ICES WKSHINI REPORT 2008

ICES DIADROMOUS FISH COMMITTEE

ICES CM 2008/DFC:02

REF. WGNAS, ACOM & LRC

Report of the Workshop on Salmon Historical Information – New Investigations from old Tagging Data (WKSHINI)

18–20 September 2008

Halifax, Canada

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CIEM Conseil International pour l'Exploration de la Mer

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Recommended format for purposes of citation:

ICES. 2008. Report of the Workshop on Salmon Historical Information – New Investigations from old Tagging Data (WKSHINI), 18–20 September 2008, Halifax, Canada. ICES CM 2008/DFC:02. 55 pp. https://doi.org/10.17895/ices.pub.9235

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Executive summary

The Workshop, established by ICES, on Salmon Historical Information – New Investigations from Old Tagging Data (WKSHINI) has been held and the present report provides the following:

- An update of information from historical oceanic tagging and recovery programmes in the format agreed at WKDUHSTI.
- An updated database of tagging and tag recovery information which was established in WKDUHSTI.
- Further development of testable hypotheses of salmon migration and behaviour in West and East Atlantic.
- Testing these hypotheses using information compiled in WKDUHSTI and new information that were made available during the meeting.
- The information was used to describe distribution of salmon of different origins and sea age in time and space and first attempts were made to assess changes in the distribution over time and in relation to hydrographical factors.

1 Introduction

1.1 Main tasks

At the 2007 Science Conference, ICES made a resolution (C. Res.) that the Workshop on Salmon Historical Information – New Investigations from Old Tagging Data (WKSHINI) (Chair Lars Petter Hansen, Norway) will meet in Halifax Canada 18–20 September 2008.

The terms of reference given by ICES were as follows:

a) build on progress made in WKDUHSTI (2007);

b) provide further information from historical oceanic tagging and recovery programmes in the format agreed at WKDUHSTI;

c) update the database of tagging and tag recovery information which was established in WKDUHSTI;

d) develop testable hypotheses of salmon migration and behaviour;

e) test these hypotheses using information compiled in WKDUHSTI and any new information which becomes available;

f) use the information to describe distribution of salmon of different river (stock) origins and sea age in time and space and assess changes in the distribution over time in relation to hydrographical factors.

The Workshop consisted of 16 participants included one by correspondence, the full address list of the participants is provided in Annex 1. The participants brought data that were discussed in detail. Most of the data were included in the template agreed at the WKDHUSTI workshop, but some additional efforts were made to include new data.

1.2 Participants

Peter G. Amiro (Canada)

Vegar Bakkestuen (Norway)

J. Brian Dempson (Canada)

Mark Fowler (Canada)

Lars P. Hansen (Norway) (Chair)

Arni Isaksson (Iceland)

Jan Arge Jacobsen (Faroes)

Lars Karlsson (Sweden)

Kjell Arne Mork (Norway)

Niall Ò Maoileidigh (Ireland)

Ted Potter (UK, England & Wales)

Dave Reddin (Canada)

Ian Russell (UK, England & Wales)

Tim Sheehan (USA) (By correspondence)

Gordon W. Smith (UK, Scotland)

Jonathan White (Ireland)

1.3 Background

Several initiatives have been undertaken by NASCO and ICES to improve the knowledge of distribution and migration of salmon at sea, which in turn may help to understand mortality of salmon at sea. In home waters large tagging programs of salmon smolts have been conducted with large numbers of tag recaptured in oceanic fishery. There have also been tagging programs at sea, both at Greenland and in the Norwegian Sea. The Report of the Workshop on the development and use of historical salmon tagging information from oceanic areas (ICES 2007/DFC:02) presented the first results from analyses of historical data on salmon at sea, and proposed a number of recommendations for further progress. In 2008 an EU project(SALSEA MERGE) was funded. The results from this project are expected to gain new and extensive information on salmon ecology and migration at sea.

There are a number of published information covering the marine life of Atlantic salmon, but there has been no systematic compilation and analyses of the total material, and below a summary of some of the knowledge is presented.

Atlantic salmon originating from several rivers are caught in the same oceanic areas at the same time (Ritter, 1989; Hansen and Jacobsen, 2003), and tagging experiments have demonstrated that Atlantic salmon from North America remain mainly in the western North Atlantic (Ritter, 1989), whereas fish from European and Norwegian populations are believed to feed mostly in the Norwegian Sea (Holm *et al.*, 2003). European fish, particularly those from southern Europe, UK and Ireland, are also abundant at West Greenland (Swain, 1980), and there is evidence that some migration of Atlantic salmon occurs between North America and Europe (Reddin *et al.*, 1984; Reddin and Friedland, 1999; Hansen and Jacobsen, 2003). Based on analyses of Caesium 137 in tissue of salmon from the West Atlantic it has been suggested that some of those fish may move into the NE Atlantic area (Tucker *et al.*, 1999; Spares *et al.*, 2007).

When coastal fishery developed more than 100 years ago in both North America and Europe (May and Lear 1971) some information became available on salmon in the local environment, but distribution and migration of salmon in oceanic areas was a "black box" until oceanic fishery developed in the 1960s at West Greenland and later in the northern Norwegian Sea. Research on material sampled from these fishery was undertaken (e.g. Parrish and Horsted, 1980; Hansen and Pethon, 1985, Reddin *et al.*, 1988; Jacobsen, 2000), and new knowledge was gained. However, these investigations did not address the temporal and spatial distribution and migration of fish in these areas.

The status of the salmon populations in both North America and Europe show a clear geographical pattern, with most populations in the southern areas in severe condition; in the north the populations are generally stable although at intermediate latitudes, populations are declining (e.g. Parrish *et al.*, 1998; ICES, 2002). Although many of the problems could be attributed to the construction of dams, pollution (including acid rain), and total dewatering of streams, along with overfishing and recently, changing ocean conditions, and intensive aquaculture many cannot be fully explained.

It is well known that there are large variations in survival of salmon among different smolt year classes (Porter and Ritter, 1984; Friedland *et al.*, 1998). Although there is a lack of direct evidence, it has been suggested that the heaviest mortality of salmon in the sea may take place during the first months after smolts leave fresh water (Doubleday *et al.*, 1979; Ritter, 1989). It is expected that many factors affect smolt survival and therefore the return of adult salmon, however these factors are poorly documented (Dempson *et al.*, 1998). Research on this subject has been strongly recommended by a number of organizations, but it was only recently that there were systematic efforts to sample salmon and especially post-smolts at sea (Lear, 1976; Reddin, 1985; Reddin and Short, 1991; Holst *et al.*, 1993; Shelton *et al.*, 1997; Holm *et al.*, 2000). Results from these studies together with the development of new techniques to analyse life-history signals from scales, bones and tissue of salmon (e.g. Friedland *et al.*, 1993) have improved our understanding of the biology of salmon post-smolts, but there are still major knowledge gaps.

Over the past 10–15 years a number of post-smolts have been caught in oceanic areas of the Northeast Atlantic during pelagic trawl surveys in the Norwegian Sea in July and August (Holm *et al.*, 2000), and north of Scotland in May and June (Holm *et al.*, 1996; Holst *et al.*, 1996; Shelton *et al.*, 1997). Based on the distribution of catches north of Scotland, the fish appeared to move northwards with the shelf edge current (Shelton *et al.*, 1997). Farther north in the Norwegian Sea post-smolts were caught beyond 70° N in July. Analysis of growth and smolt age distribution strongly suggested that most of the post-smolts originated from rivers in southern Europe (Holst *et al.*, 1996). This was supported by the recapture of a salmon that had been tagged in April 1995 in southern England, and recovered about 2000 km farther north three months later, demonstrating the capacity for rapid travel by post-smolts.

There is evidence that the marine distribution of Atlantic salmon depends on temperature (Reddin and Shearer, 1987), but whether distribution of food is an important factor is still an open question. The biomass of Atlantic salmon in the ocean relative to other pelagic oceanic fish species is extremely small, and salmon during its marine phase is thought to be an opportunistic pelagic predator, supporting rapid growth rate by exploiting a wide range of invertebrates and fish prey. The wide variety of food in different areas and periods suggests that salmon abundance is unlikely to be very sensitive to annual changes in the availability of any particular prey (Jacobsen and Hansen, 2001).

When Atlantic salmon have reached catchable size, their marine distribution, which reflects the fishery, is easier to document. Many countries have had major tagging programs on smolts and adults, and some of these fish have been recaptured in the high seas fishery. In the East Atlantic, salmon are found over large areas in the Norwegian Sea.

It is difficult to know the true distribution of salmon at sea, as recoveries depend on the distribution of the fishery and fishing effort. However, high seas salmon fishery have developed in areas of high abundance of fish and the tag recoveries may therefore reflect the main area of distribution of catchable fish during a limited period.

In summary, Swain (1980) analyzed a time-series of smolt taggings in European rivers in relation to recaptures off West Greenland as did Ruggles and Ritter (1980) for North American smolt taggings. Møller Jensen (1980a) used tag recoveries from West Greenland in 1972 to assess the distribution along the West Greenland coast of salmon originating from North America and Europe. These investigations demonstrated that Atlantic salmon from a number of different rivers in North America and Europe were present in the area. Furthermore, based on much more comprehensive material, Reddin (1988) and Reddin *et al*. (1988) used discriminate analysis of scale characteristics and concluded that catches of salmon off West Greenland were split fairly evenly between the two continents. It is more difficult to determine the country of origin, but Canada accounts for most of the North American component and Scotland for most of the European fish (Møller Jensen, 1980a). However, in recent years, the proportion of salmon originating from Europe seems to have decreased (Reddin and Friedland, 1999). All in all, salmon tagged as smolts in home waters and recaptured at West Greenland have originated from Canada, the United States, Scotland, England, France, Norway, Sweden, Iceland, and Ireland, and some Russian salmon may also be present in the area.

In the East Atlantic, salmon are found in large areas in the Norwegian Sea. In the 1970s, there was an important commercial longline fishery far north in the Norwegian Sea in February-May. The concern of the effects on salmon stocks caused by this fishery resulted in recommendations from ICES to collect information on stock composition as well as to estimate effects on home-water stocks. Recoveries of fish in this fishery that had been tagged as smolts, and recaptures in coastal and fresh-water fishery of salmon tagged in the Norwegian Sea suggested that Norwegian salmon were most abundant, although fish from the United Kingdom, Sweden, and Russia were also present. Most of the fish were recaptured in home waters the same year they were tagged, suggesting that they were maturing (Rosseland, 1971). Towards the end of the 1970s, fishing for salmon in the northern Norwegian Sea was banned, and fishing was limited to the area within the Faroese Exclusive Economic Zone (EEZ).

The distribution of Atlantic salmon in the ocean is still not well known, but the limited information indicates that salmon are not evenly distributed. Salmon from North America seem to stay in the West Atlantic area, although some fish can move into the Northeast Atlantic. It is also evident that a relatively large proportion of the European MSW salmon moves far into the West Atlantic to feed. Salmon from many populations differ in how long they stay at sea; hence different sea age-classes from the same populations may be present in different areas (Jacobsen *et al.*, 2001). For example, MSW salmon may move farther away from home than grilse, as suggested by Scarnecchia (1984) for salmon originating in Iceland. A better map of Atlantic salmon distributions at sea in time and space would help us to understand the fluctuations in their survival and life history. The distribution of Atlantic salmon in the sea seems to reflect environmental factors like surface temperature and surface currents (Reddin and Friedland, 1993), and probably also the availability of suitable food organisms (Jacobsen and Hansen, 2000), as growth and survival are important fitness characters as well.

Smolt tagging programmes in many countries and adult tagging experiments at sea during since 1960s have provided information of the composition of country of origin of salmon in the North Atlantic. The general pattern is that salmon from the Northwest Atlantic are mainly confined to the western area, although salmon from the Northeast Atlantic are found both in the eastern and western part of the Atlantic.

The present report aims to compile information from salmon tagged in home waters and subsequently recaptured in the oceanic salmon fishery at Faroes, Norwegian Sea and Greenland and assess their distribution in space and time.

1.4 Material

The Workshop compiled the tag recovery information in the agreed Framework recommended at the 2007 Workshop (ICES, 2007). Further each country went through their data to remove duplicates and correct possible errors and inconsistencies. All data were loaded into a database for easy retrieval and to ensure a common format.

The tag recovery information from the West and the East Atlantic was compiled into two separate databases at the present Workshop, but the same format was used for later combination. Recoveries have been obtained from oceanic and offshore areas with main focus on tag recoveries from oceanic areas in the West Atlantic as well as in the East Atlantic. The distribution of Atlantic salmon in the North Atlantic is shown in Figure 1. The majority of the information was from smolt tagging in home waters and subsequent recaptures in oceanic areas. Some data on older fish were also available. More details will be presented under the respective West and East Atlantic section of the report.

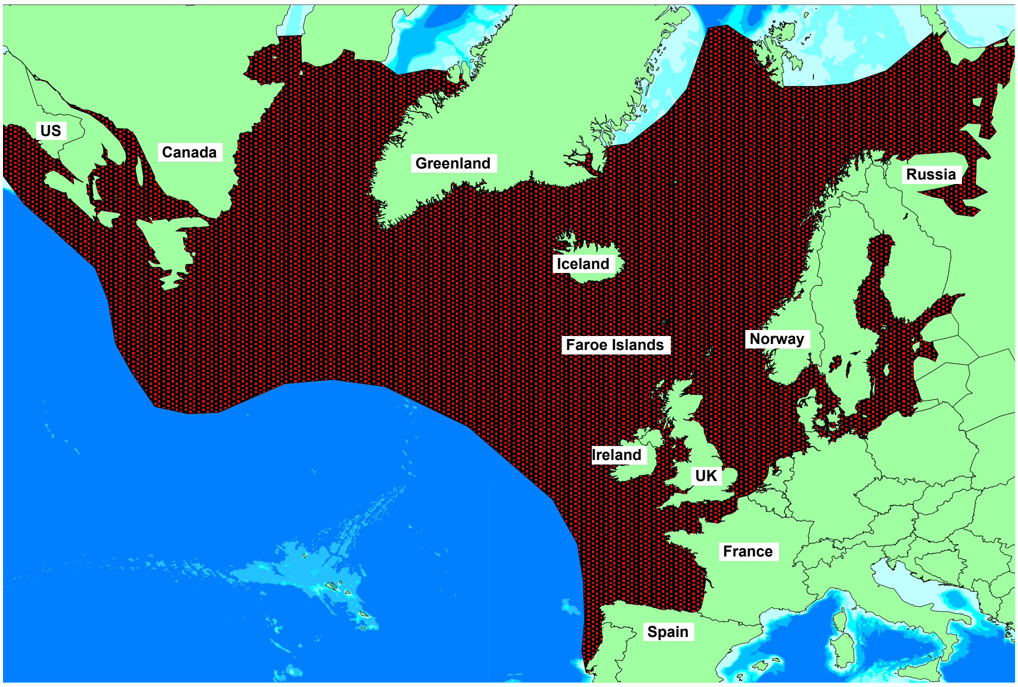

Figure 1. Approximate oceanic distribution areas of Atlantic salmon.

