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The incidence of escaped farmed Atlantic salmon, *Salmo salar* L., in the Faroese fishery and estimates of catches of wild salmon

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The proportion of Atlantic salmon escaped from fish farms and caught in the Faroese salmon fishery was estimated using scale analysis. Samples were obtained of fish landed in the commercial fishery from 1980/1981 to 1990/1991 fishing seasons and from research catches in the 1991/1992 to 1995/1996 seasons. The material collected was in some years limited to only part of the fishing season. The estimated proportion of farmed salmon in the fishery was relatively low from 1980/1981 to 1986/1987, but increased considerably thereafter, and reached a peak in the 1989/1990 fishing season when more than 40% of the catch was estimated to be of farmed origin. Later, the proportion declined, and in recent seasons the proportions of farmed salmon were estimated to be around 20%. These estimates were used to split the Faroese catch into wild and farmed components. It is concluded that if farmed components in salmon catches are not accounted for, catches of wild salmon will be overestimated and assessments of fisheries and stocks of wild salmon confounded. Furthermore, the increase observed in catch per unit of effort (c.p.u.e.) in the 1980s and early 1990s might have been caused by an increasing abundance of farmed salmon.

Key words: Atlantic salmon, wild salmon, escaped farmed salmon, Faroes, Norwegian Sea, scale analysis, long-line, assessment

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Introduction

In recent years, salmon farming has expanded considerably. In 1995, 411 580 t were produced in the North Atlantic, with Norway and Scotland accounting for the majority of the production (ICES, 1997). In comparison, the total nominal landings of salmon in commercial fisheries in the North Atlantic in 1995 were 3339 tonnes (ICES, 1997). This catch figure, however, also includes a proportion of salmon released as smolts for ranching, or for stock enhancement, and fish farm escapees (ICES, 1997). In any case, the total number of salmon in fish farms far outweigh the number of wild salmon. This must only heighten our interest in escapes into the wild of salmon from fish farms.

Evidence from the Norwegian fish farming industry indicates that losses from the cages can occur at any time after the fish are placed in the sea and at all life stages. Escaped fish are caught in fisheries and, when sexually mature, they enter fresh water to spawn (e.g. Hansen *et al.*, 1987; Gausen and Moen, 1991; Lura and Sægrov, 1991; Webb *et al.*, 1991).

Tagged farmed salmon released directly into Norwegian coastal waters were recaptured in the high seas fishery at Faroes (Hansen *et al.*, 1987), and Hansen *et al.* (1993) demonstrated that large numbers of escaped farmed Atlantic salmon were present in oceanic waters in the Northeast Atlantic ocean and accounted for a substantial part of the commercial salmon catches at Faroes.

The entry of fish farm escapees into most areas of the North Atlantic (e.g. Gausen and Moen, 1991; Lund *et al.*, 1991; Webb and Youngson, 1992; Hansen *et al.*, 1993; Carr *et al.*, 1997; Stokesbury and Lacroix, 1997;

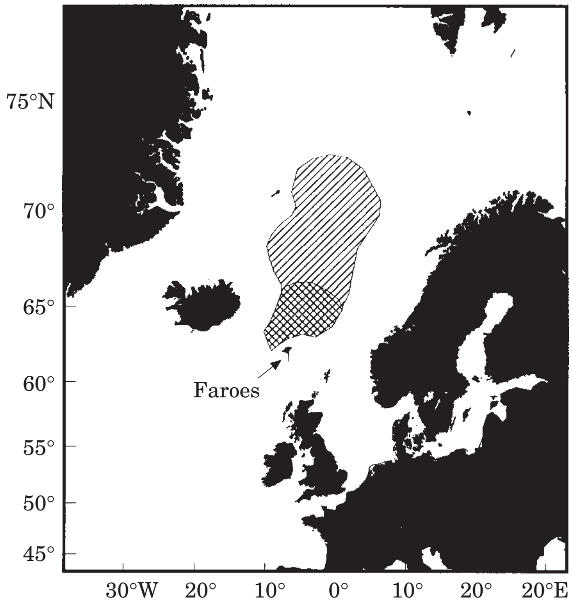

Figure 1. Map of the Northeast Atlantic showing the Faroese fishing areas for salmon where scale samples were obtained. Fishing areas prior to 1984 are shown as hatched areas and after 1984 as crosshatched areas, when quota restrictions were in force and the fishery was confined to the Faroese area.

