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Origin and migration of wild and escaped farmed Atlantic salmon, *Salmo salar* L., in oceanic areas north of the Faroe Islands

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We examined the distribution, migration and origin of wild and escaped farmed Atlantic salmon, *Salmo salar* L., in the northeast Atlantic ocean north of the Faroe Islands based on individual tagging of salmon in this area. Recoveries of wild salmon were reported from homewaters in nine north Atlantic countries, and in a number of different rivers throughout the distribution range of Atlantic salmon. Most tags were recovered in Norway, but relatively large numbers of returns were observed in Scotland and Ireland as well. No fish were recaptured at Faroes. Fish tagged in the autumn tended to return to areas closer to the tagging site than fish tagged in the winter. This strongly suggests that salmon originating from most areas of the distribution range are at some life stage present in this area, but in variable proportions at different times. Most of the salmon returned home to spawn the next autumn, and the fish that stayed for another year originated from northern areas of Europe. All recoveries of farmed salmon were in Norway except one on the west coast of Sweden, suggesting that they could have escaped mainly from Norwegian fish farms. Assessment of the proportion of wild salmon from different countries present north of the Faroe Islands revealed that 40% of the fish were of Norwegian origin, and Scotland and Russia accounted for about 20% each. Four tags of wild fish were reported from Canada, all in the same year they were tagged. This demonstrates that adult Atlantic salmon can cross the north Atlantic ocean in less than 6 months.

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Keywords: farmed salmon, migration, ocean, tagging, wild salmon.

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Introduction

Atlantic salmon are distributed over large areas in the northeast Atlantic. Inside the Faroes Exclusive Economic Zone (EEZ) salmon have been exploited for a relatively long period of time (Jákupsstovu, 1988), but for several reasons (buy-out of quotas, low abundance and low first sale values of salmon) the fishing effort has been very low, or even absent in recent years. The fishery exploits mainly two-sea-winter (2SW) fish, although some 1 and 3SW fish are also caught. Recaptures at Faroes of salmon tagged as smolts in different countries have revealed that salmon from many countries are present in the area (Jacobsen *et al.*, 2001), but no quantitative analysis of stock distribution has been carried out. From results of tagging experiments in home waters there is direct evidence that salmon of different smolt year classes originating from different areas in Norway, Scotland and Sweden are caught side by side during the same time period in the same area (Hansen, 1993). Most of the recaptures of tagged salmon, however, originated from hatchery reared smolts.

A tagging experiment at sea around the Faroe Islands was carried out during the period of 1969 to 1976 (Jákupsstovu, 1988). Most of the salmon tagged were small (1SW), and thus may not reflect the composition of stocks in the area. Most recaptures of the tagged fish

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were reported from Scotland and Norway, and there were also several fish recovered from Ireland.

In recent years, large numbers of farmed salmon have been observed at Faroes, accounting for a significant proportion of the Faroese salmon catch. In the first half of the 1990s, the proportion of farmed fish in this area was estimated at between 25 and 40% (Hansen *et al.*, 1999). There is direct evidence that farmed salmon escaping from net pens in Norway enter this area (Hansen *et al.*, 1987), but no information on the movement and survival of these fish in the ocean.

It has been suggested that marine environmental factors influence distribution, movement and survival of Atlantic salmon (Reddin and Friedland, 1993). There is large variation in survival between different smolt year classes, and in the last few years a significant decline in marine survival as well as growth of salmon has been observed for many stocks. This has been proposed to be related to cooling of the sea surface (Friedland *et al.*, 1993, 2000).

For the management of salmon in the ocean it is of great importance to understand salmon marine life history and dynamics, as well as the temporal and spatial population structure. In this paper, we examined the origin and migration of wild and escaped farmed salmon utilizing the Faroese area during parts of their oceanic feeding phase.

Material and methods

As a part of a salmon research project in the northeast Atlantic Ocean at Faroes from 1992 to 1995, wild and farmed Atlantic salmon were tagged and released back into the sea. The salmon were caught north of the Faroe Islands using commercial floating long-lines carrying about 2000 hooks, that were baited with sprat (*Sprattus sprattus*). The lines were usually set early in the morning, hauling started approximately at noon and was completed between 5 and 10 h later. The fishing took place between November and March of 1992/93, 1993/94 and 1994/95. The area fished during the autumn (November–December) was closer to the Faroes than the area fished in the winter (February–March) (Figure 1).

Immediately after capture, the salmon that were subjectively judged to have a fair probability of survival were individually tagged with numbered Lea tags. The fish were measured (fork length) and a few scales were removed from the dorso-lateral area as recommended by Shearer (1992). If possible, the hook was removed, but in cases where removal could seriously damage the fish, it was left in the fish. The salmon were kept in a tank with a continuous inflow of seawater onboard the vessel to allow the fish to recover after handling and tagging. If the fish appeared fit by visual inspection, it was released.