2 Hypotheses to be tested

The Workshop aimed to test a number of hypotheses, and the material and time available allowed the following to be fully or partly tested:

- The distribution of salmon at sea is random;
- The migration of salmon to marine feeding areas is consistent over time (years, months) and space (route);
- The distribution and migration of salmon at sea is independent of sea age;
- The distribution and migration of salmon at sea is independent of geographical origin of stocks (e.g. northern vs. southern stocks);
- The distribution of European and North American salmon at West Greenland has not changed over time;
- The distribution of North American salmon caught at West Greenland is independent of stock origin (e.g. USA, Quebec, Maritime, Newfoundland-Labrador, etc.);
- The distribution of European salmon caught at the Faroe Islands is independent of country of origin (e.g. Norway, Sweden, Finland, Denmark, Ireland, Iceland, United Kingdom, Russia etc.);
- The distribution of European salmon caught at West Greenland is independent of country of origin (e.g. Norway, Sweden, Finland, Denmark, Ireland, Iceland, United Kingdom, Russia etc.);
- The distribution of salmon at sea is independent of sea surface temperature (SST);

3 North West Atlantic

Tag recoveries from salmon tagged in homewaters and during International Tagging Experiments at Greenland, between the early 1960s and the present, were made available to the workshop. The data provided were only for the Greenland area (Figure 2), and were collated into the format agreed at WKDUHSTI to allow GIS and various statistical analyses to be performed. In total, there were 5,080 individual recoveries and of these 4,743 had latitude and longitude for the recovery location (Table 1). However, because much of the data were derived from tag recaptures at a time before global positioning satellites became common, or were derived from market-based scanning programmes, most of the latitudes and longitudes were ascribed to individual fish recapture sites from the locations of communities within Greenland. In many cases where the community was unknown only the NAFO Division was available and the recapture latitude and longitude was set to the midpoint for each individual NAFO Division (Figure 2). Thus the latitudes and longitudes provided are for the most part not the true latitudes and longitudes of the site where the fish were recaptured. This contrasts with the data from the east Atlantic where the exact position was frequently available. For the West Atlantic, because of the restrictions imposed by the precision of the geo-position, analyses were restricted to broad-based geographical distributions.

In addition to the information from salmon tagged in homewaters and recovered at Greenland there were also recaptures from International Tagging Experiments carried out on adult salmon caught at west Greenland. From these experiments, there were 241 individual fish available, of which 240 had detailed GIS recapture coordinates (Table 2). Because the fish were tagged at Greenland only those recaptures from homewaters to which country of origin could be given were used. There were 167 recoveries from the fishery at Greenland that were not used in subsequent analysis.

There are several issues with the use of this database. First, the distribution of tag returns depends on the distribution of fishing effort. Fishing effort is unknown for the Greenland fishery and so we do not know if the number of tags returned from each area represents the true distribution of fish or just the distribution of fishing effort or a combination of both. Also, in areas and times with no fishing effort there cannot be recaptures. Second, the tags recaptured are not adjusted by the number of fish originally tagged and nor are they adjusted for the relative production of salmon in each country. Thus, for the USA which tags a large proportion of its production, but relative to other countries produces fewer fish, the number of tags in the database although being very high represents a small number of salmon in total. Third, is that for the Greenland fishery relatively few of the tag recaptures were originally assigned a latitude and a longitude when recovered, thus this information had to be inferred from the community or the NAFO Division as previously explained. Otherwise, there was no latitude or longitude assigned. In addition to the above, the fishery has been subject to various management measures over the period, for example variation of season dates and the introduction of quotas. These factors have necessarily limited the analysis to only broad general comparisons.

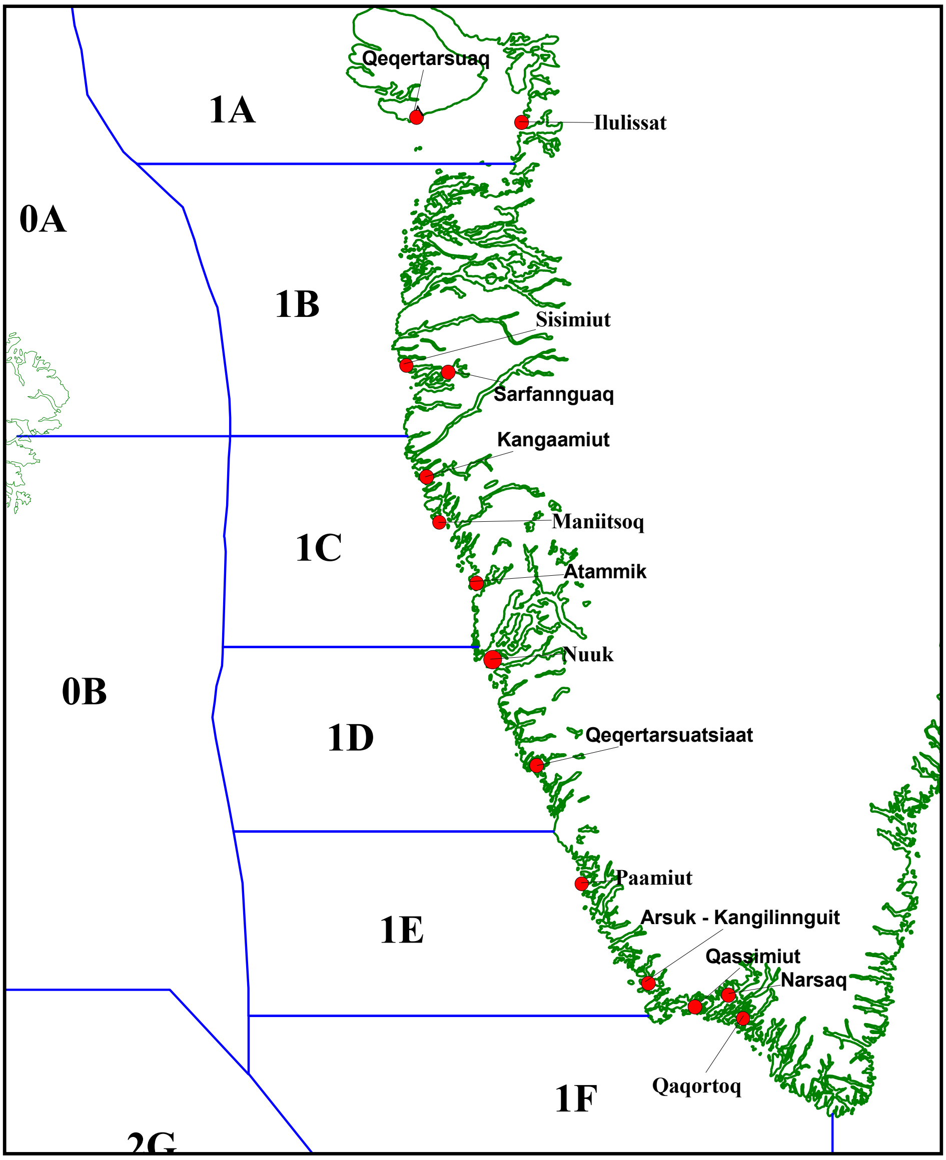

Figure 2. Greenland NAFO Divisions.

Table 1. Recaptures from salmon tagged in rivers and hatcheries in homewater countries that were recaptured at Greenland. W – wild and H – hatchery.

Country	Region	Life Stage	Origin	Numbers Recovered	Numbers with GIS co-ordinates	Release Years
Canada		Smolt/kelt	W/H	1819	1819	67-81, 83-91, 93-98
Iceland		Smolt	W/H	24	17	66, 71-72, 74-74, 80,84-85
Ireland		Smolt	W/H	137	137	63, 02, 03
Norway		Smolt	W/H	145	132	67-74, 76-81, 84-94, 98
Sweden		Smolt	W/H	7	7	Unknown
United Kingdom	Scotland	Smolt	W	399	271	68, 70-78, 80-91, 96-98, 02
	England & Wales	Smolt	W/H	387	200	60-76, 78, 80-81, 02
	Northern Ireland	Smolt	W/H	4	2	88, 90
USA		Smolt	H	2158	2158	62, 63, 65-76, 79-91, 03, 04, 06
Total				5080	4743	

Table 2. Recaptures from salmon tagged in Greenland during international tagging experiments and recovered in various countries. The tags recovered from Greenland were not used in further analyses.

Location	Region	Life Stage	Origin	Numbers Recovered	Numbers with GIS co-ordinates	Recovery Years
Canada		Adult-1SW	Unknown	19	19	1969, 1971-72
France		Adult-1SW	Unknown	2	2	1972
Greenland		Adult-1SW	Unknown	167	167	1969, 1971-72
Iceland		Adult-1SW	Unknown	1	0	1972
Ireland		Adult-1SW	Unknown	12	12	1969, 1971-72
Norway		Adult-1SW	Unknown	0	0	
Spain		Adult-1SW	Unknown	1	1	1972
United Kingdom	Scotland	Adult-1SW	Unknown	26	26	1969, 1971-72
	England & Wales	Adult-1SW	Unknown	13	13	1969, 1971-72
	Northern Ireland	Adult-1SW	Unknown	0	0	
USA		Adult-1SW	Unknown	0	0	
Total				241	240	

3.1 Testing hypotheses related to the distribution and migration of Atlantic salmon in the North Atlantic

Observational summaries presented as GIS-type maps can provide informative overviews of general patterns associated with the distribution and migration of salmon in the North Atlantic. For example, descriptive syntheses showing similarities or differences in country or rearing origin (hatchery/wild) of salmon captured in distant fishery such as those at Greenland or the Faroes can easily be produced. Patterns can be enhanced where temporal (annual, seasonal) or other information is available or when superimposing information, say, associated with environmental conditions. Graphical summaries are also useful when exploring questions associated with differences in life-history (e.g. sea age, river/smolt age), growth rate or size of fish, type (wild vs. hatchery), or when categorizing differences in spawning history (maiden vs. repeat spawners) of recaptured fish.

An example to test the hypothesis that the distribution of Canadian origin salmon at west Greenland is independent of stock origin, either for a specific year, or for a period of years of particular interest. Alternatively, one could also compare the proportional distribution of tag recaptures; say Canadian and American, at east and west Greenland:

	West Greenland	East Greenland	Total
Canada	1817	2	1819
USA	2126	32	2158
Total	3943	34	3977

Here, the explanatory variable (X) would be country of origin although the response variable (Y) would be the region of recovery (east vs. west Greenland). Thus, the null hypothesis to be tested is that the proportion in each response variable category is the same for each of the treatment groups. More sophisticated analyses may also be possible. For example, differences in the spatial and temporal distribution of Arctic charr in north Labrador were analyzed using a categorical data-modelling procedure (Dempson and Kristofferson 1987). Here, a log-linear model was fitted to the number of tag recoveries by location and year. Inherent in the interpretation of the above examples, or any subsequent analyses that may be undertaken, is the realization that resulting tag recaptures are derived from, and hence are dependent on returns from various fishery. Accordingly, it is understood that the distribution of tag recaptures tells as much about the distribution of fishing effort as it does about the distribution of the fish themselves. Use of log-linear models to analyze salmon distributional patterns have been carried out by Kallio-Nyberg *et al*. (2000) and Jutila *et al*. (2003).

In the absence of information on the actual numbers of tags that were released from respective areas, it is not possible to scale the recaptures relative to a common denominator. Further, as noted previously, a range of other problems exist that could confound interpretation of the results and need to be acknowledged when any analyses are carried out. Analyzing data by individual years may circumvent some of these problems, but is often likely to be constrained by the amount of data available in any year. Ideally, tag recaptures should be scaled to the numbers of fish caught or to catch-per-unit effort. In the categorical analysis of Arctic charr tag recoveries referred to above, the model included a term for numbers of fish caught because both effort and catch differed among locations.

Preliminary analyses – West Greenland tag recoveries

Basic to the information of the distribution of salmon at sea is whether or not the distribution of recaptures are independent of sea age. This is similar to asking if grilse and MSW (or potential MSW salmon) are found in similar locations. For the Greenland area, we know that the distribution is very dependent on sea age as only MSW salmon have been caught there (Idler *et al*., 1979). This is mainly due to the timing of the fishery, as by late July and August grilse are already entering or have entered their home rivers and so cannot be at Greenland simultaneously. Salmon may be present in the Greenland area at a younger age, but not represented in catches. Thus, postsmolts may be at Greenland but rarely caught there perhaps because of the size of the mesh used in this fishery which would in general be too large to retain postsmolts.

Information from tag recoveries (external tags and CWTs) at west Greenland, over the entire time-series, were initially examined to determine whether the distribution of tag recoveries was equal among three different regions: northwest Greenland (NAFO Divisions 1A to 1C), southwest Greenland (NAFO Divisions 1D to 1F), and east Greenland. Results for Canada, USA, Norway, UK (Scotland), and UK (England & Wales) were consistent in that tag recoveries for all countries were not uniformly distributed (all Chi-squared tests $p < 0.0001$). However, given that these results are likely related to the differential distribution of fishery among these regions (there is very little salmon fishing at east Greenland), a reanalysis of the data were carried out for west Greenland to test whether tag recoveries were uniformly distributed among the NAFO divisions.

Re-analysis of tag recoveries specific only to west Greenland demonstrated similar results. For all countries of origin, salmon tag recoveries were not uniformly distributed across the respective NAFO divisions (all Chi-squared tests $p < 0.0001$). Tagged salmon from Canada and USA were more commonly captured in northern locations (NAFO Divisions 1B and 1C), although tagged European origin salmon tended to be caught further south in NAFO Divisions 1E and 1F. As expected then, the recovery of North American origin salmon differed significantly from that of European salmon at west Greenland (likelihood ratio G-test = 1044.88, $p < 0.0001$). Collectively, 35% of North American tag recoveries occurred in NAFO Divisions 1A and 1B compared with only 17% of European tag recoveries. In contrast, 56% of the tag recoveries of European origin were from NAFO areas 1E and 1F compared with only 17% of North American recoveries (Figure 3).

Within North America, a comparison of the distribution of Canadian vs. USA tag recaptures at west Greenland were also found to differ (likelihood ratio G-test = 81.61, $p < 0.0001$). Canadian salmon were more commonly recaptured in northern areas than USA fish. A comparison of European salmon from Norway, Ireland, UK(Scotland) and UK(England & Wales) yielded similar differences (likelihood ratio G-test = 53.51, $p < 0.0001$) with salmon from Norway and UK(Scotland) recovered more in northern areas although salmon from Ireland and UK(England & Wales) were more likely to be recaptured in southwest Greenland.