Youngson *et al.*, 1997) where wild salmon are also found, poses several possible problems. First, interbreeding of farmed and wild salmon has been suggested to have negative effects on wild stocks (e.g. Hindar *et al.*, 1991). Second, transmission of parasites and diseases occurs between farmed and wild stocks (e.g. Håstein and Lindstad, 1991). Third, raw catch records from fisheries exploiting both wild fish and farm escapees will confound the assessment of stock status of wild fish. It is therefore of great importance to identify the proportion of farmed fish and adjust catch records accordingly.

The aim of the present paper is to develop a time series of the estimated proportion of escaped farmed salmon in the Faroese long-line fishery, and subsequently to estimate the number and catch per unit effort (c.p.u.e.) of farmed and wild salmon caught.

Material and methods

The Faroese Fishery Laboratory has systematically sampled scales from the commercial long-line fishery for Atlantic salmon north of the Faroes since 1980 to determine the smolt age and sea age of the salmon caught. These scale samples were re-examined in order to estimate the occurrence of farmed salmon in the fishery. The material analysed was collected from the 1980/1981 fishing season onwards to the 1995/1996 fishing season, and came mainly from the areas north of the Faroes (Fig. 1). In November to December sampling was carried out closer to the Faroes than in January to April, and in the years prior to 1984 part of the samples were taken far north of the Faroe Islands in international waters in the Norwegian Sea. From the 1980/1981 fishing season to the end of 1990, commercial salmon catches were sampled, whereas from 1991 to 1995 samples were obtained from a research fishery operated by only one vessel. During the whole period, scale samples were collected randomly from the catch, and the fish were measured (fork length; cm) and weighed to the nearest 0.1 kg.

Identification of farmed fish was carried out by scale analysis (Lund *et al.*, 1989; Lund and Hansen, 1991). This method has been developed by analysis of scales from Norwegian salmon of known origin, and the characters used were estimated smolt size, the characteristics of the transition zone from fresh water to salt water, the position of sea winter bands, the number of summer checks, and the proportion of replacement scales at the marine stage. To be classified as reared, at least two out of the six characters examined must indicate that the fish were of reared origin. This method has been shown to give good separation between farmed and wild salmon, but fish that escaped at the smolt stage or were released as smolts for ranching or enhancement are difficult to detect accurately, and their numbers are thus underestimated (Lund and Hansen, 1991).

Sampling was not carried out throughout the fishing seasons; in 11 out of 16 seasons only part of the season was sampled, and in two seasons sampling was carried out only in 1 month (Table 1). The number of scale samples collected on a monthly basis varied from 22 to 270 and on seasonal basis from 100 to 850 (Table 1).

Monthly variations within fishing seasons in the proportion of farmed fish were examined using χ^2 tests. The only significant differences occurred in the 1991/1992 ($p<0.001$) and 1993/1994 ($p=0.018$) fishing seasons, whereas in the 12 other fishing seasons, when data from two or more months were available, no signficant differences were detected. To split the total catch of salmon at Faroes by season into wild and farmed components, it was found appropriate to use the unweighted mean proportions by season of fish from these two groups in the calculations, as no clear trend could be observed within the seasons. Hence we treat the monthly samples as being random samples from the whole season.

To introduce confidence intervals on the estimated proportions of the farmed component each season, and on estimated catches of wild and farmed salmon, the binomial error function was calculated using Monte-Carlo simulation (@Risk, 2000 simulations) to estimate the 5 and 95% bounds assuming non-symmetrical variance around the mean proportions. The possible error due to non-random sampling by month within each season is not considered in this calculation. Confidence

Table 1. The material used for classification of salmon sampled in the Faroes long-line fisheries since 1980. *Samples only from latter part of the season (January to April); **Only 1 month sampled that season.

