivers as smolts in spring and move quickly into oceanic areas (e.g. Holm *et al.*, 1982). In the Northeast Atlantic, results from smolt-tagging experiments and post-smolt surveys have strongly indicated that ocean currents transport the fish northwards (Jonsson *et al.*, 1993; Shelton *et al.*, 1997; Holst *et al.*, 2000). Based on the current systems in Norwegian coastal and Atlantic water, the geographical distribution of the recaptures suggests a similar conclusion.

Smolts imprint, i.e. learn cues, sequentially on their way from the river to the sea and use that information for homing on the return migration (e.g. Hansen *et al.*, 1993). The homeward migration may be divided into two phases: an oceanic phase with fast movement from the ocean to coastal areas and a slower migration from coastal areas, to the natal river. Hatchery-reared salmon released as smolts in fresh water have a migratory pattern similar to that of wild salmon (Hansen *et al.*, 1993). Even hatchery-reared smolts released directly into the sea tend to return to the same marine area from which they were released (Carlin, 1969; Sutterlin *et al.*, 1982; Hansen *et al.*, 1989), but because they were not released into fresh water, they enter any river in that area to spawn.

The null hypothesis that the survival of large farmed salmon was independent of the time of escape is rejected. Some fish were recaptured as bycatch in fisheries for marine fish species close to the release site during the first few weeks after release. Interestingly, several of these fish were reported from nets set at depths of at least 100 m. Later, the fish were taken in variable numbers in commercial and recreational fisheries for salmon, dependent on the time of release. The reported recapture rate in these fisheries for the groups released during autumn was extremely low, but it increased with the date of release, suggesting that the closer to maturity the fish are when they escape, the higher the probability of survival to maturity. Note that this pattern was similar for the two areas.

The time of smolting, usually a period of about one month in spring, coincides with conditions favourable for survival of smolts in the sea (e.g. Hansen and Jonsson, 1989; McCormick *et al.*, 1998). Similarly, hatchery-reared salmon smolts released from a marine site at the time of the wild smolt run tended to survive relatively well, and they returned to the same area from which they were released and entered local rivers in that area to spawn (Hansen and Jonsson, 1991). Tagged hatchery-reared salmon post-smolts, reared in salt water and released sequentially for one year, showed annual variation in both survival and homing precision, with poor survival of the groups released in late summer and autumn and poor homing precision of fish released in winter (Hansen and Jonsson, 1989, 1991). A release of tagged, large farmed salmon early in summer, a few months before spawning, indicated that the recaptured fish tended to move north with the current, and when they were ready to spawn, they entered fresh water in that area. They appeared not to have a homing instinct (Hansen *et al.*, 1987).

The results from the present experiment suggest that large salmon escaping from fish farms show migration and survival patterns similar to those of cultured post-smolts released at monthly intervals from a marine site (Hansen and Jonsson, 1989, 1991). Salmon that escape from fish farms during autumn survive less well than fish released during winter or early spring. The fish released at Meløy were recaptured in the sea, as well as in fresh water north of the release site, as were most of the fish released at Bersagel. Some of the fish from the latter group were recaptured in areas southeast of the release site and entered fresh water in this area. Assuming that fish entering fresh water had made their final decision about where to spawn, it can be concluded that the farmed salmon in the present experiment were not imprinted to any particular river or marine site, and therefore, could be regarded as "homeless".

The distribution and direction of migration of the farmed salmon could be explained by transportation with the currents. If so, this may also explain why so few fish released in November and December were recovered. These fish may have been transported with the currents so far to the north that, when they attained sexual maturity, they were either too far from the coast to detect fresh water or they did not survive in the cold Arctic water. Fish released closer to maturation might have a higher probability of entering fresh water to spawn than fish released in the year before they mature, but the relatively low recovery rates of these fish (<6%) suggest that significant numbers of them also died. Marine mortality of wild and hatchery-reared salmon is great at the post-smolt stage in the first weeks or months after they leave their home river. The salmon in the present

study were large, in their second year at sea, and this may have protected them from significant predation. Wild adult salmon, however, are not normally present along the Norwegian coast during winter; the first adult returns appear in late April and early May. Based on the results from this study, it is proposed that salmon that escape during early autumn, in the year before they become sexually mature, are transported with the currents to Arctic areas and, subsequently, do not survive the winter.

On the other hand it is suggested that fish farm escapees from the Faroe Islands, Ireland, and Scotland are transported with the currents, and fish that become sexually mature when they are close to coastal areas may occur in Norwegian and Russian fisheries and enter salmon rivers to spawn. Under the same hypothesis, some fish farm escapees from Norway may enter Swedish and Russian rivers, escapees from Ireland may enter fisheries and salmon rivers in Northern Ireland and Scotland, and some Irish and Scottish escapees may even enter rivers in Sweden and Denmark. To test this hypothesis ICES and NASCO have recommended that a coordinated release experiment of individually tagged, large farmed salmon should be carried out in the Northeast Atlantic by those countries with a fish farming industry.

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