As some studies have demonstrated that the environment changed around the late 1980s (ICES, 2003) this may also have influenced the distribution of North American and European salmon at Greenland (ICES, 2001). Thus, 1989 was used to establish two time periods for analysis: Period 1 data up to 1989 and Period 2 data for 1989 and later. For both North American salmon (likelihood ratio G-test = 122.90, $p < 0.0001$) and European salmon (likelihood ratio G-test = 88.33, $p < 0.0001$) the distributions between periods was found to differ among NAFO Divisions. In both cases, North American and European salmon were found further south at Greenland in the later period then in the former. This may have been temperature related as period 2 has been cooler then period 1. However, it may also be related to changes over time in fishery management measures (e.g. fishing times may have been more extensive in earlier years), or in the fishing effort in different NAFO Divisions.

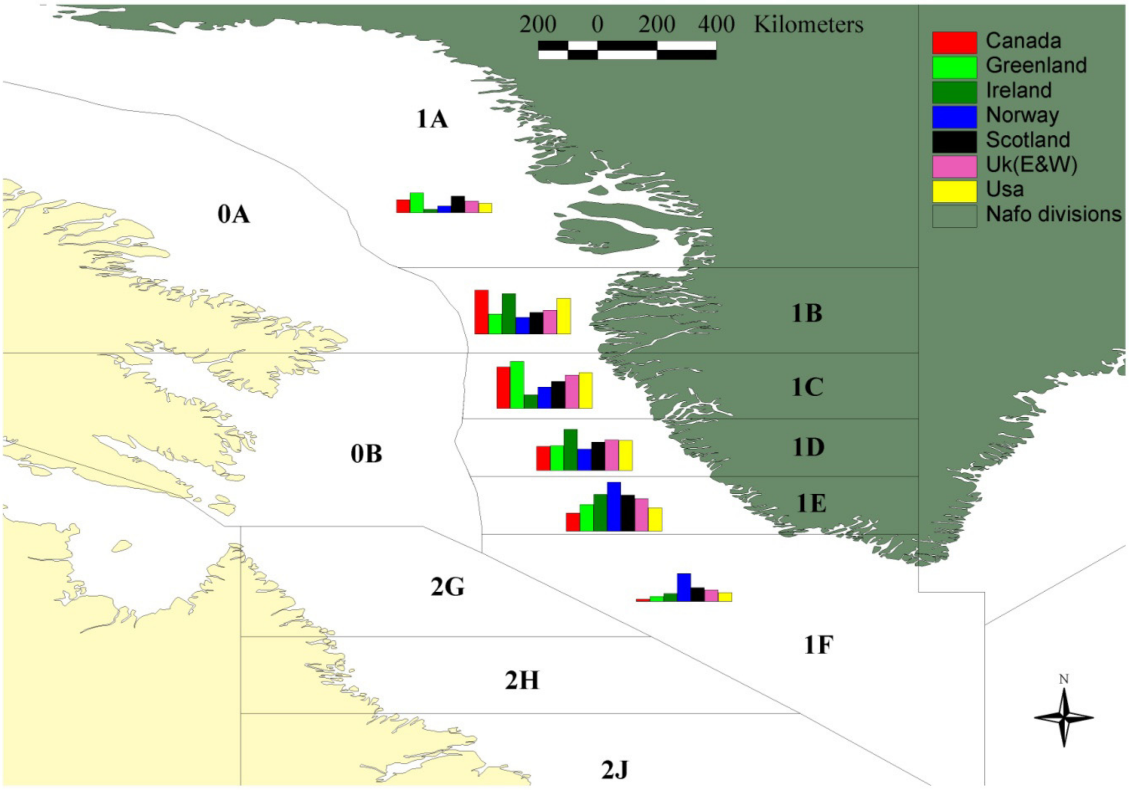

Figure 3. Map showing the percentage of recaptures by country from each NAFO Division at west Greenland.

3.2 Hypothesis: Kelts and postsmolts do not show the same distribution pattern (Canada) i.e. the distributions of adult and smolt tag recaptures are independent

The database was queried for rivers that contained recoveries from both adult and smolt tagging. It was noted that while data recaptures of tags applied to both adults and smolts were available, large differences in the numbers of tags applied to these stages impeded extensive analysis of the relative recapture proportions for a release location. Contrasts of the temporal and spatial distribution of one of these release locations indicate that for at least one location, Saint John River in the Scotia Fundy area, recovery of tagged post-spawning adults suggests a similarity to the recovery locations of tagged smolts (Figures 4 to 11). However, it was further noted that juvenile tags were applied exclusively to hatchery origin smolts and adult tags were applied to wild origin adult salmon. Even though it was known that tags were applied in different seasons to wild adult salmon from several possible locations in the Saint John River, Westfield and Mactaquac Dam being the most frequent, no further selection of recaptures by these factors was applied to the data due to the scarcity of distant recaptures for this tagging stage.

First a comparison of the broader distribution of the recapture locations of salmon tagged as smolts vs. salmon tagged as adults was assessed by Chi-square tests of proportions with an equal distribution hypothesis.

Recoveries of salmon tagged as juveniles (J) and as adults (A) were split into groups according to latitudes 55° 20 and 46° 00 to give three broad regions as 1. Scotia/Fundy (southern), 2. Newfoundland (mid–range), and 3. Greenland (northern).

	Scotia/ Fundy,	Newfound land	Greenland	Row total
Number (A)	2711	547	5	3263
Proportion	0.8300	0.1700	0.0015	0.28
Proportion	0.2800	0.3400	0.0140	
Proportion	0.2300	0.0470	0.0004	
Number (J)	6904	1047	361	8312
Proportion	0.8300	0.1300	0.0430	0.72
Proportion	0.7200	0.6600	0.9900	
Proportion	0.6000	0.0900	0.0310	
Column Total	9615	1594	366	11575
Proportion	0.8300	0.1400	0.0320	

A test for independence of all factors gave a $Chi^2 = 159.64$ with d.f.= 2 and resulted in p=0.

Therefore the test for independence of proportional recaptures for Saint John River among J and A applied tags for recapture regions indicated that regional distributions were dependent of the stage tagged.

Second, a more specific test was conducted to compare the relative proportions of hatchery juveniles vs. wild adults recaptured in Greenland.

		1.00	2.00	3.00
H	J	6904	1047	361
W	A	2711	547	5

Proportions were:

0.831	0.126	0.043
0.831	0.168	0.002

The hypothesis that the proportion of recoveries of hatchery reared juveniles is equal to that of wild adults in Greenland waters was rejected (P= 0.000, X-square = 9729.567, d.f. = 1), as was the inverse hypothesis that the proportion of recoveries of wild adults is equal to that of hatchery juveniles (P=0.000).

These results indicate that Saint John River salmon tagged as juveniles are more likely to be recovered in Greenland waters than salmon tagged as adults.

A further hypothesis that the distribution of tag recaptures was similar among the six ICNAF areas within Greenland waters was attempted using a similar method.

The following latitudes were used to assign recaptures to the ICNAF areas:

>6850 = A

>6615 & <=6850 = B

>6415 & <=6615 = C

>6230 & <=6415 = D

>6045 & <=6230 = E

>5740 & <=6045 = F

As noted above the recoveries of salmon tagged as wild adults at home (Saint John River) within West Greenland were only 5 salmon. Therefore, there are insufficient recoveries to conduct a valid Chi Square test of the independence of recapture proportions of tags applied to juvenile and to adult salmon.

		A	B	C	D	E	F	TOTAL
H	J	35	112	129	42	29	11	358
W	A		1	1	1		2	5

The proportions were:

0.09777	0.31285	0.36034	0.11732	0.08101	0.03073
0.00000	0.20000	0.20000	0.20000	0.00000	0.40000

Therefore, we might conclude that the apparent distribution of recoveries of salmon tagged as adults in the river does not reflect that of recovery of salmon tagged as juveniles, but we cannot prove that the recapture distribution of salmon tagged as adults is valid. We do not have enough recoveries in Greenland of salmon tagged as adults to give an expected distribution, so cannot provide a valid contrast with the recapture distribution of salmon tagged as juveniles. Furthermore it was noted that recaptures of tags applied to adult salmon was not adjusted for local in-season recaptures.

3.3 Hypothesis: The distribution of recaptures of tagged hatchery smolts is not the same as the recapture distributions of tagged wild origin smolts

In the Scotia/Fundy area the Tobique River tagging provided the best dataset to address this question. However, it should be noted that virtually all the wild recoveries derive from recoveries made in 1974, while the hatchery recoveries derive from a number of years, 1981 predominant, and none from 1974. Recapture locations were 1. Scotia/Fundy, 2. Newfoundland, and 3. Greenland.

The numbers and proportions were:

	1	2	3	
H	91	42	9	142
W	8	45	12	65
proportionH	0.64085	0.29577	0.06338	
proportionW	0.12308	0.69231	0.18462	

First, a test of the independence of the proportion of recaptures by origin of tagged salmon indicated that recapture proportion was not independent of origin. Chi^2 = 48.136 d.f.= 2 (p=0)

Second, there was a significant difference in the proportion of salmon recaptures from Greenland specifically, based on wild vs. hatchery origin of smolts from the Tobique River (X-square = 13.0719, d.f. = 1, p-value = 0.0003), and the inverse hypothesis (hatchery vs. wild) was also rejected (p= 0.0002).

Our results suggest that wild salmon tagged as juveniles are about 3 times more likely to be recaptured in Greenland than tagged hatchery smolts. However, differences in recovery and reporting probabilities, survival, tagging effects, and fishing effort, both between and within years, suggest further exploration of the data and confounding factors is required before sound statements can be made about recapture proportions.

Third, within Greenland only four of the six ICNAF areas were represented, and only 21 recaptures were available for testing.

	H	W			
B	7	2	north	8	6
C	1	4			
D	1	5	south	1	6
F		1			
total	9	12			

Based on these few data statistical interpretation through the use of Chi-square was not conducted.

3.4 Hypothesis: The distribution of recaptures from smolts tagged in the USA is the same as smolts tagged in the Big Salmon River and inner Bay of Fundy stock

Almost all tagged smolts are hatchery origin. No recoveries of Big Salmon fish came from Greenland waters. Therefore no statistical comparison was possible. In comparison to the Tobique River tagging described above, the Big Salmon River had 354 recoveries, more than the Tobique which gave 21 recoveries in Greenland waters, and 166 of the Big Salmon recoveries were made subsequent to the tagging year. The US recoveries in Greenland waters are tabulated below by ICNAF area.

A	B	C	D	E	F	TOTAL
128	658	610	351	289	105	2141

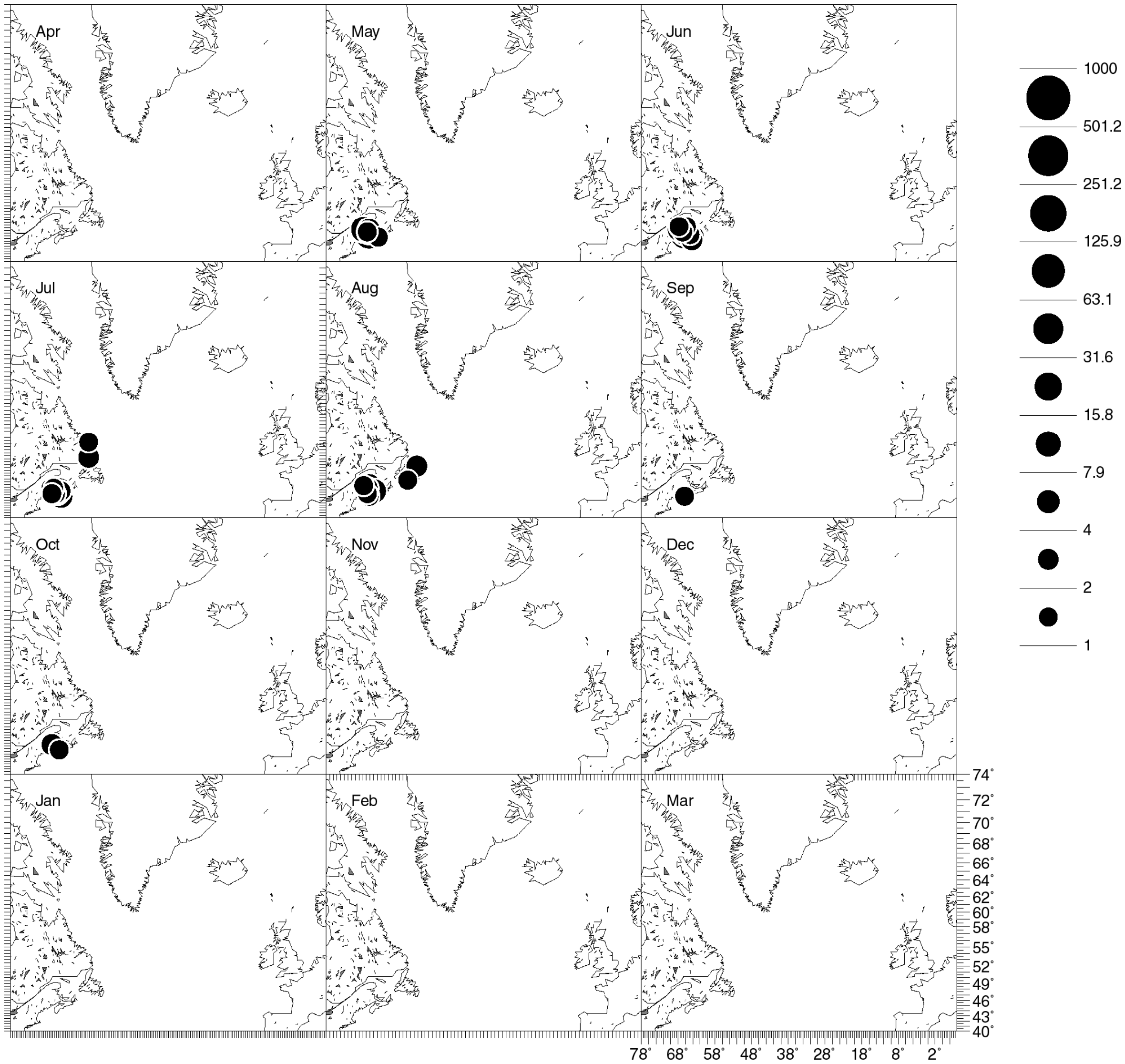

Figure 4. Release-year (post-smolt) recoveries from the Saint John River of tagged hatchery smolts aggregated for all available years by 5 minute squares and plotted by month.