Season	Time	Year	Wild	Reared	Unclassifiable	Total
1980/81	January	1981	153	4	1	158
	March	1981	124	3	5	132
1980/81*	January–March		277	7	6	290
1981/82	January	1982	74	3	1	78
	February	1982	70	0	0	70
	March	1982	44	1	1	46
	April	1982	22	0	0	22
1981/82*	January–April		210	4	2	216
1982/83	February	1983	48	1	1	50
	March	1983	63	2	1	66
	April	1983	63	0	5	68
1982/83*	February–April		174	3	7	184
1983/84	January	1984	147	4	5	156
	February	1984	52	5	2	59
1983/84*	January–February		199	9	7	215
1984/85	January	1985	71	8	1	80
	February	1985	47	4	1	52
	March	1985	90	6	3	99
	April	1985	35	2	2	39
1984/85*	January–April		243	20	7	270
1985/86	January	1986	52	2	3	57
	February	1986	53	4	3	60
	April	1986	75	2	1	78
1985/86*	January–April		180	8	7	195
1986/87	March	1987	134	4	2	140
	April	1987	66	2	1	69
1986/87*	March–April		200	6	3	209
1987/88	January	1988	45	3	2	50
	February	1988	73	10	0	83
	April	1988	82	4	1	87
1987/88*	January–April		200	17	3	220
1988/89	November	1988	75	23	2	100
	January	1989	91	20	8	119
	April	1989	83	12	6	101
1988/89	November–April		249	55	16	320
1989/90	January	1990	106	87	13	206
	February	1990	36	32	5	73
1989/90*	January–February		142	119	18	279
1990/91**	December	1990	49	42	8	99
1991/92	November	1991	71	47	4	122
	December	1991	117	69	10	196
	February	1992	100	102	6	208
	March	1992	87	40	2	129
	April	1992	133	56	9	198
1991/92	November–April		508	314	31	853
1992/93	November	1992	11	8	6	25
	December	1992	54	18	22	94
	March	1993	125	61	14	200
1992/93	November–March		190	87	42	319
1993/94	November	1993	132	58	10	200
	December	1993	124	65	9	198
	January	1994	15	5	5	25
	February	1994	112	27	10	149
	March	1994	153	50	13	216
1993/94	November–April		536	205	47	788
1994/95	November	1994	120	34	2	156
	February	1995	83	22	1	106
	March	1995	88	16	7	111
1994/95	November–March		291	72	10	373
1995/96**	December	1995	195	64	11	270

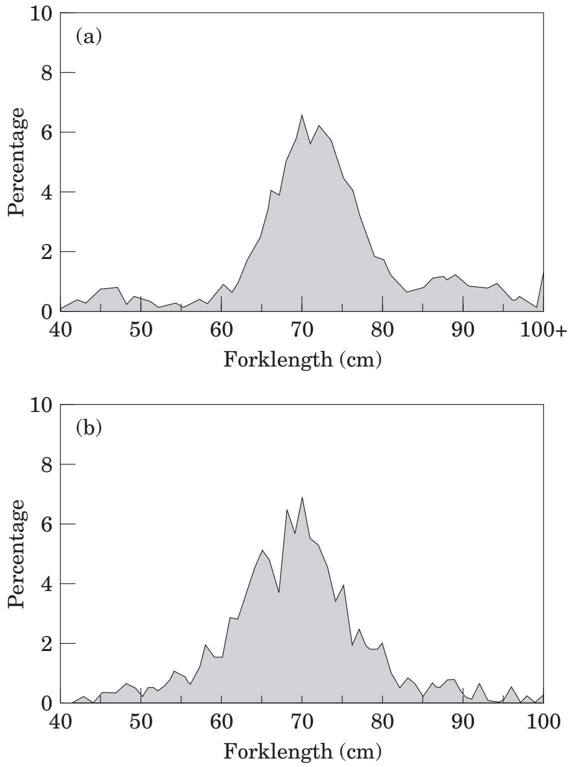

Figure 2. Fork length distribution of wild salmon (a) (n=3887) and salmon escaped from fish farms (b) (n=967), based on samples taken north of the Faroes for scale readings during the fishing seasons 1980/1981 to 1994/1995.

intervals for the c.p.u.e. estimates were calculated using the same method.