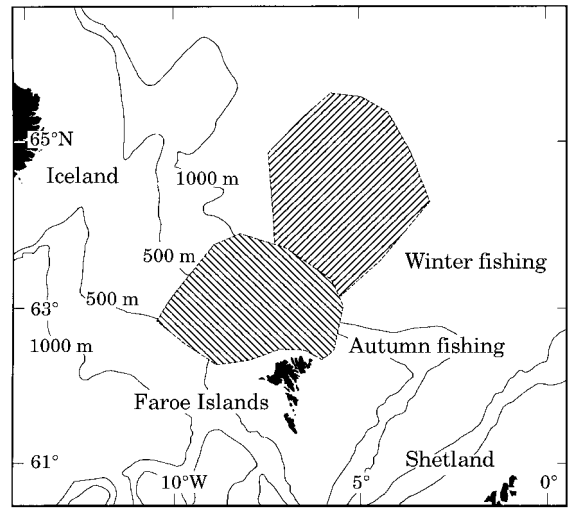

Figure 1. Areas of tagging north of the Faroes. The autumn fishery is located closer to the isles and as the season progresses the fishery moves in a northeastern direction farther into the Norwegian Sea.

Table 1. Number of wild and escaped farmed salmon tagged and released by month in Faroese waters November 1992 to March 1995.

Month	No. wild salmon	No. farmed salmon	Total
November 1992	469	212	681
December 1992	204	62	266
March 1993	1311	793	2104
November 1993	126	50	176
December 1993	102	41	143
February 1994	80	26	106
March 1994	132	57	189
November 1994	392	106	498
December 1994	149	36	185
February 1995	311	100	411
March 1995	535	154	689
Total	3811	1637	5448

All fish were categorized as wild or farmed origin by examining whether they showed external characters like fin erosion which is common on reared salmon (Lund *et al.*, 1989), and by analysis of scales (Lund and Hansen, 1991). In total, 3811 wild and 1637 farmed salmon were tagged and released (Table 1), and Figure 2 shows that length distributions in the autumn and winter of both groups of fish were similar.

The sea age of wild salmon was estimated by splitting the length frequencies into sea age cohorts (see e.g. ICES, 1996), i.e. fish less than 57 cm fork length were taken to be one sea winter (1SW), fish between 57 and 82 cm fork length were taken to be 2SW, and fish larger than 82 cm were 3SW. Among the wild salmon, 2SW

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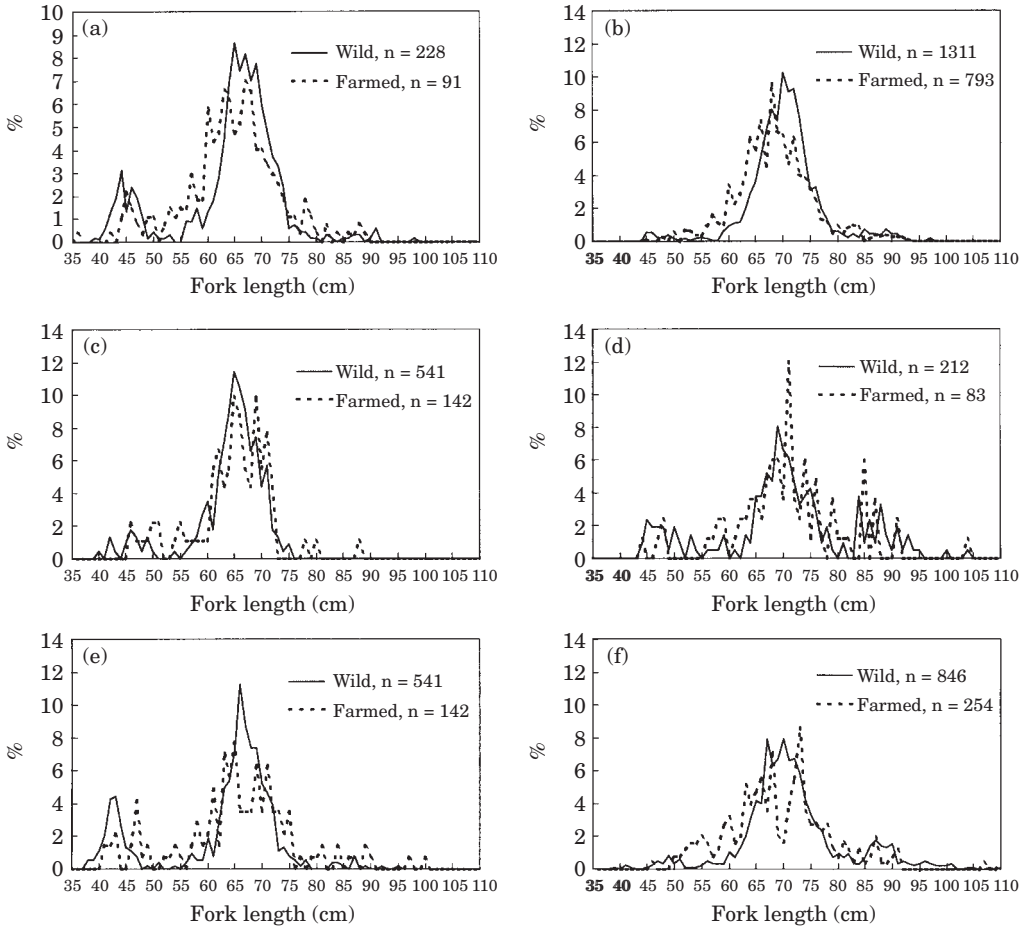