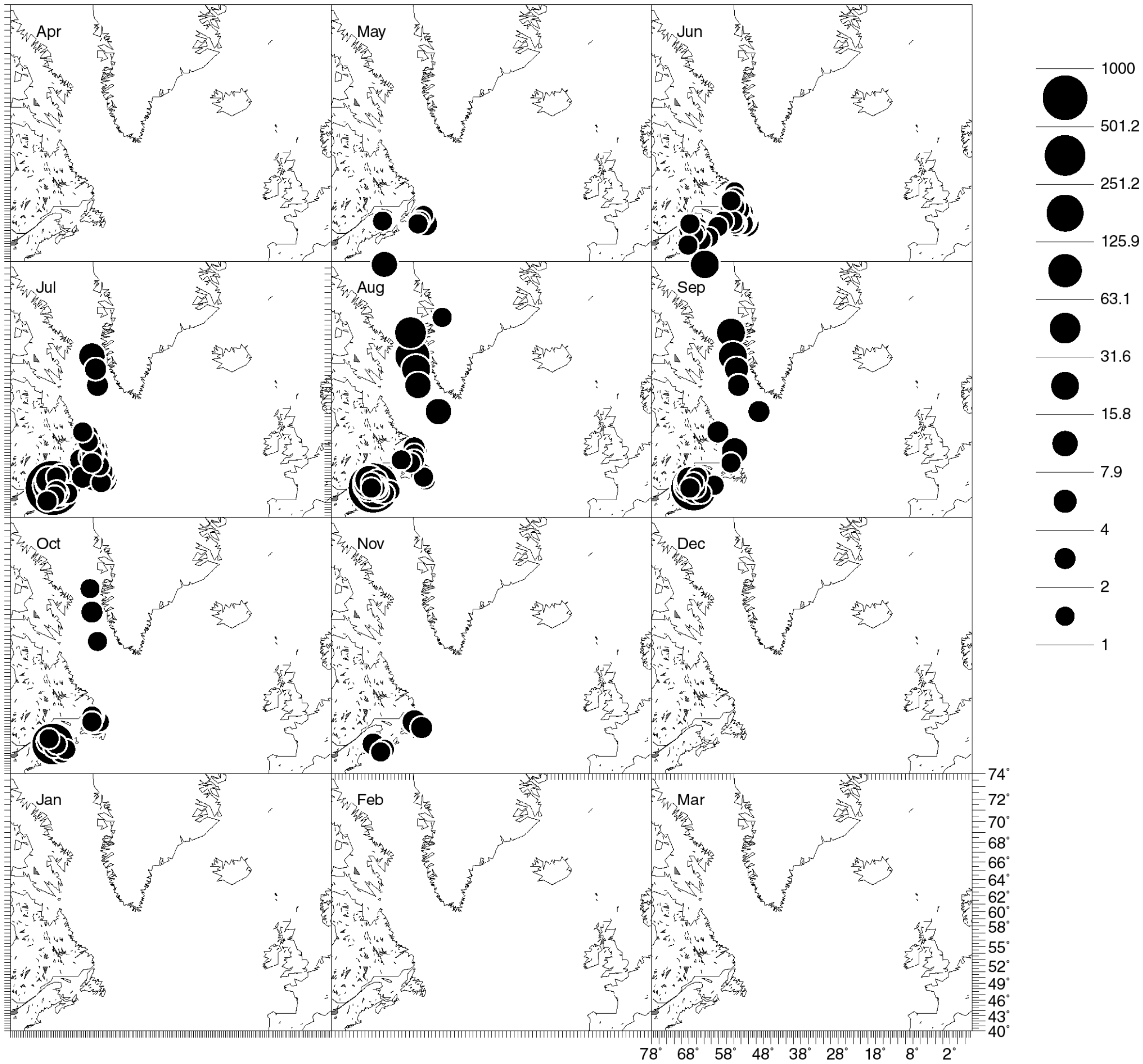

Figure 5. One-sea-year recoveries from the Saint John River of tagged hatchery smolts aggregated for all available years by 5 minute squares and plotted by month.

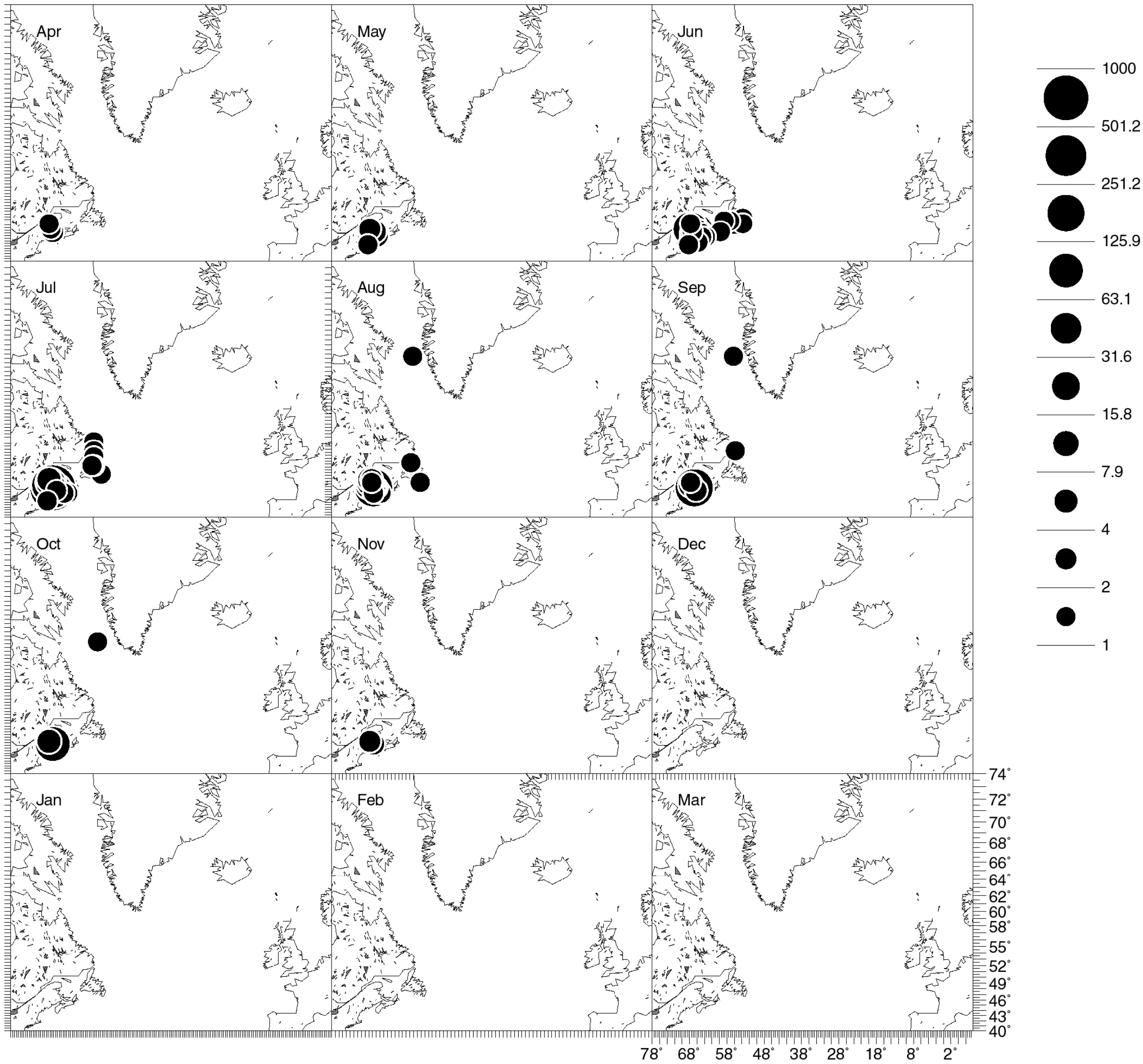

Figure 6. Two-sea-year recoveries from the Saint John River of tagged hatchery smolts aggregated for all available years by 5 minute squares and plotted by month.

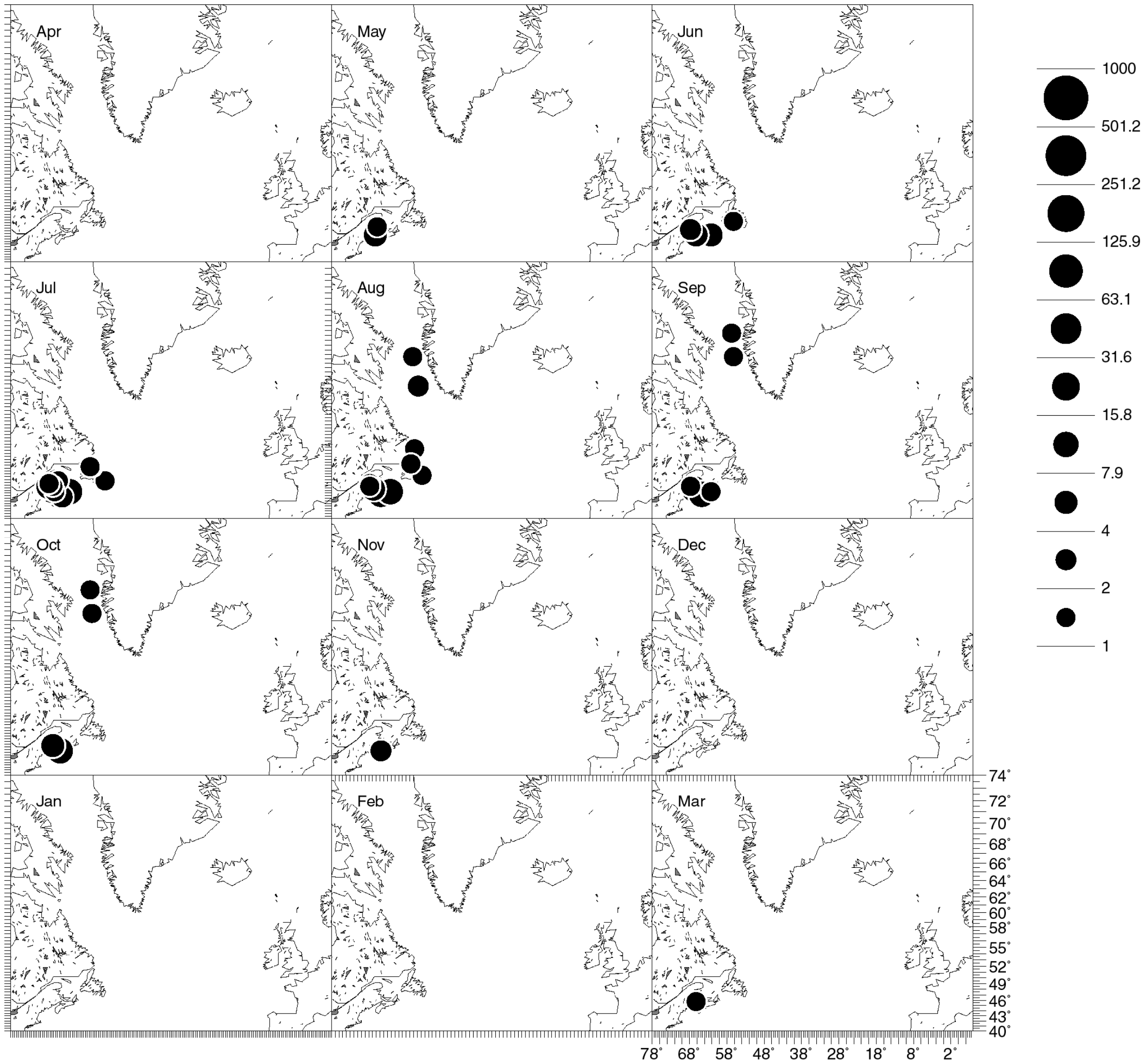

Figure 7. Three-sea-year recoveries from the Saint John River of tagged hatchery smolts aggregated for all available years by 5 minute squares and plotted by month.

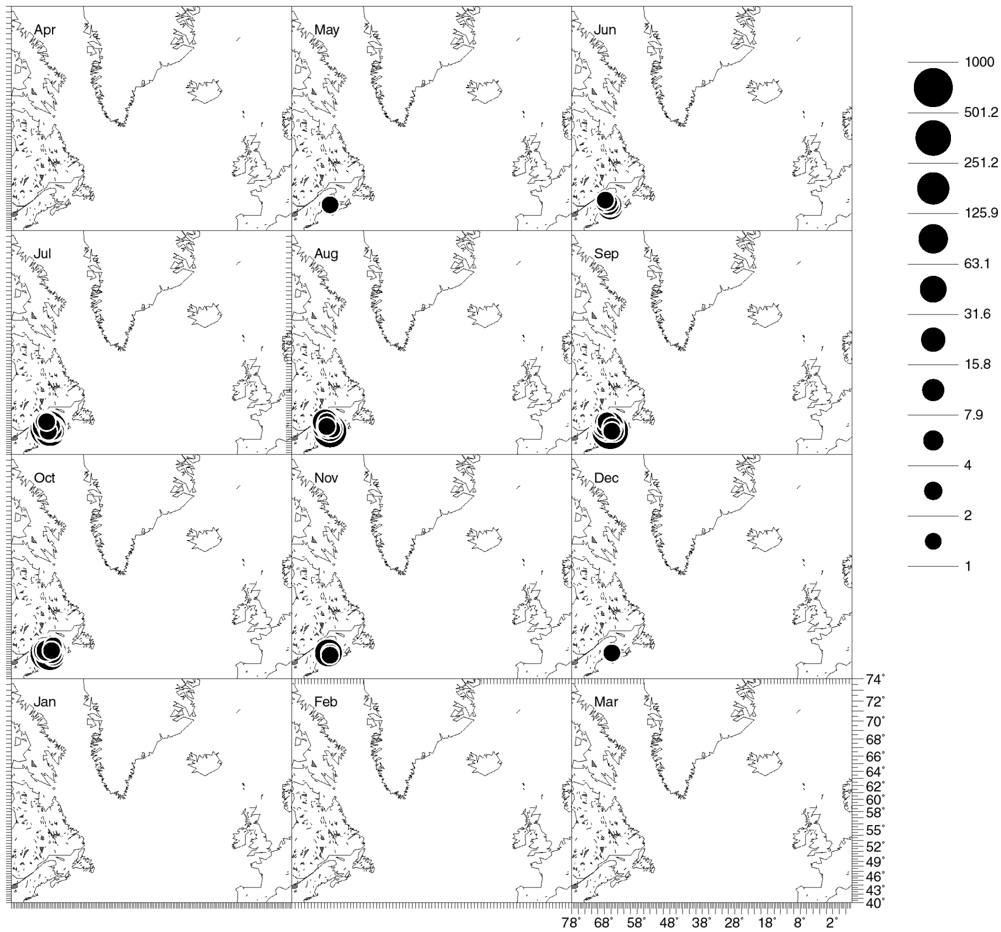

Figure 8. Release-year recoveries from the Saint John River of tagged wild adult aggregated for all available years by 5 minute squares and plotted by month.