Results

The fork length distribution of the total number of salmon estimated to be of wild and farmed origin is shown in Figure 2. Although there were some variations among seasons, the majority of the wild fish were between 60 and 80 cm in length [Fig. 2(a)]. This corresponds to the size distribution of salmon in their second sea year which is the dominating component in the commercial fishery. Fish less than 60 cm and larger than 80 cm are usually in their first and third winter at sea. From the 1980/1981 to 1986/1987 fishing seasons the estimated number of farmed salmon was small, but increased thereafter. The great majority of farmed salmon were also between 60 and 80 cm [Fig. 2(b)].

The time series of the estimated proportions of farmed salmon in the Faroes fishery between the 1980/1981 and the 1995/1996 fishing seasons are shown in Figure 3, superimposed on the time series of the total production of farmed salmon in the Northeast Atlantic the same year (i.e. the proportion of farmed salmon in 1980/1981 season is compared to the production in 1981 etc.). The proportion of farmed fish was relatively low from 1980/1981 to 1986/1987, increased considerably thereafter, and reached a peak in the 1989/1990 and 1990/1991 fishing seasons, when more than 40% of the fish sampled were estimated to be of farmed origin. Thereafter, the proportion declined, and in the last three fishing seasons of the time series the proportion of farmed fish was estimated to be around 20%. This development reflects the trends in production of farmed salmon in the Northeast Atlantic until the 1992/1993 fishing season, but after that the proportion of farmed salmon at Faroes fell while farmed production continued to increase. The estimated proportion of farmed salmon in the Faroese fishery was significantly correlated with the total production of farmed salmon in the Northeast Atlantic (Spearman rank correlation analysis: $r_s=0.78$, $p=0.0006$).

Estimated catches at Faroes of wild and farmed salmon are shown in Figure 4. A decline in the catches of wild salmon from the 1988/1989 fishing season to the 1990/1991 fishing season is apparent when the catches have been corrected for farmed salmon. Since 1991 in Faroese boat owners have agreed to accept compensation for not fishing the salmon quota, allowing only one research vessel to operate in the area. Low catches from the 1991/1992 fishing season and onwards should therefore not be confused with low stock levels.

Catch per unit effort levels for wild and farmed salmon for the fishing seasons 1981/1982 to 1994/1995 are shown in Figure 5. During the time series the effort has declined, and since 1991 only one vessel has been operating. However, it appears that there is an increasing trend in c.p.u.e. for all salmon combined, from the 1981/1982 to 1992/1993 fishing season, which is explained by an increased c.p.u.e. of farmed salmon. In the 1993/1994 and 1994/1995 fishing seasons c.p.u.e. values were relatively low.

Discussion

The methodology used to classify the fish tends to underestimate the proportion of reared fish, in particular those escaped at the freshwater stage, or at an early marine stage (Lund *et al.*, 1989; Lund and Hansen, 1991). On the other hand, the method will also detect some of the salmon released for ranching or as smolts in stock enhancement programmes. However, a large part of these fish carry external or internal tags, often combined with fin clips. The salmon analysed in the present material were screened for tags, and tagged fish were not included in the analysis. Furthermore, the number of hatchery reared smolts released into rivers in the Northeast Atlantic is relatively small compared with the number of wild salmon present, except in Iceland where ranching has been established as an industry. However,