Figure 2. Fork length distributions of wild and farmed salmon tagged north of the Faroes during three fishing periods 1992/93–1994/95. The fishing period is divided into an autumn (November–December) and winter (February–March) season.

fish are the dominant sea age group accounting for more than 80% of the wild fish tagged (Figure 3). It should be noted that the incidence of 1SW fish was more pronounced in the autumn than in the winter, whereas 3SW fish occurred in a higher proportion in the winter.

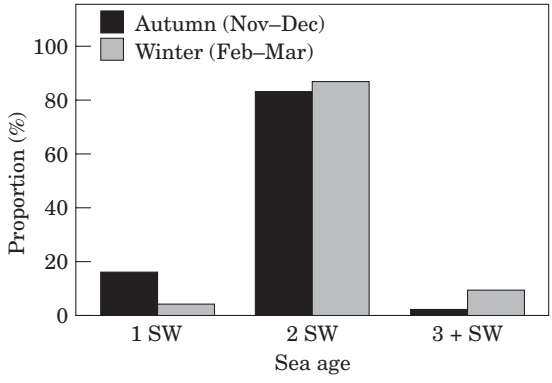

Figure 3. Estimated sea age distribution of wild Atlantic salmon tagged north of the Faroes by season. Total number of observations is 3811 fish.

Tags were reported by commercial fishermen operating in home waters, and from anglers in rivers, and they were asked to submit information about date, time and site of recapture, the size of the fish and the gear used for catching the fish. The distance between tagging and recapture site (migration distance) was estimated using the shortest distance (straight line between the two sites), and are thus minimum distances.

To estimate the origin of wild salmon in this area we corrected the observed number of recaptures by country with their respective mean exploitation rates in homewaters (ICES, 1996). The recaptures from each country were also adjusted for their respective homewater tag reporting rates (ICES, 1998). Monte Carlo simulations (1000 simulations using the Excel add-on "@Risk", Palisade Corp. NY, USA, www.palisade.com) were used to estimate 95% confidence limits on the estimated proportion of fish returning to different countries. This

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Table 2. Reported recapture rates of salmon in number (% in brackets) tagged at Faroes in the autumn (November–December) and winter (February–March).

Season	Wild	Farmed	Total
Autumn 1992	11 (1.6)	1 (0.4)	12 (1.3)
Winter 1993	36 (2.7)	8 (1.0)	44 (2.1)
Autumn 1993	3 (1.3)	1 (1.1)	4 (1.3)
Winter 1994	5 (2.4)	2 (2.4)	7 (2.4)
Autumn 1994	7 (1.3)	1 (0.7)	8 (1.2)
Winter 1995	25 (3.0)	6 (2.4)	31 (2.8)
Total	87 (2.3)	19 (1.2)	106 (1.9)

was done by introducing a uniform 10% error bound on the mean exploitation rates, and assuming a uniform distribution of the respective exploitation rates between the lover and upper bounds provided from each country. Furthermore, an uncertainty due to the low number of recaptures was introduced by simulating draws from a binomial distribution with a probability calculated from the actual number recaptured from each country to the total number of releases. Farmed salmon were excluded from the analysis.

Results

The overall reported recapture-rate of the number of salmon tagged was small, only 106 fish were recovered which is 1.9% of the number of salmon tagged. Of wild fish 87 individuals (2.3% of the number tagged) were recaptured, whereas 19 (1.2%) of the fish identified as fish farm escapees were recovered (Table 2). The recapture rate of fish of farmed origin was significantly lower than for wild fish ($\chi^2=6.8$, d.f.=1, $p=0.009$). For both wild and farmed salmon, the recapture rates were lower for fish tagged in the autumn than in winter ($\chi^2=7.3$, d.f.=1, $p=0.007$). Tags were reported from many countries in the North Atlantic (Table 3), both from marine fisheries and in freshwater. No tags were recovered by the research vessel at Faroes or from West Greenland.