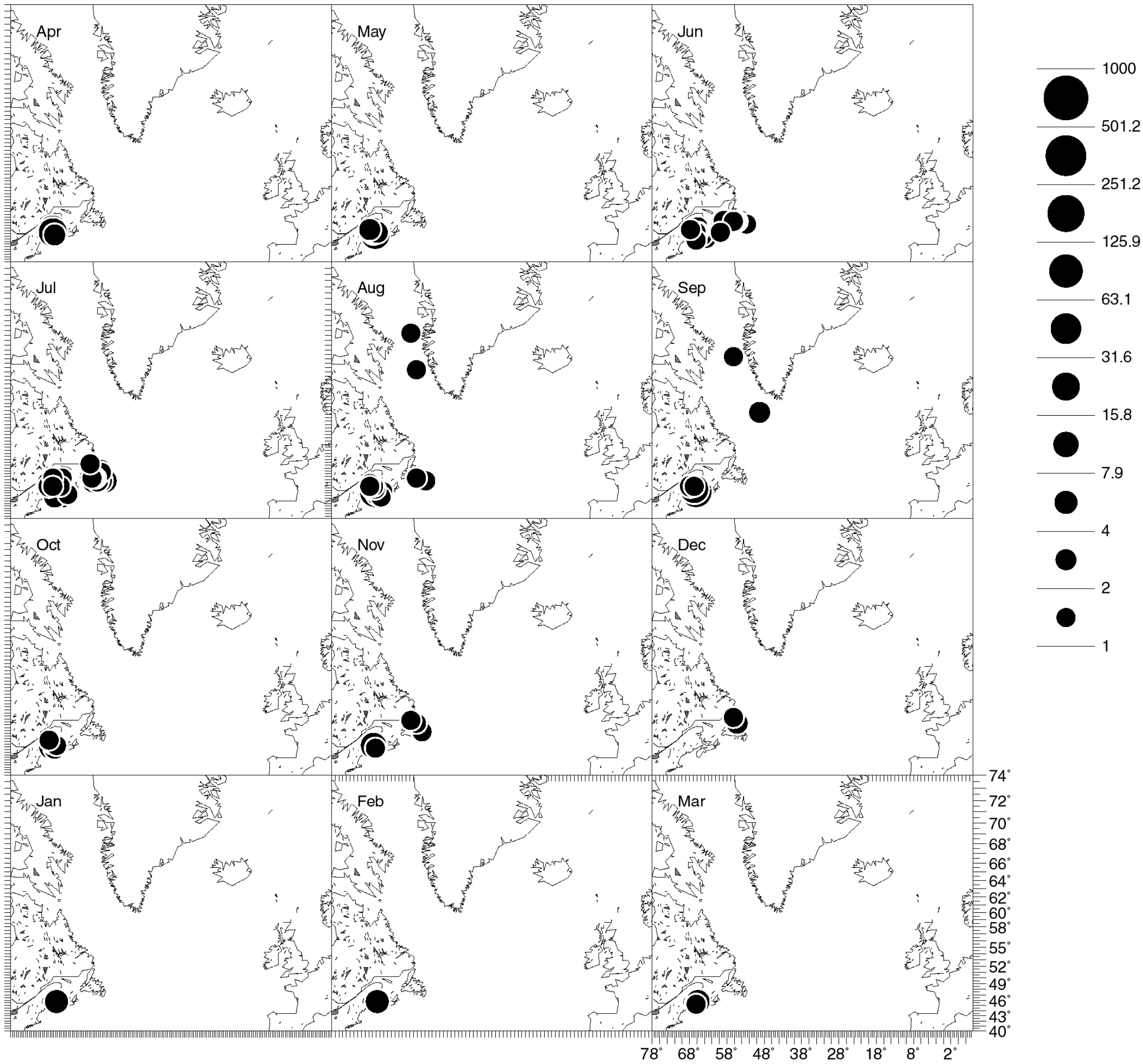

Figure 9. Second-year recoveries from the Saint John River of tagged wild adult aggregated for all available years by 5 minute squares and plotted by month.

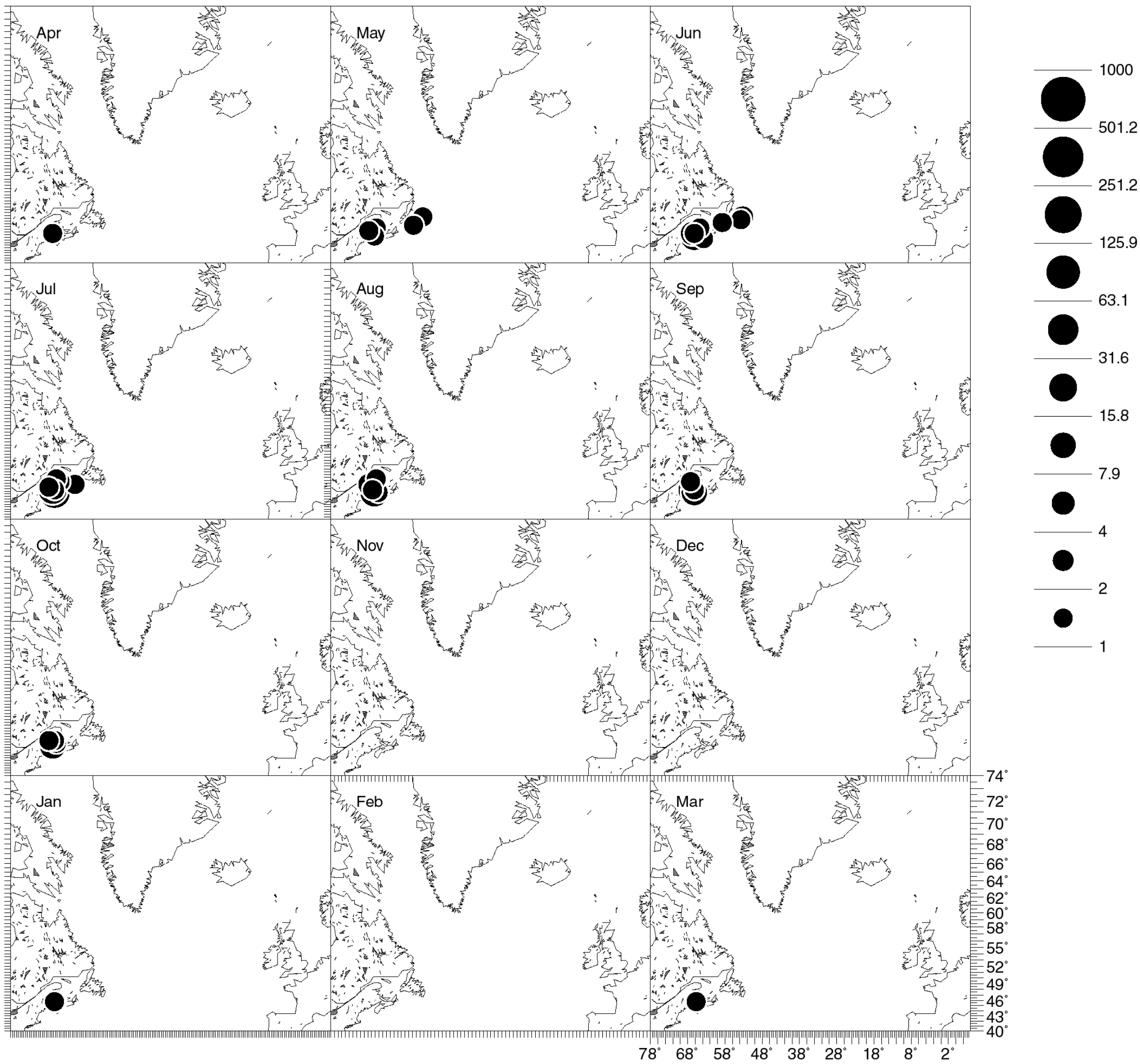

Figure 10. Third-year recoveries from the Saint John River of tagged wild adult aggregated for all available years by 5 minute squares and plotted by month.

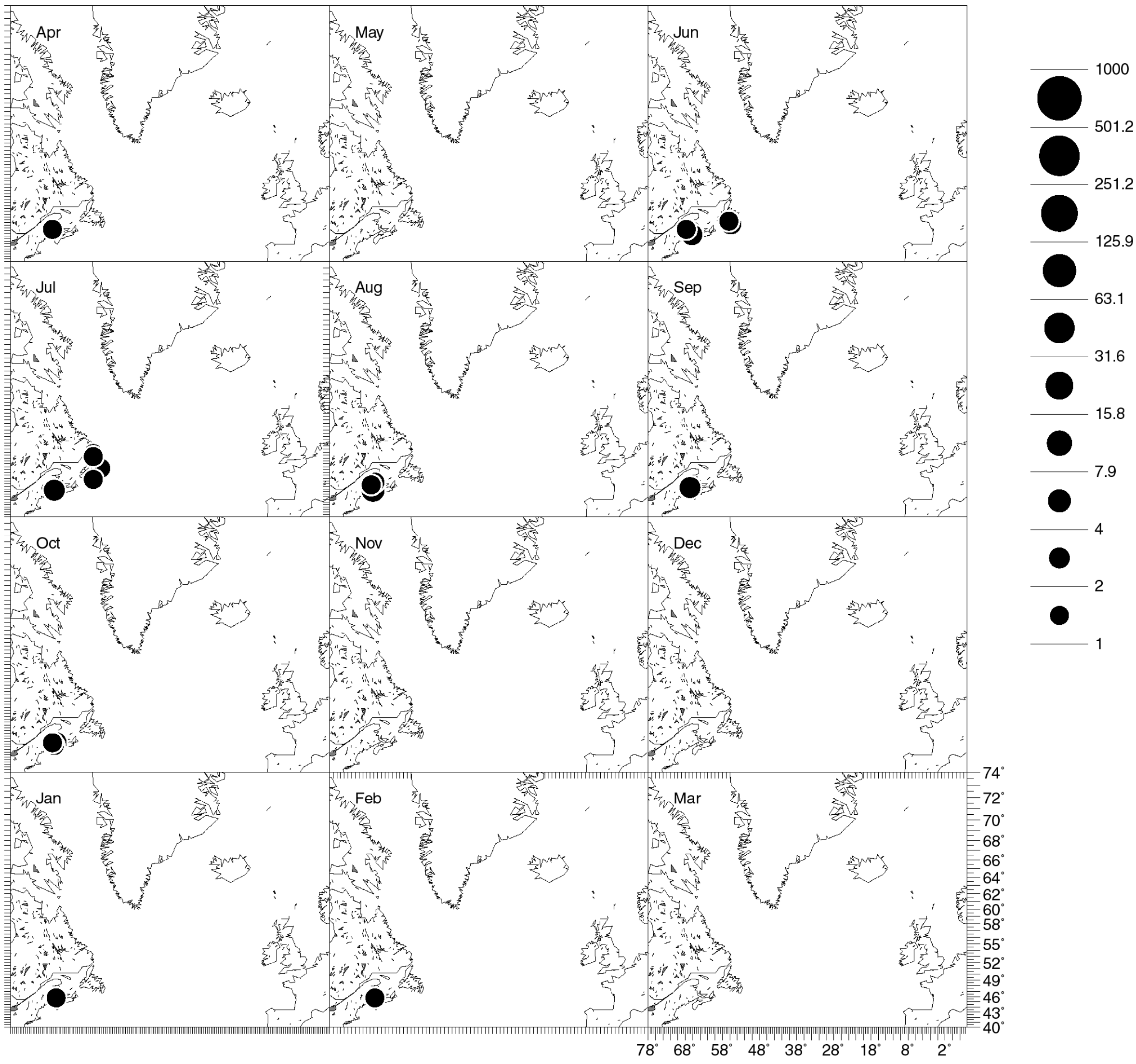

Figure 11. Fourth-year recoveries from the Saint John River of tagged wild adult aggregated for all available years by 5 minute squares and plotted by month.

Principle Components analysis and Bray-Curtis Cluster analysis were applied to the Greenland tag recaptures, based upon the abundance of recoveries in each NAFO Area by country of origin. Principle Components analysis was based on correlation matrices with 3 components calculated and Bray-Curtis was performed using single linkage. Both were performed in BioDiversity Pro.

Analyses were initially performed on raw abundances, (Figures 12 and 13) and second percentage abundance (Figures 14 and 15) to reduce the influence in the data of very high abundances from Canada and the USA and to aid description. The resulting cluster patterns between raw and percentage abundance analyses were fundamentally the same, with the percentage approach giving a slightly larger separation between countries. USA and Canada clustered separately from other countries and demonstrated most similarity in abundance and NAFO recovery areas. PCA positioned UK (Scotland) and UK (England & Wales) in close proximity and separate from remaining countries. This was reflected in the Bray-Curtis clustering, which demonstrated them to have the same percentage similarity as the USA – Canada cluster. Ireland and Norway separated away from the UK (Scotland) – UK (England & Wales) grouping. While PCA clustered Norway, UK (Northern Ireland), Iceland and Ireland in close proximity, Bray-Curtis separated UK (Northern Ireland) and Iceland early, indicating their dissimilarity to the abundances and NAFO recapture areas shown by salmon from other countries.

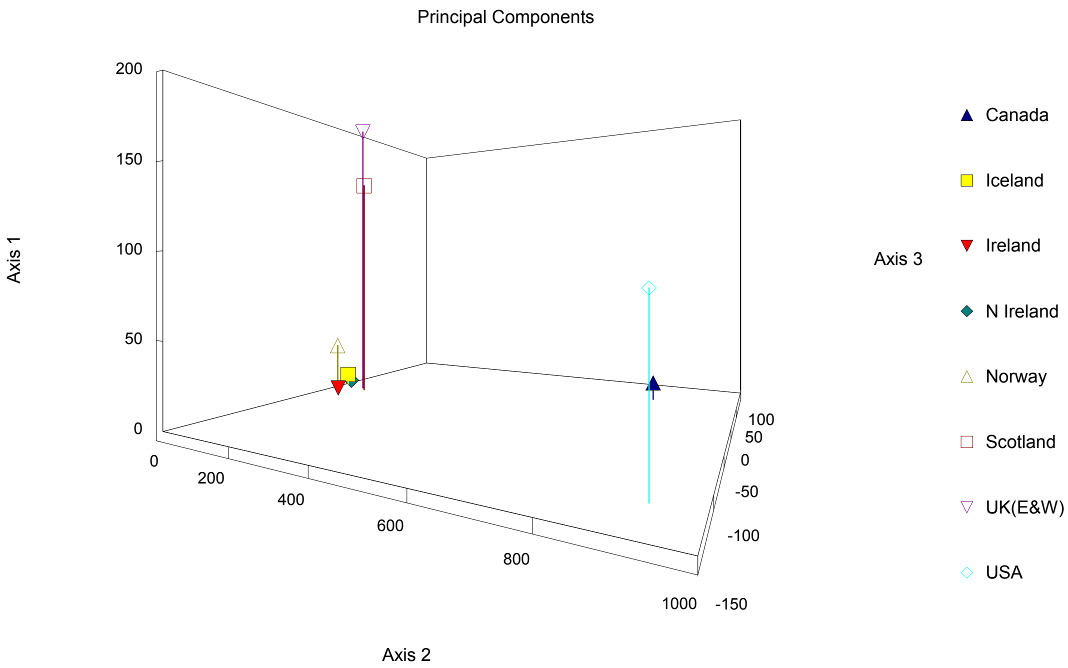

Figure 12. Principle Components Analysis of salmon recapture abundances in NAFO areas from tagging countries.