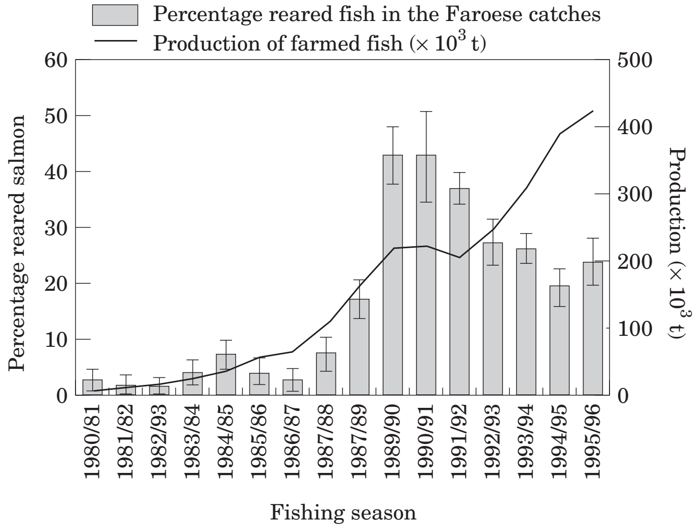

Figure 3. Production of farmed salmon in the Northeast Atlantic and estimated percentage of escaped farmed salmon caught in the Faroese long-line fishery for salmon. Error bounds (95% confidence limits) on the separation of catch into wild and farmed salmon are indicated (Monte Carlo simulation, 2000 simulations using @Risk).

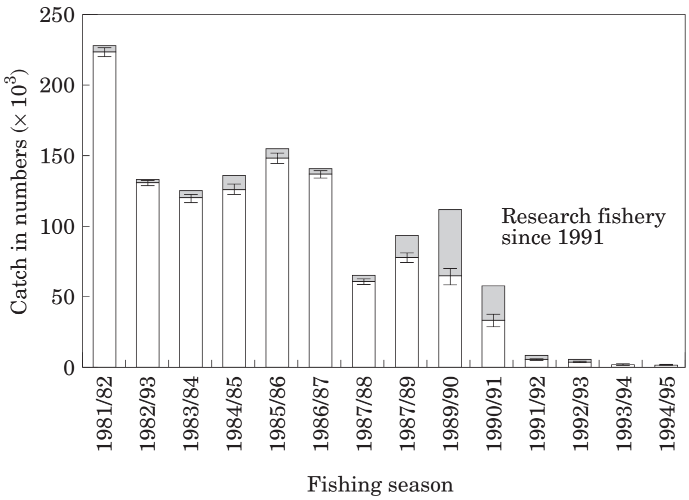

Figure 4. Estimated catches of wild (open bars) and farmed (shaded bars) Atlantic salmon in Faroese waters from the 1981/1982 fishing season. In the intersection between wild and farmed fish each year 95% confidence levels are shown (Monte Carlo simulation, 2000 simulations using @Risk). Low catches from 1991/1992 and onwards are due to the fact that the "fisheries" were conducted by a single research vessel.

very few fish tagged in Icelandic ranching operations have been reported from the Faroese fishery, suggesting that they exploit other feeding areas. All in all, this suggests that deliberately released salmon smolts are a relatively small component of the salmon sampled, and that escaped farmed salmon account for the major proportion.

A bias in the estimated proportions of farmed salmon might have been introduced due to the limited sampling in the first part of the time series where only the latter part of the fishing season (January to April) was sampled. Although in the 1993/1994 fishing season there was a significant downward trend in the proportion of farmed fish as the season progressed, i.e. from November to March, no clear trend was observed within the other seasons. We could therefore not provide any corrections to the time series due to data deficiency. Any bias would have had little effect prior to the 1988/1989 fishing season when the proportion of farmed fish was low. However, in the 1989/1990 fishing season and in particular in the 1990/1991 fishing season, when the proportion of farmed fish was at its maximum in the