The recapture rate of wild salmon increased significantly with sea age at tagging (Figure 4) ($G=15.4$, d.f.=2, $p<0.001$). However, the power of the test might be questioned, as only two 1SW fish were recovered, but the recapture rate of 3SW was significantly higher than of 2SW fish ($\chi^2=10.6$, d.f.=1, $p=0.001$).

The recapture rates of fish with the hook left in when released were significantly higher than of fish with no hook when released ($\chi^2=7.5$, d.f.=1, $p=0.006$), which might indicate that for some of the fish, the removal of the hook prior to release, was lethal.

In wild fish, there was an apparent difference in the geographical distribution of recaptures of fish tagged and released in the autumn (Figure 5) and the winter (Figure 6). Fish tagged in the autumn were recaptured relatively close to the site of release, in southern Norway, Scotland, Ireland and Iceland, whereas fish tagged in the winter were also recaptured in more distant areas such as Russia, northern Norway, Sweden, Denmark and Spain and Canada. This suggests that fish from distant areas are more abundant in the Faroese area in the winter than in the autumn. Tag returns were scattered over large areas of Norway and Scotland suggesting that fish over wide geographic areas of these countries were present in the same areas at Faroes. Tag recaptures were also reported from major salmon rivers in these countries such as the Numedalslågen, Drammenselv, Gaula, and Namsen in Norway; Spey, Brora, Tay, North Esk, and Dee in Scotland.

Four tags were reported from Canada, one tagged in March 1993 and recaptured in River Miramichi in September 1993, three tagged in February/March 1995 and of those two subsequently recaptured in the Miramichi in September 1995 and one in Kouchibouguac River (close to the Miramichi) in October 1995. These salmon crossed the north Atlantic ocean in 6 months or less.

Of the 19 fish farm escapees recaptured, 18 were recovered from Norway, and one from the west coast of Sweden (Table 4). The geographical position of the recaptures demonstrates that the fish were distributed over a wide area of coastal Norway (Figure 7).

Overall estimates of the proportion of wild salmon originating from different countries in the research fishery during these three fishing periods are presented in Table 5 together with the assumptions and approximations made. It is not surprising that Norway accounts for the major proportion (40%), whereas the mean estimated proportion of salmon from Scotland and Russia is close to 20%. The estimates indicate that there are only a relatively small number of fish from other countries in the area. No similar analysis was carried out for the farmed fish, but under the assumption that escaped farmed salmon tend to return to the area from where they escaped, the great majority appear to be of Norwegian origin.

Of the wild fish tagged and released, 7 individuals of a total of 87 fish recaptured in home waters (8.0%), stayed for an additional year in the sea before returning to home waters (Table 3). These fish grew 10–22 cm in length until they were recaptured more than one year after they were tagged. Five of these fish originated from Norway, one from Sweden and one from Russia. They were all tagged as 2SW fish, and thus they returned home as 3SW fish. The recaptures from the mid and southern part of Europe returned home during the same season they were released. Two of the 19 farmed fish fish recaptured (10.5%) stayed for an additional year in the sea.

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Table 3. Recaptures in number of wild salmon in different countries tagged in the Norwegian Sea, north of the Faroes during the 1992/1993, 1993/1994 and 1994/1995 fishing periods. Rec.=recapture.

Country	Tagged 1992/1993		Tagged 1993/1994		Tagged 1994/1995		Total	
	Rec. 1993	Rec. 1994	Rec. 1994	Rec. 1995	Rec. 1995	Rec. 1996	No.	%
Norway (NO)	23	2	2		17	3	47	54.0
Scotland (SC)	8		1		3		12	13.8
Ireland (IR)	3		2		4		9	10.3
Russia (RU)	1	1	3		1		6	6.9
Sweden (SW)	2	1			1		4	4.6
Canada (CA)	1				3		4	4.6
Denmark (DE)	2						2	2.3
England (EN)	1						1	1.1
Iceland (IC)	1						1	1.1
Spain (SP)	1						1	1.1
Total	43	4	8	0	29	3	87	99.8

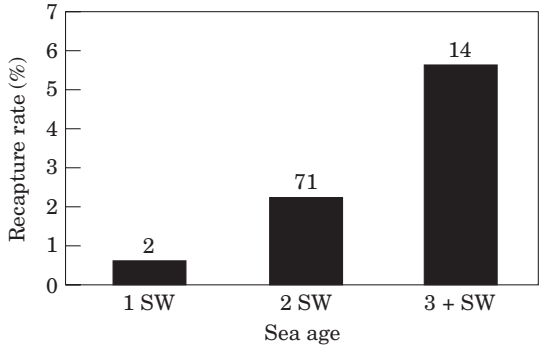

Figure 4. Recapture rates by sea age of wild salmon tagged and released north of the Faroes during 1992/1993–1994/1995. The figures show the number of observations.