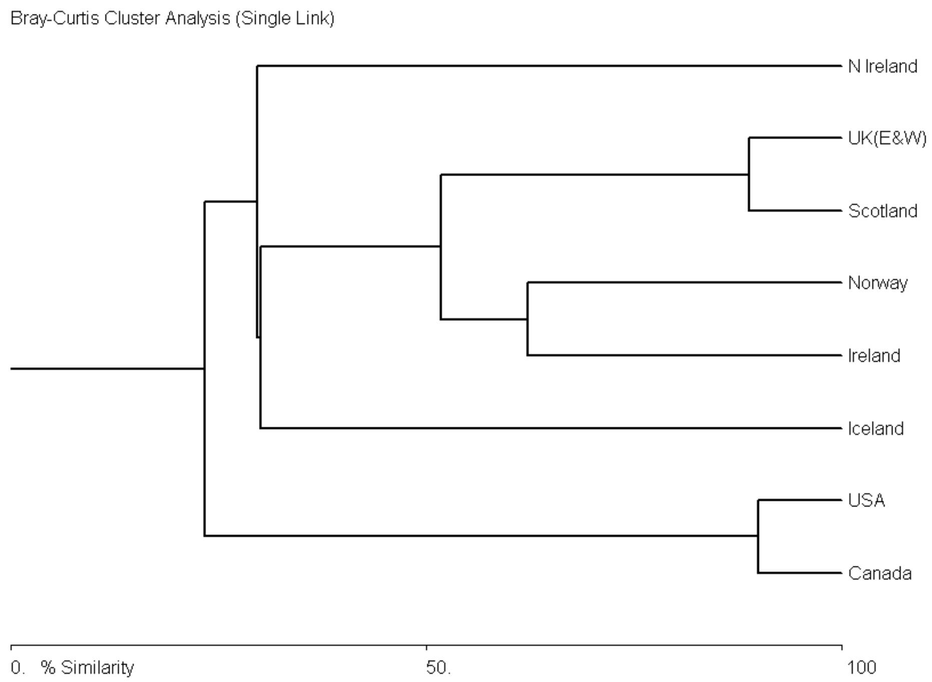

Figure 13. Bray–Curtis Cluster Analysis of salmon recapture abundances in NAFO areas from tagging countries.

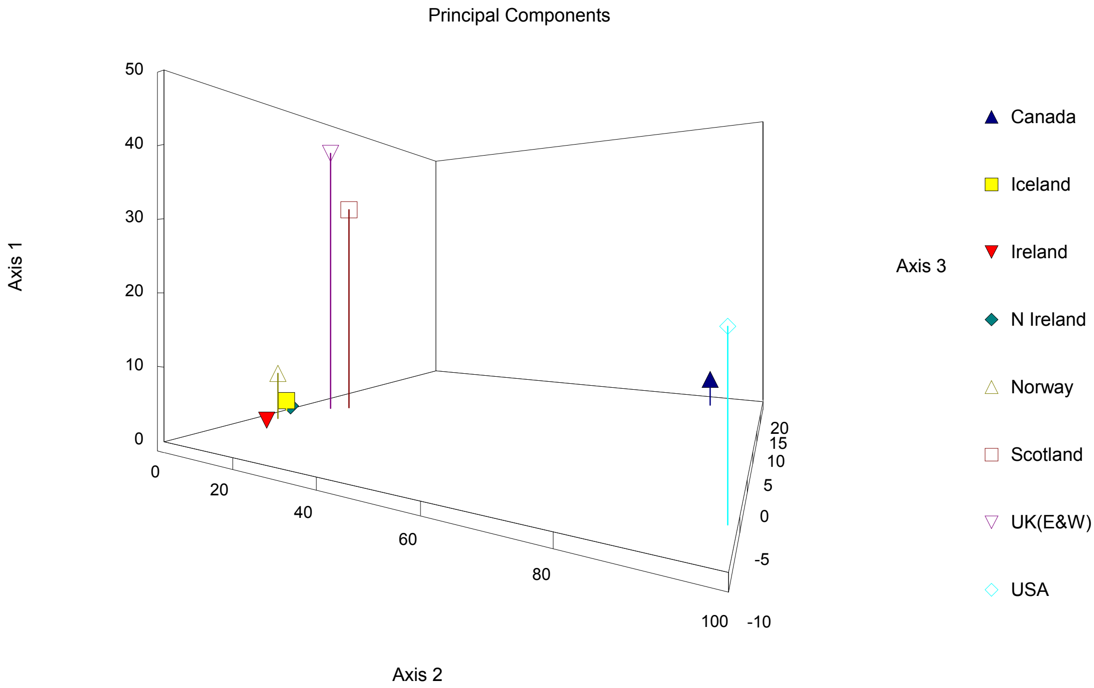

Figure 14. Principle Components Analysis of salmon recaptures as percentage abundances in NAFO areas from tagging countries.

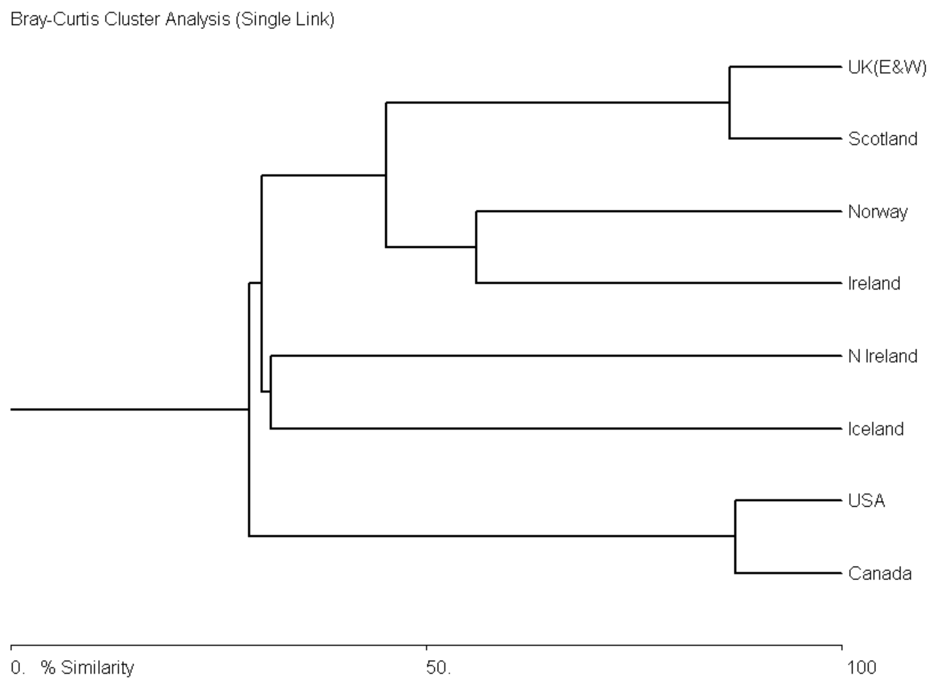

Figure 15. Bray–Curtis Cluster Analysis of salmon recaptures as percentage abundances in NAFO areas from tagging countries.

Time series of SST averaged over the different NAFO areas (near the coast) for August are shown in Figure 16. The data are 5 years averages using only the month August. Several cold periods can be seen in the time-series for all areas, especially around 1970 and 1983. Around mid 1990s a drop in temperature is also observed for nearly all areas but not at the southern area. The most significant cold period around

1970 occurred similar to the "Great Salinity Anomaly" (Dickson *et al.*, 1988) that was a result of increased ice transport out the Fram Strait that flow southwards with the East Greenland Current.

Averaged SST for August for two periods (1965–1985 and 1986–2006) is shown in Figure 17 and the difference between the periods in Figure 18. The latter period was warmer than the former over the whole region (typically 0.5–1.5 deg.C. warmer dependent of area).

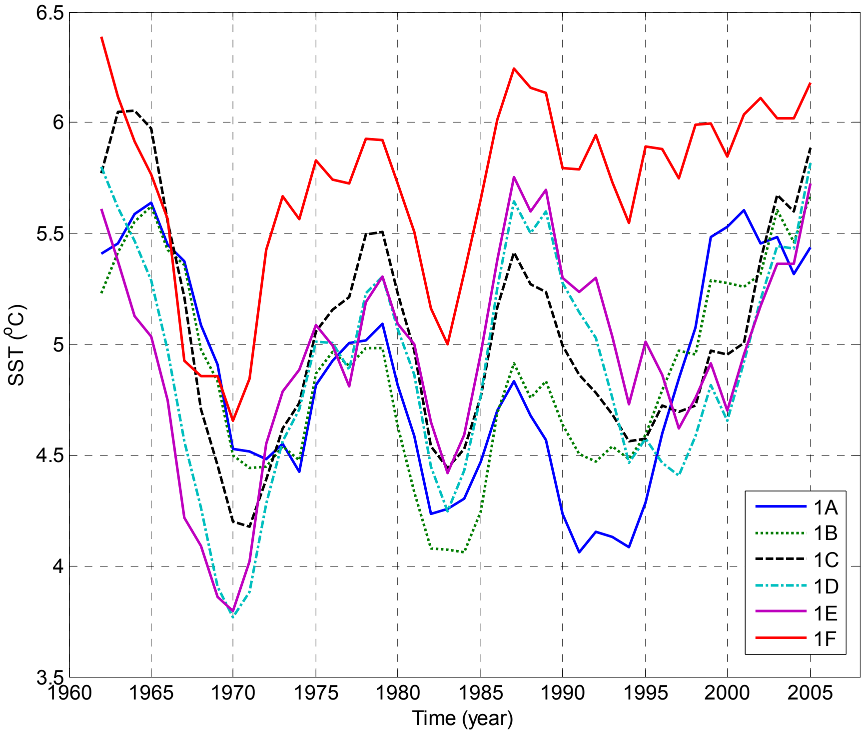

Figure 16. SST averaged over the different NAFOs area along and close to the West Greenland coast. The data are 5 years averages. The different areas where the SSTs are averaged over are shown in the figures below.

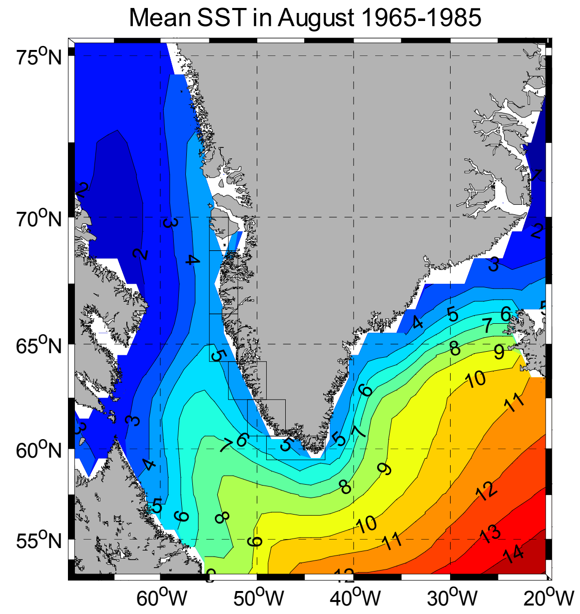

Figure 17. SST for August averaged over 1965–1985 (left) and 1986–2006 (right).

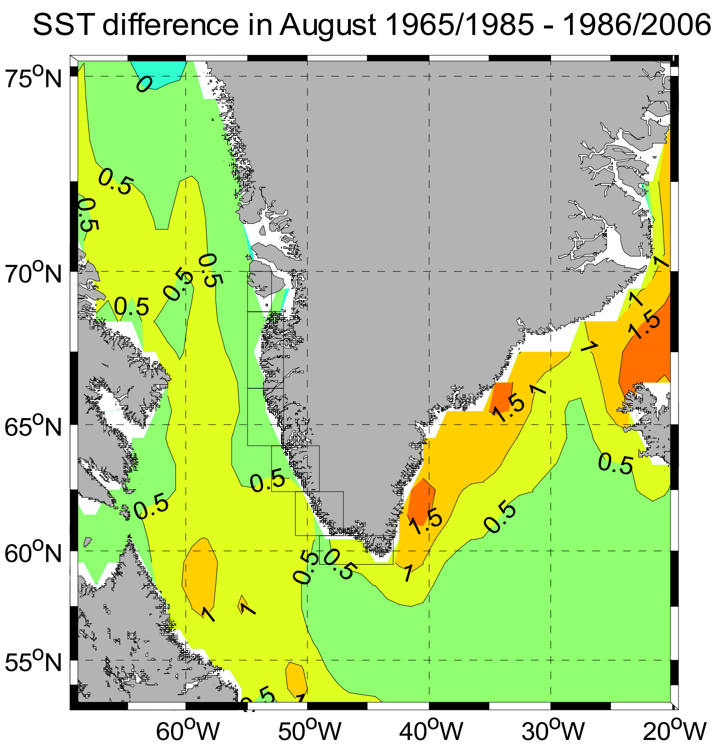

Figure 18. SST difference between the two periods (1986/2006–1965/1985) for August.

4 North East Atlantic

4.1 Material

Tag recoveries from salmon tagged in homewaters and during offshore tagging experiments in the Northeast Atlantic, from the late 1960s to the present, were made available to the workshop. The main difference between the homewater and oceanic tagging data is the life-history stage of the salmon at tagging and the tagging locality. Homewater or smolt tagging is the most widespread form, with usually large batches of smolts being tagged annually in many European countries (ref. ICES annual reports of tag releases). Offshore and oceanic tagging has usually been undertaken for dedicated experiments over shorter time periods (a few years) in a limited area and in a local (experimental) fishery, e.g. two experiments in Faroese waters in the early 1970s (Jákupsstovu, S.H. 1988) and 1990s (Hansen and Jacobsen 2000).

In the present report, only recoveries of salmon tagged in homewater have been analysed. Data from offshore tagging programmes are available in the common database.

The data provided were collated into the format agreed at WKDUHSTI to allow GIS and various statistical analyses to be performed. In total more than 14 million salmon smolts have been tagged in homewaters in the countries around the Northeast Atlantic up to the present.