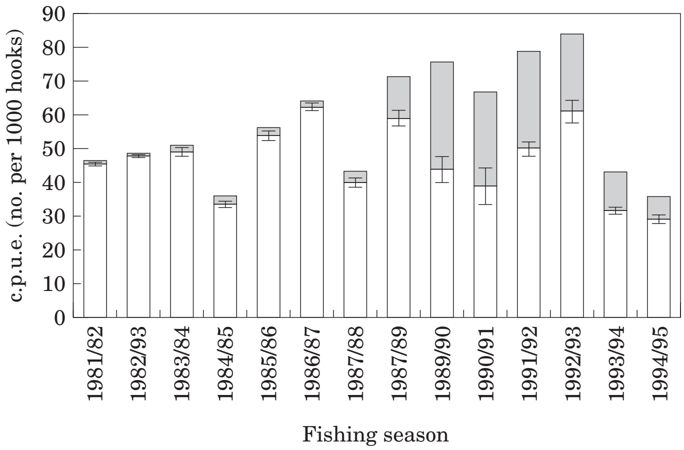

Figure 5. Catch per unit effort (c.p.u.e.; catch in number per 1000 hooks per day) of wild salmon (lower portion of the bars) and escaped farmed salmon (shaded bars) in the Faroese salmon fisheries since the 1981/1982 fishing season. Since 1991 only one research vessel has been operating in the area. Error bounds (95% confidence limits) on the separation of catch into wild and farmed salmon are indicated (Monte Carlo simulation, 2000 simulations using @Risk).

time series, the sampling was limited to only 2 months and 1 month, respectively. The estimated proportions of farmed fish in those two fishing seasons might therefore be more uncertain than in fishing seasons when sampling was more complete.

The variation in the proportion of farmed salmon among seasons in the salmon fisheries at Faroes is relatively consistent with the increase in overall production of farmed salmon in the Northeast Atlantic until the 1992/1993 fishing season. In the 1992/1993 to 1995/1996 fishing seasons however, the proportion of farmed salmon was significantly lower that in the previous three seasons, despite the fact that the production of farmed salmon increased considerably during the same period. The most likely reason for this is a reduction in number of fish escaping from fish farms. Alternatively, because the proportion of farmed salmon is also dependent on the number of wild salmon present in the area, this apparent inconsistency might also be explained by increased abundance of wild fish, although this is not supported by trends in c.p.u.e. (Fig. 5). Furthermore, recent assessments of salmon stocks in the North Atlantic strongly suggest a decline in the abundance of wild salmon in the area (ICES, 1997).

The total production of farmed salmon in the Atlantic in 1995 was 411 580 t (ICES, 1997). Of this, 95% were produced in Europe, and of the total production Norway and Scotland accounted for 72 and 17%, respectively. The production at Faroes was 9000 tonnes which represents about 2% of total production in the Atlantic. Salmon escape from cages in all areas where farms are present, and it is reasonable to assume that the largest number of fish escape from Norwegian farms.

In Norway, experimental releases of tagged farmed salmon during their first year in sea cages have shown that the survival to sexual maturity is highest when the fish are released in the spring. When they are released in late summer and autumn, survival is low (Hansen and Jonsson, 1989). Furthermore, in most cases these fish return to the general marine area from where they escaped. However, fish that escaped in March strayed to rivers far from the site of escape, although they were not reported from areas other than Norway and the west coast of Sweden (Hansen and Jonsson, 1991). The high proportion of farmed salmon observed in Norwegian home water fisheries (Lund *et al.*, 1996), combined with the fact that Norway accounts for the major production of farmed salmon in the Atlantic, strongly suggest that most farmed salmon occurring in the Norwegian Sea are of Norwegian origin. This is supported by the fact that tagged farmed salmon released on the Norwegian coast were recaptured in the Faroese fishery (Hansen *et al.*, 1987). However, we cannot rule out that farmed fish escaping from cages in Scotland, Faroes, and Ireland also contribute to the Faroese fishery.

When assessing salmon fisheries and wild salmon stocks, it is important to estimate the farmed and ranched component of the catch. If such fish are not accounted for, their presence will result in an overestimate of the catches of wild salmon and the size and status of the wild stocks will be obscured. Had escaped fish not been accounted for, assessments of the Faroese fishery would have been impaired, particularly from the 1988/1989 fishing season to the 1991/1992 fishing season, when the farmed proportion was very high. Furthermore, the increasing trend in c.p.u.e. for salmon caught from the 1981/1982 to 1992/1993 fishing season would have been attributed to an increasing abundance of farmed salmon, rather than wild fish.

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