Most of the fish were recaptured between 3 and 11 months after release, ranging from 48 days for a Scottish 2SW wild salmon (tagged 17 March and recaptured 1 May 1993) to nearly two years for a Norwegian 2SW wild salmon (Figure 8). The shortest journey home was made by a salmon homing to the west coast of Norway (600 km), and the longest migration distance was to Canada (4500 km), estimated from a straight line between site of tagging and recapture.

Discussion

Fish that were tagged in the winter seemed to have survived better than fish tagged in the autumn. There may be several explanations for this. Firstly, the fish that were tagged in the autumn were smaller than those tagged in the winter, and may thus be more vulnerable to handling and tagging stress (Fowler and Stobo, 1999) and subsequent size selective predation. Secondly, these fish spent more time in the sea than fish tagged in the winter, and may thus become exposed to marine mortality factors for a longer period of time. Furthermore, based on analyses of smolt age and sea age distribution of salmon at Faroes, Jacobsen *et al.* (2001) suggested that fish originating from rivers in middle and southern Europe were more abundant in the Faroese area in the autumn than in winter. If this holds true, we cannot rule out the possibility that the apparent differences in survival reported in the present paper may reflect a trend observed in the last decade, that marine mortality rates of salmon stocks from southern Europe have increased more quickly than for salmon from northern regions in the Atlantic (Parrish *et al.*, 1998; ICES, 1999).

The relatively low recapture rate of wild salmon (2.3%) in the present sea tagging experiment compared with the previous sea tagging project in the Faroese area (4.6%) (Jákupsstovu, 1988) might further indicate a decrease in marine survival. However, in recent years significant reductions in fishing effort have been made both at Faroes as well as in home waters which have overall reduced exploitation rates (ICES, 1999).

Atlantic salmon home to the rivers they left as smolts (e.g. Thorpe, 1988; Hansen *et al.*, 1993). Thus, it is reasonable to conclude that salmon tagged at Faroes and subsequently recaptured in fresh water are most likely to have returned home. It is also reasonable to assume that most salmon caught in coastal areas in homewaters have returned to their country of origin.

The distribution of the tag recoveries tells us about the origin of salmon in the Faroese area where tagging took place. The estimated proportions of salmon from different countries in the research fishery show that Norwegian salmon stocks account for the major part of the stock complex, although there are also significant numbers of Scottish, Russian and Irish salmon. Because 1SW fish account for most of Irish salmon runs, the apparent high handling and tagging mortality of the 1SW salmon released may lead to underestimation of their contribution north of the Faroes. This is further supported by the observed presence of many micro-tagged 1SW salmon of Irish origin reported from the

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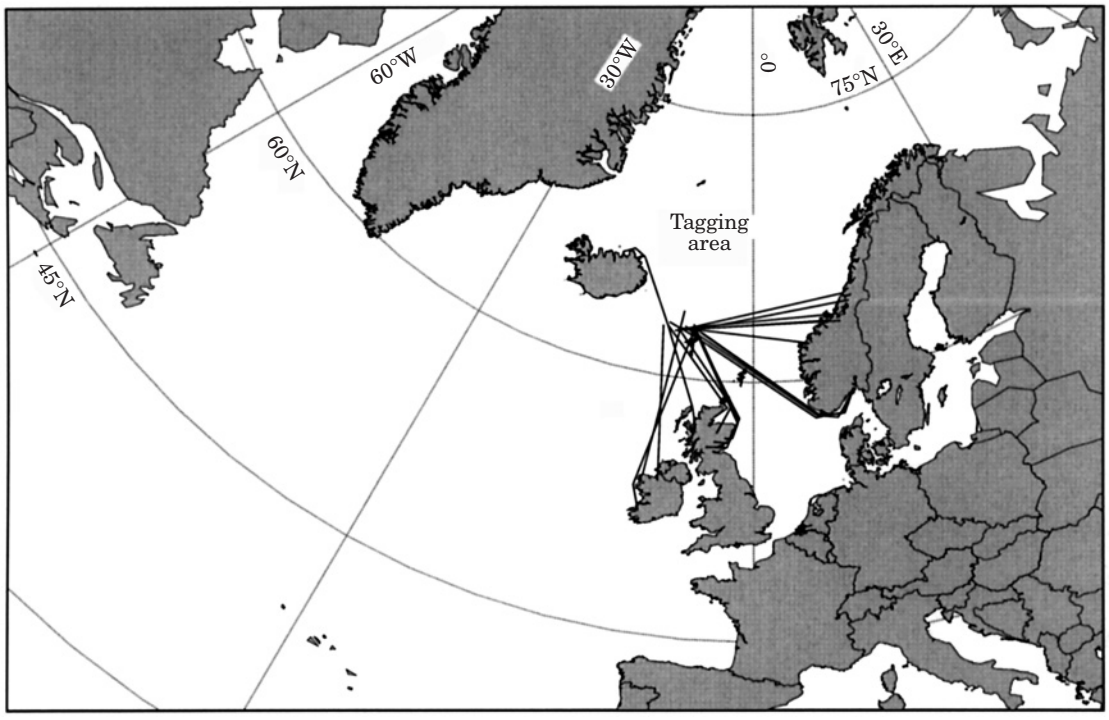