Countries of origin for reported tag recoveries include Canada, Denmark, Faroes, France, Iceland, Ireland, Norway, Spain, Sweden, UK (England & Wales), UK (N. Ireland), UK (Scotland), USA, France, and Russia. The majority of these were hatchery reared. The available tag recoveries were compiled into a common database (Table 3). Data from France and Russia, and certain entries from other countries (mainly Sweden, Denmark, and Iceland) were not included at the time of writing owing to missing recovery information and incomplete coding. Of 2,651 recorded recoveries, an exact recovery position was available for 2,509. These were digitized for analyses. The data include recoveries of both CWT and external tags.

In addition to the 2,651 smolt tagging recoveries, 810 recaptures of salmon tagged as adult fish in offshore and oceanic areas were included (Table 4) giving 3,461 recoveries from the Northeast Atlantic in the database at present.

Table 3. Northeast Atlantic tagging database holding information of salmon tagged in homewaters (mainly as smolts) and recaptured in oceanic areas. The data include both CWT and external tags.

Country *	No recaptures	No recaptures with exact position
Canada	6	5
Denmark	10	5
Faroes	99	75
France	1	1
Iceland	27	23
Ireland	158	133
Norway	1760	1730
Spain	1	1
Sweden	376	358
UK (England&Wales)	69	57
UK (N.Ireland)	8	7

UK (Scotland)	135	113
USA	1	1
Total	2651	2509

*** Data from France and Russia as yet to included in the database as of 22 September 2008.**

Table 4. Northeast Atlantic tagging database holding information of mainly adult or sub-adult salmon tagged in oceanic and offshore waters.

Area	Time	No tagged	No recaptured	No. with exact position
Greenland	1965–1972	2,293	93	?
Norwegian Sea	1969–1972	4,744	521	521
Faroes	1969–1976	1,946	90	?
	1992–1995	5,448	106	106
Total		14,431	810	627

Use of the recapture data

There are several issues with the use of this database. First, the distribution of tag returns depends on the distribution of fishing effort. There is a need to scale the number of tags returned from each area so data represents the true distribution of fish and not just the distribution of fishing effort. Although fishing effort data are available for most of the Faroese fishery it was not possible in the time available to apply these coherently across the dataset and hence was not used in the present analysis. Second, the tags recaptured are not adjusted by the number of fish originally tagged and nor are they adjusted for the relative production of salmon in each country. Thus, for countries which tag a small proportion of its production, but relative to other countries produce more fish, the number of tags in the database while being very low; represent a large number of salmon in total. In addition, the Faroese fishery has been subject to various management measures over the period, for example shortening of season dates and the introduction of quotas and quota by-outs, so influencing the returns and adding to complexity of comparisons without standardizing data for changes in the resulting effort. These factors have necessarily limited the analysis to only broad general comparisons in the present report.

In the absence of information on the actual numbers of tags that were released from respective areas, it is not possible to scale the recaptures relative to a common denominator. Further, as noted above, a range of other problems exist that could confound interpretation of the results and need to be acknowledged when any analyses are carried out. Analysing data by individual seasons (or months) may circumvent some of these problems, but is often likely to be constrained by the amount of data available in any time interval. Ideally, tag recaptures should be scaled to the numbers of fish caught or to catch-per-unit effort.

Fishery data

CPUE (catch-per-unit effort) data from the Faroese longline fishery since the late 1970s are available at the Faroese Fisheries Laboratory. CPUE data are needed in order to be able to separate potential changes in the distribution of tag recapture rates in various areas from changes in the fishery. As noted above these data have not yet been used in such an analysis.

Environmental data – SST dataset

The Hadley Centre sea surface temperature (SST) (SST) dataset (HadSST2) was used in comparison with tag recovery distributions. This SST data comprises monthly averages with one degree horizontal resolution, compiled from the International Comprehensive Ocean-Atmosphere Data Set, ICOADS, from 1850 to 1997 and from the NCEP-GTS from 1998 to the present.

4.2 Preliminary analysis – recoveries from homewater tagging in the Northeast Atlantic

A total of 2,651 salmon tagged in their Home Rivers, with internal or external tags were recovered in the sea fishery off the Faroes Islands between 1968 and 2000. The principal gear type was floating longline. The following summary assessment is based upon ICES statistical rectangles (ICES rectangles) as a means of subdividing catch to assess distribution, spatially and temporally by country of origin, and frequency patterns in the data.

Catches per country, per year (Figure 19) demonstrated that the largest catches originated from Norway. Salmon tagged in North America, France and Spain was also caught off the Faroes during the time-series, however owing to their small numbers (1 fish per country) they were removed for the following analyses so as not to confound predominant signals in the data. Most catches were recorded during the 1980's, peaking in 1983 at 454 tagged fish. Of the 2,651 records, 53% were recovered between 1982 and 1986, 82% between 1982 and 1990 and 96% between 1978 and 1994.

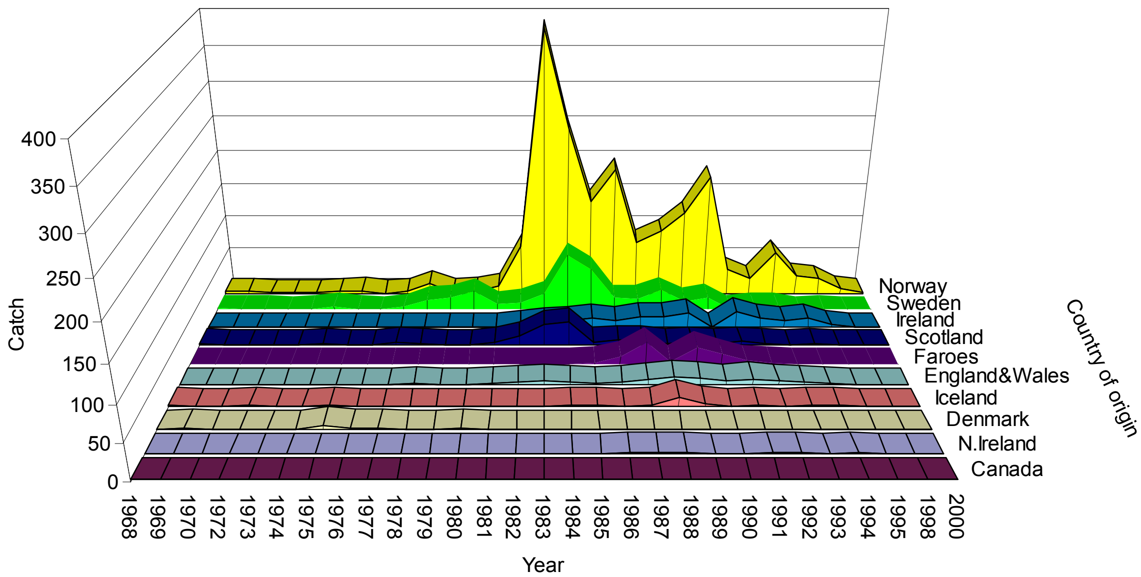

Figure 19. Salmon catch at the Faroes by Country of origin and year.

Frequency abundance of salmon recoveries in ICES rectangles around the Faroes demonstrated a mean of 25.4 salmon per rectangle. This was skewed to the right (skewness 2.69; kurtosis 7.31) and demonstrated similarity to a negative-binomial distribution (Elliott, 1977) (Figure 20). As may be expected, an X^2 test against an expected even distribution over the area, demonstrated significant differences (X^2=1,351, p<0.0001, 49 d.f. based upon 5 count bins).

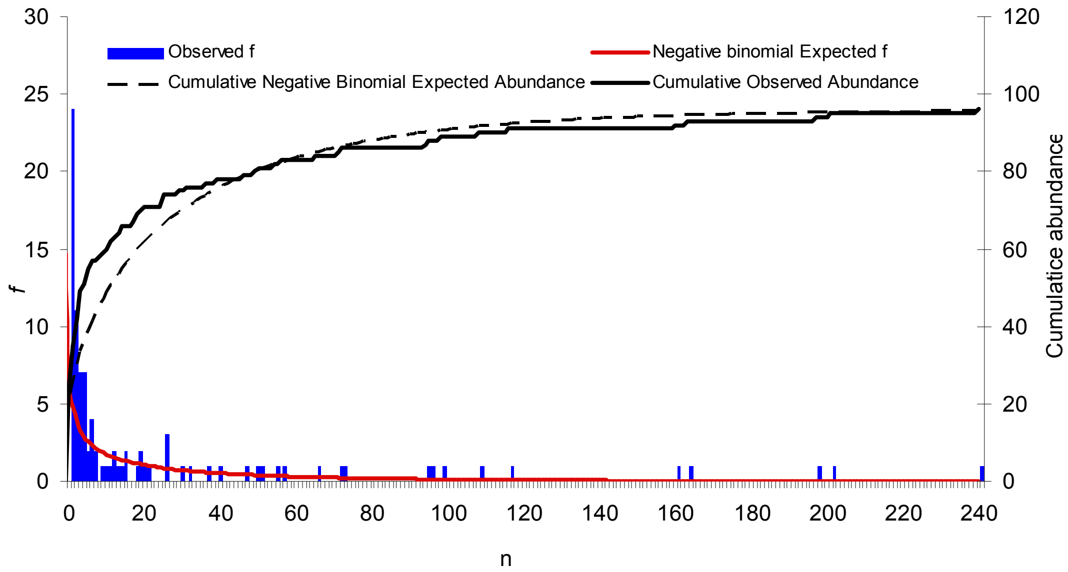

Figure 20. Frequency distribution of tagged salmon recovered around the Faroes by ICES rectangle, predicted negative binomial frequency distribution and associated cumulative abundances.

4.3 Hypothesis: The distribution of salmon at sea is random

Recoveries of tagged fish in ICES rectangles ranged from 1730 fish from Norway to three fish from Denmark and five from Canada. Distributions of salmon by country of origin were also skewed to the right (Table 5) and X^2 tests for agreement with an even distribution were significantly different in all case except Denmark, probably owing to the small number of returns in this instance.

X^2 tests of variance to mean ratio as a test for patchiness showed 56 of 96 ICES rectangles around the Faroes to have a significant aggregation of salmon returns (Rice and Lambshead, 1994). The inverse analysis by tagging country, reveals that all recaptures were significantly aggregated by tagging country, except for Denmark which showed a random distribution (again probably owing to the small number returns) (Table 6). While only 3 recovery frequencies showed agreement with expected negative binomial distributions (Ludwig and Reynolds, 1988), plots of observed/negative binomial expected frequencies showed close approximations for all countries (Figure 21).

Table 5. Descriptive statistics of tagged salmon recoveries in ICES rectangles around the Faroes by country of release: n = number of ICES rectangles containing recoveries; count = number of salmon recaptures per country; *p* = probability of even distribution X^2.

Tagging country	n	n>0	Count	Max	Min	Mean	Med-dian	Skew-ness	Kurt-oses	Even dist X^2	p
Canada	96	3	5	3	0	0.052	0.0	7.724	64.58	206	<0.001***
Denmark	96	3	3	1	0	0.031	0.0	5.474	28.56	93	0.54
England & Wales	96	24	57	7	0	0.594	0.0	3.286	11.64	322	<0.001***
Faroes	96	21	77	13	0	0.802	0.0	3.686	13.90	625	<0.001***
Iceland	96	13	22	4	0	0.229	0.0	3.511	13.53	187	<0.001***
Ireland	96	33	133	20	0	1.385	0.0	3.701	16.18	678	<0.001***
N.Ireland	96	6	8	2	0	0.083	0.0	4.464	20.40	136	<0.001***
Norway	96	82	1730	156	0	18.02	3.0	2.680	6.784	6263	<0.001***
Scotland	96	31	113	12	0	1.177	0.0	2.853	8.298	518	<0.001***
Sweden	96	48	370	47	0	3.854	0.5	3.411	14.45	1395	<0.001***

Table 6. Aggregation of tagged salmon by country of release in ICES rectangles around the Faroes as s²/mean X^2 test; "*k*" parameter from the negative binomial frequency distribution, and associated X^2 test for agreement with negative binomial distribution; *p* = probability.

Tagging Country	N	Variance	Mean	S2/ mean X2	P	Aggregated	K	Neg-bin freq X^2	P
Canada	96	0.11	0.05	206	0.000***	Yes	0.035	2.93	0.402
Denmark	96	0.03	0.03	93	0.539	No	-0.610	0.00	0.971
England & Wales	96	2.01	0.59	321	0.000***	Yes	0.222	18.35	0.010**
Faroes	96	5.28	0.80	624	0.000***	Yes	0.120	17.82	0.165
Iceland	96	0.45	0.23	187	0.000***	Yes	0.177	1.45	0.866
Ireland	96	9.88	1.39	677	0.000***	Yes	0.210	28.67	0.095
N.Ireland	96	0.12	0.08	136	0.004**	Yes	1.730	6.84	0.033*
Norway	96	1188.0	18.02	6262	0.000***	Yes	0.374	310.92	0.000***
Scotland	96	6.42	1.18	518	0.000***	Yes	0.208	20.74	0.054
Sweden	96	56.59	3.85	1394	0.000***	Yes	0.251	62.51	0.064

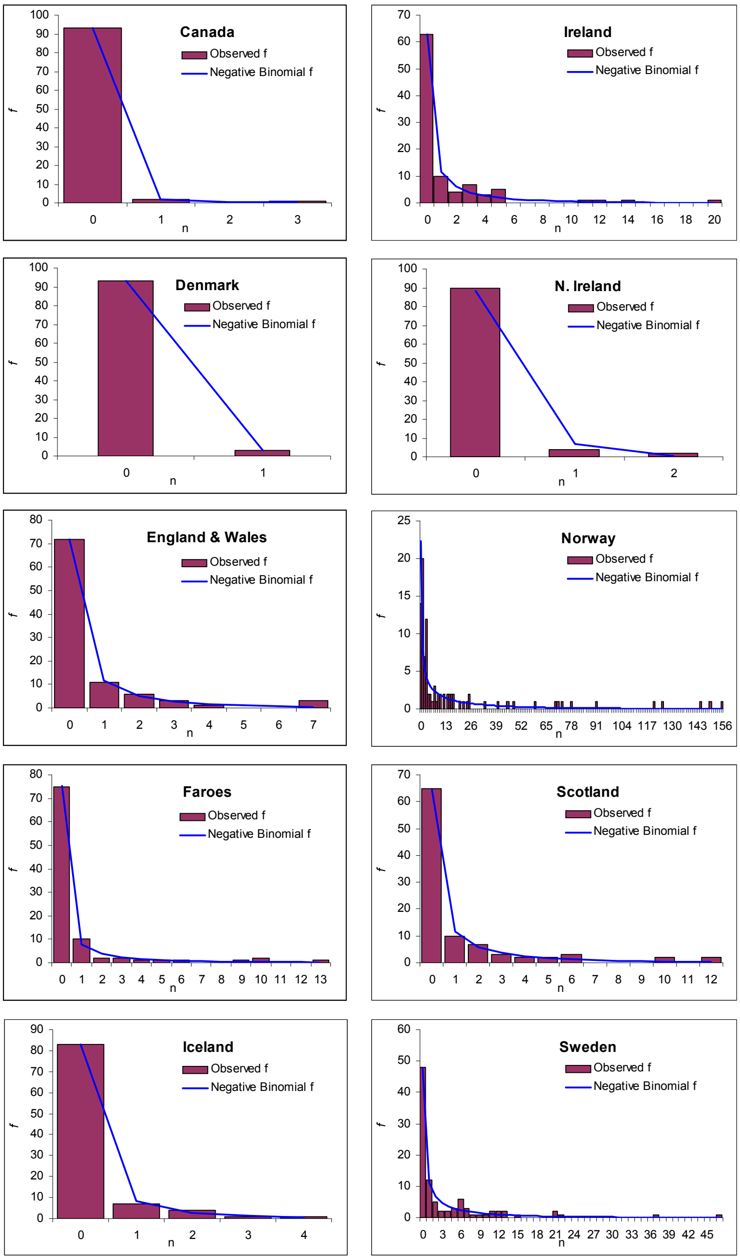

Figure 21. Observed and negative binomial frequency distributions of Northeast Atlantic recaptures by country of origin.