Figure 5. Geographical distribution of wild salmon tagged and released north of the Faroe Islands in the autumn and recaptured in home waters. The lines indicate the shortest direct migration route home.

Faroes fishery during autumn (Jacobsen *et al.*, 2001). All in all, the geographical distribution of tag returns to homewaters, strongly suggests that fish from most areas of the distribution range of Atlantic salmon at some life stage are present in the Norwegian Sea area north of the Faroe Islands. This does not mean that all stocks are systematically abundant in the area, but pass through occasionally, or that components of stocks use the area for feeding. This is supported by the fact that tagged wild fish were recovered in Canada, Spain and eastern part of European Russia, as well as in all major salmon producing countries in Europe.

Over 90% of the fish recaptured were reported from homewaters the same season that they were tagged, and relatively few fish stayed in the ocean for another year. This shows that a large proportion of the salmon in the area was indeed sexually maturing the next autumn. This figure is an overestimate as fish that stay in the ocean for another year are subjected to a higher natural mortality than fish that returned home one year earlier. Indirect estimates of the incidence of maturity of salmon caught in the Faroes fishery in 1982 and 1983 suggested that 80% of the multi sea winter (MSW) fish were maturing (ICES, 1984), which corresponds to the figure in the present paper. Fish that stayed for another year in the ocean were of northern origin (Norway, Sweden and Russia). The sample size was relatively small, but fish from the northern countries may stay in the north east Atlantic during the marine phase, whereas fish from mid and southern Europe stay in the area for a limited time arriving from other oceanic areas. As support for this, it has been shown that fish from south and mid Europe are much more abundant at Greenland than fish from the northern countries (Jensen, 1980a).

The distribution of salmon at Faroes has been assessed earlier from sampling the fishery over a number of years. Some of the results have been reported by Jákupsstovu (1988), who also reported on results of a tagging programme during the period 1969 to 1976 where in total 1946 salmon caught on long line were tagged and released back into the sea. A total of 90 recaptures were reported, 33 in Scotland, 31 in Norway and 15 in Ireland suggesting that salmon from these countries were most abundant around Faroes, followed by England/Wales (5), Sweden (2), Russia (1), and 3 tagged at West Greenland. These results are somewhat different from those in the present study, and the main reason for this may be that the previous tagging study was conducted relatively close to the Faroes, and south of the islands. Also the fact that most of the salmon tagged were 1SW fish (85% of the total number tagged), whereas the present tagging experiment was conducted further north on mainly 2SW salmon (80%). The size distribution of salmon in the area north of the Faroes generally increases with latitude (Jákupsstovu, 1988; ICES, 1996).

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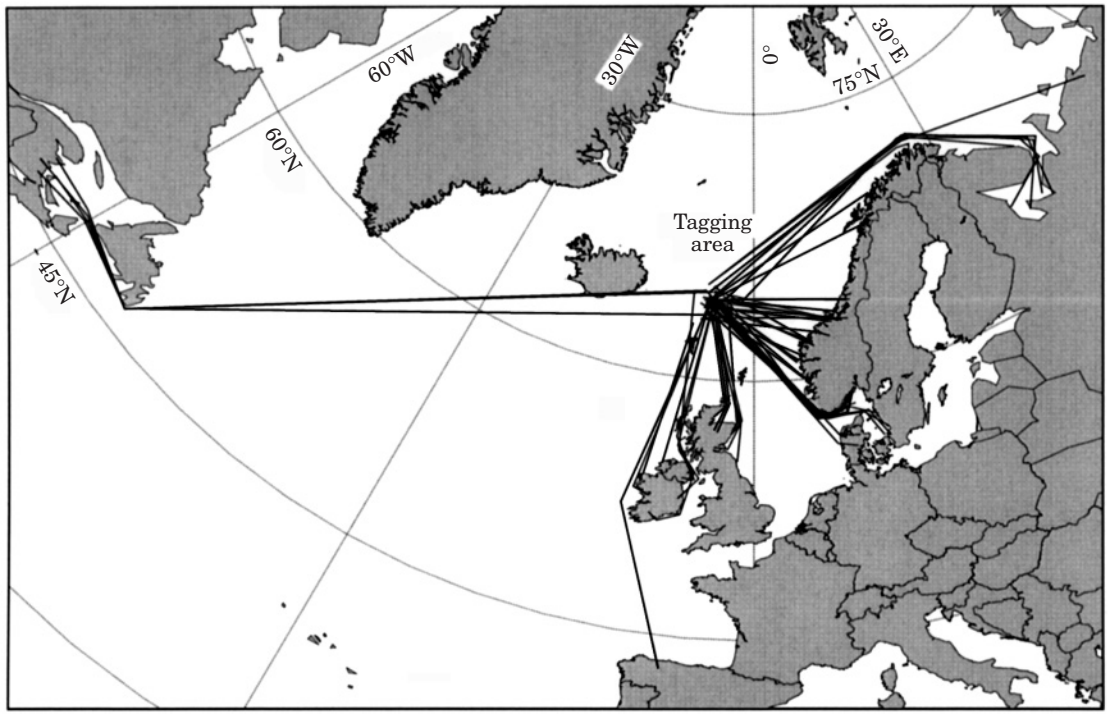

Figure 6. Geographical distribution of wild salmon tagged and released north of the Faroe Islands in the winter and recaptured in home waters. The lines indicate the shortest direct migration route home.

Table 4. Number of escaped farmed salmon recaptured by country. The fish were tagged at Faroes during the 1992/93, 1993/94 and 1994/95 fishing periods. Rec.=recapture.

	Tagged 1992/1993		Tagged 1993/1994		Tagged 1994/1995		Total	
Country	Rec. 1993	Rec. 1994	Rec. 1994	Rec. 1995	Rec. 1995	Rec. 1996	No.	%
Norway	8	0	3	0	5	2	18	94.7
Sweden	1	0	0	0	0	0	1	5.3
Total	9	0	3	0	5	2	19	100.0

Some of the fish tagged during 1969–1976 (Jákupsstovu, 1988), apparently were on their way westwards, as they were reported from West Greenland later the same year. Conversely, salmon tagged at West Greenland have been reported in the area north of the Faroes the following year (ICES, 1984). From this it may be suggested that salmon of European origin may move through the Faroese area on their way to the feeding areas in the west Atlantic as well as on their way home. The fact that there were no tag returns in Greenland from the present experiment is probably caused by the very significant reduction in the fishing effort in this area in recent years (ICES, 1996), and that the proportion of salmon of European origin in this area has declined considerably (Reddin and Friedland, 1999). Furthermore, it is well known that MSW fish of European origin are present at both west and east Greenland (Jensen, 1967; Swain, 1980; Jensen and Lear, 1980; Jensen, 1980a, 1980b; Horsted, 1988; Scarnecchia, 1989), although the proportion of European salmon relative to North American salmon at West Greenland has varied between 25% and 66% during the period 1969–1997, with a general decrease in the incidence of European fish in recent years (Reddin and Friedland 1999).

The abundance of farmed fish in the ocean has been relatively high in recent years (Hansen *et al.*, 1999). In several countries a large salmon farming industry has developed, particularly in Norway and Scotland, which account for most of the production (540 000 tonnes in 1998) in the North Atlantic (ICES, 1999). Escapees of farmed fish have been observed in several areas in the north-east Atlantic, and contribute to a relatively large extent to salmon fisheries in Norway and Faroes.

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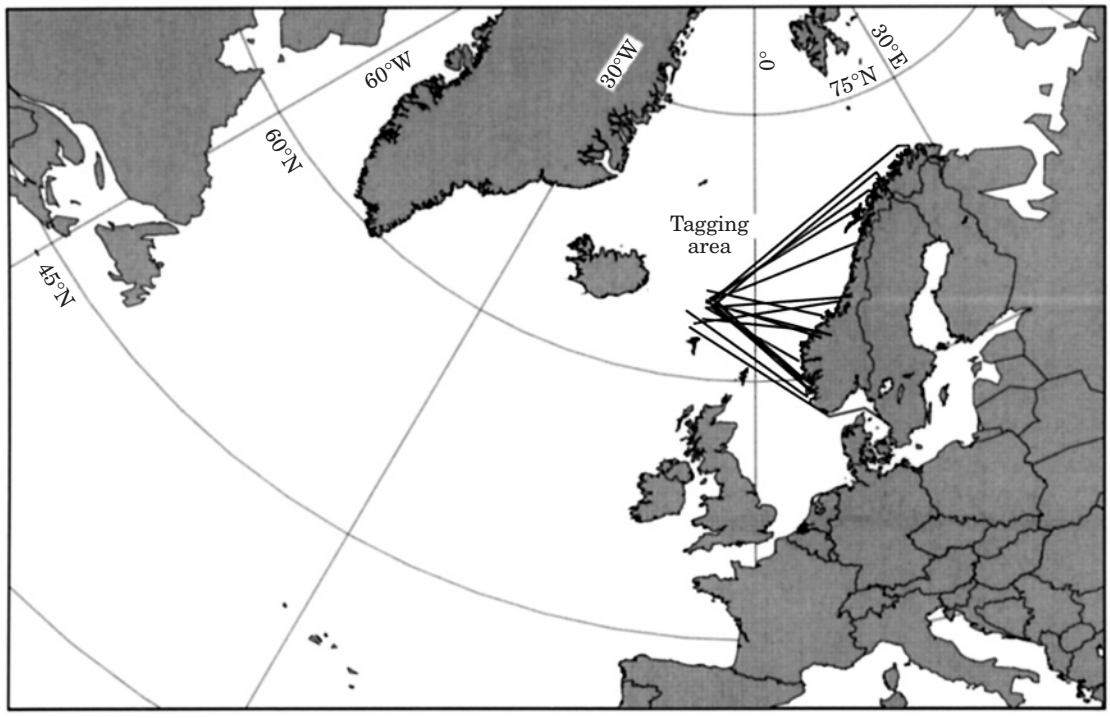

Figure 7. Geographical distribution of escaped farmed salmon tagged and released north of the Faroe Islands in the autumn and winter and recaptured in home waters. The lines indicate the shortest direct migration route home.

Table 5. Results of the Monte Carlo simulation (''@Risk'') to estimate the proportion (%) of fish tagged at Faroes returning to different countries. Confidence limits (95%) were based on 1000 simulations. Recoveries were adjusted for homewater exploitation rates and tag reporting rates (ICES, 1998).

Country	Number recaptured	Tag reporting rate		Exploitation rate		Estimated number recaptured	Simulation		
		Min	Max	Min	Max		'−5%	Mean (%)	'+95%
Norway	47	0.40	0.60	0.50	0.80	145	27.2	39.6	51.7
Scotland	12	0.80	1.00	0.10	0.30	67	8.8	19.2	32.5
Russia	6	0.60	0.80	0.10	0.15	69	7.6	18.3	30.5
Canada	4	0.65	0.85	0.15	0.28	25	1.6	6.9	13.6
Ireland	9	0.60	0.80	0.50	0.75	21	2.5	5.7	9.4
Denmark	2	0.40	0.60	0.14	0.34	17	0	4.7	11.8
England	1	0.40	0.60	0.15	0.35	8	0.6	2.3	4.7
Sweden	4	0.55	0.75	0.55	0.90	8	0	2.3	7.1
Spain	1	0.60	0.80	0.55	0.85	2	0	0.6	1.8
Iceland	1	0.80	1.00	0.40	0.60	2	0	0.6	1.7
Total	87					364		100.2	

Hansen and Jonsson (1991) showed that reared salmon kept in salt water, tagged and released into a Norwegian fjord every month throughout a year, tended to return to the geographical area of release and enter nearby rivers to spawn, except when released in late winter when they tended to stray farther away from the release site. When the fish were released in late summer and autumn, their survival was poor (Hansen and Jonsson, 1989). These observations have recently been supported by results from sequential releases of individually tagged large farmed salmon from two fish farms in Norway (L. P. Hansen, pers. comm.). Thus this may help to explain the observed lower recapture rate of farmed salmon in the present study. Alternatively, it has been observed that escaped farmed salmon enter fjords and freshwater later in the season than wild fish (Lund *et al.*, 1991) which

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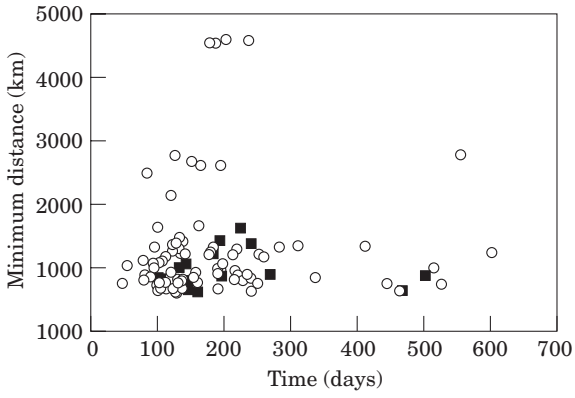

Figure 8. Minimum distances travelled versus days at liberty. Wild salmon are shown as open circles and escaped farmed salmon as filled squares.

may result in a lower exploitation rate on farmed than wild fish, and thus lower number of tags recovered if a large proportion of the farmed fish enter home waters after the fishing season has closed. The observation that most of the tagged farmed salmon in the present experiment were recaptured in Norway, may suggest that these fish escaped from Norwegian fish farms.

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