The observed spatial distribution of salmon recoveries north of the Faroes suggested clumping around two main areas, one northeasterly and one southwesterly (Figure 22). Significance testing of this apparent distribution was done using the "Average Nearest Neighbour" method, and we thus reject the hypothesis that the distribution of salmon at sea is random:

Average Nearest Neighbour Summary.

Observed Mean Distance	0.029402
Expected Mean Distance	0.096141
Nearest Neighbor Ratio	0.305820
Z Score	-66.612861
p-value	0.000000

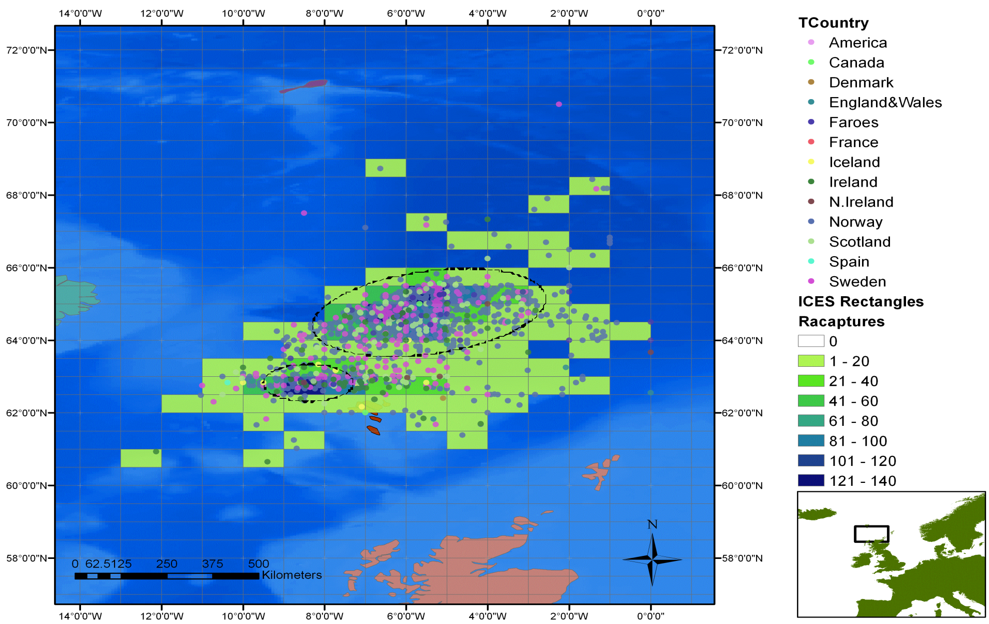

Figure 22. Spatial distribution of salmon recaptures around the Faroes and associated densities per ICES rectangles with hypothesized clusters indicated by dashed ovals.

Principle Components analysis

Principle Components analysis and Bray-Curtis Cluster analysis were applied to the Faroes tag returns, based upon the abundance of recoveries in each ICES rectangle by country of origin. Principle Components analysis was based on correlation matrices with 3 components calculated and Bray-Curtis Cluster Analysis was performed using single linkage. Both were performed in the computer package BioDiversity Pro.

Analyses were performed on raw abundances (Figures 23 and 24). Norway and Sweden separated out most notably in PCA analysis, indicating differences in distributions of their recoveries among ICES rectangles compared to tag recaptures from other Countries, and probably a result of their large recoveries (1,732 and 370, respectively). Recoveries from other countries aggregated, with Scotland and Ireland showing close proximity, as did Canada and Denmark, Faroes and England-Wales and Iceland and Northern Ireland. It should be noted that these groupings might be confounded by the inhomogeneous distribution in the catches (or fishing effort) between autumn and winter season fishery. Therefore further analyses need to include season or month as a parameter, but preliminary results lend support of the rejection of the hypothesis on random distribution.

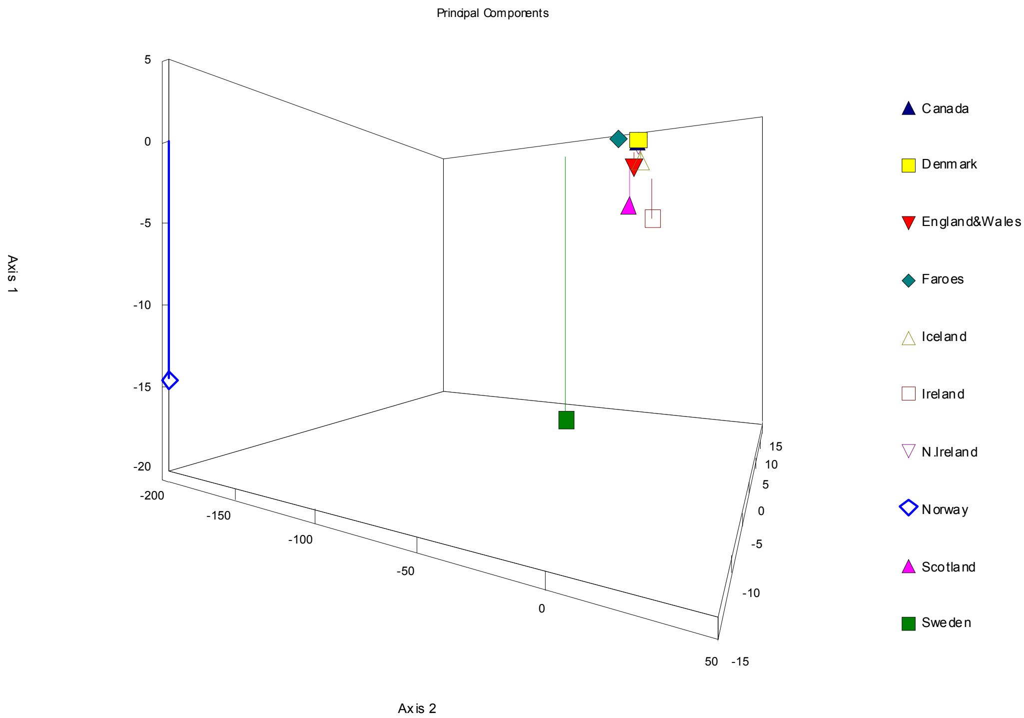

Figure 23. Principle Components Analysis of salmon recaptures abundances in ICES rectangles from tagging countries.

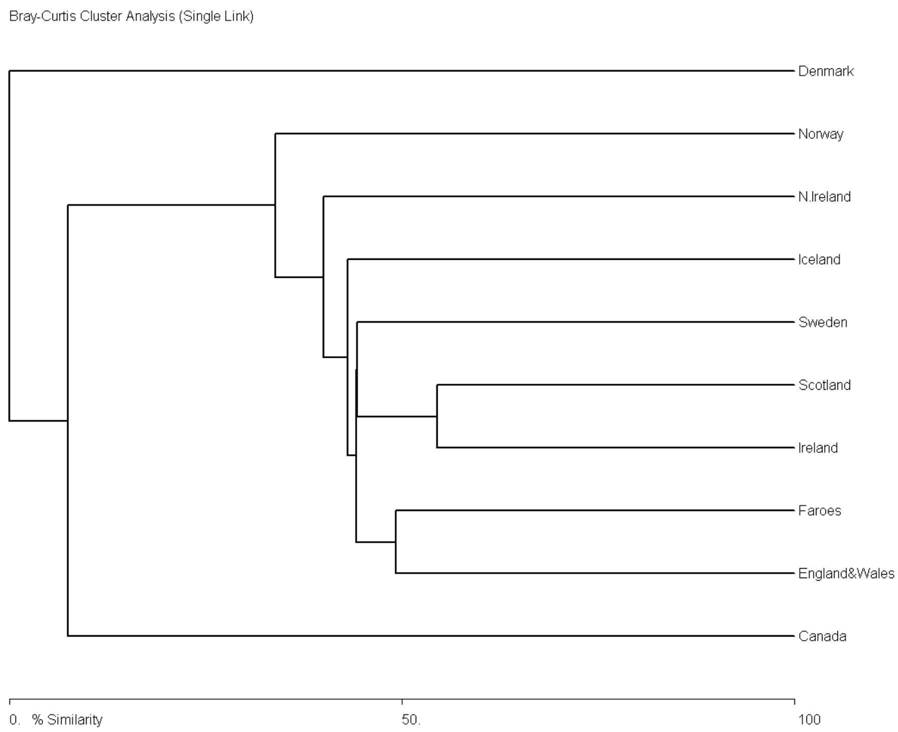

Figure 24. Bray–Curtis Cluster Analysis of salmon recaptures abundances in ICES rectangles from tagging countries.

4.4 Hypothesis: The distribution and migration of salmon at sea is independent of sea age

Basic to the information of the distribution of salmon at sea is whether or not the distribution of recaptures is independent of sea age. Sea age of recoveries differed by country of origin, with the majority of fish from Norway and Sweden, the Faroes, Iceland and England & Wales being 2 SW fish while the majority of salmon from Ireland and Northern Ireland were 1 SW fish (Table 7). Overall the majority of salmon caught were 2 SW fish (71%).

Table 7. Salmon at sea age (sea winters, SW) for recoveries around the Faroes by country of origin, by number (and percentage per country).

COUNTRY OF ORIGIN	SEA AGE (YEARS)							
	0	%	1	%	2	%	3	%
Canada	3*	(50)	0	(0)	1	(17)	2	(33)
Denmark	0	(0)	5	(50)	2	(20)	3	(30)
England & Wales	1	(1)	15	(22)	47	(68)	6	(9)
Faroes	15	(15)	2	(2)	78	(79)	4	(4)
Iceland	0	(0)	5	(19)	20	(74)	2	(7)
Ireland	0	(0)	123	(78)	35	(22)	0	(0)
N. Ireland	0	(0)	5	(63)	2	(25)	1	(13)
Norway	0	(0)	230	(13)	1358	(77)	172	(10)
Scotland	18	(13)	25	(19)	73	(54)	19	(14)
Sweden	3	(1)	73	(19)	258	(69)	42	(11)
Sum	40	(2)	483	(18)	1874	(71)	251	(9)

* **This is an error in the database as all recoveries from Canada were MSW fish.**

Catch areas for sea age-groups 0, 1, 2 and 3 were clustered (see Global Moran's Index below and Figure 25), further, catches of the MSW fish appear to have been more prevalent in the northeast catch area (Figure 26). Results suggest rejection of the hypothesis and we must conclude that the different sea ages are not distributed at random but clustered. A word of caution should be mentioned here since the sea age distribution might be confounded by the differences in the spatial distribution of the fishery in a year (Figure 26).

Global Moran's Index Summary.

MORAN'S INDEX	0.019064
Expected Index	-0.000398
Variance	0.000000
Z Score	33.185868
p-value	0.000000

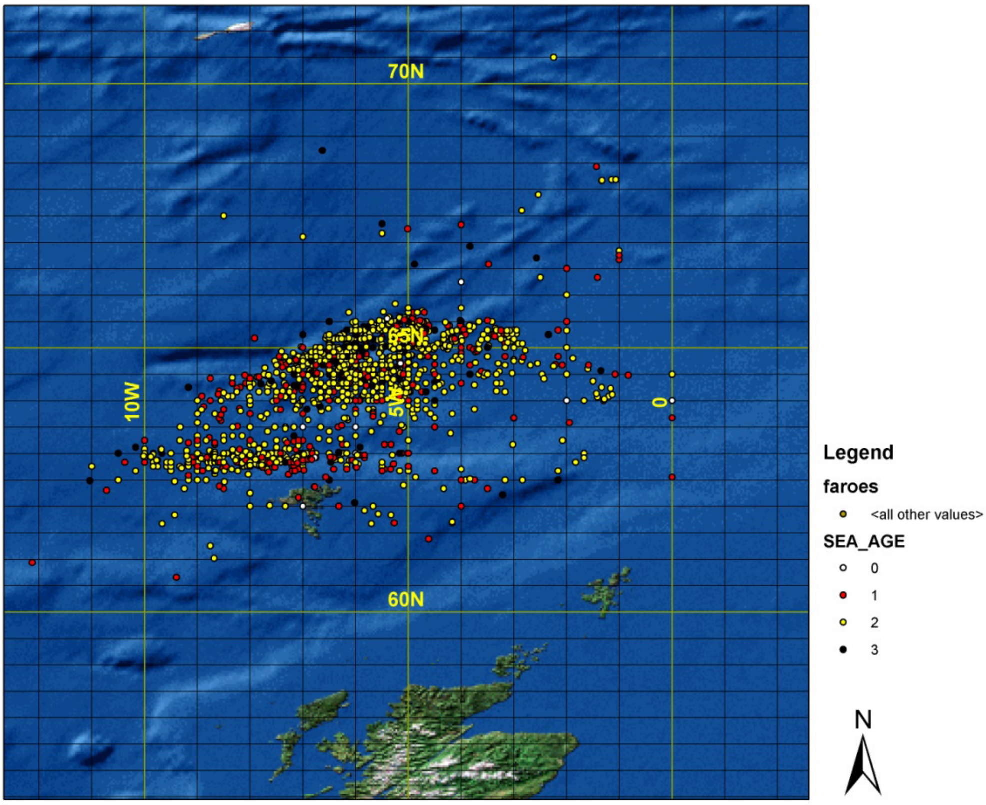

Figure 25. Distribution of salmon recaptures north of the Faroes grouped by sea age 0, 1 and 2.

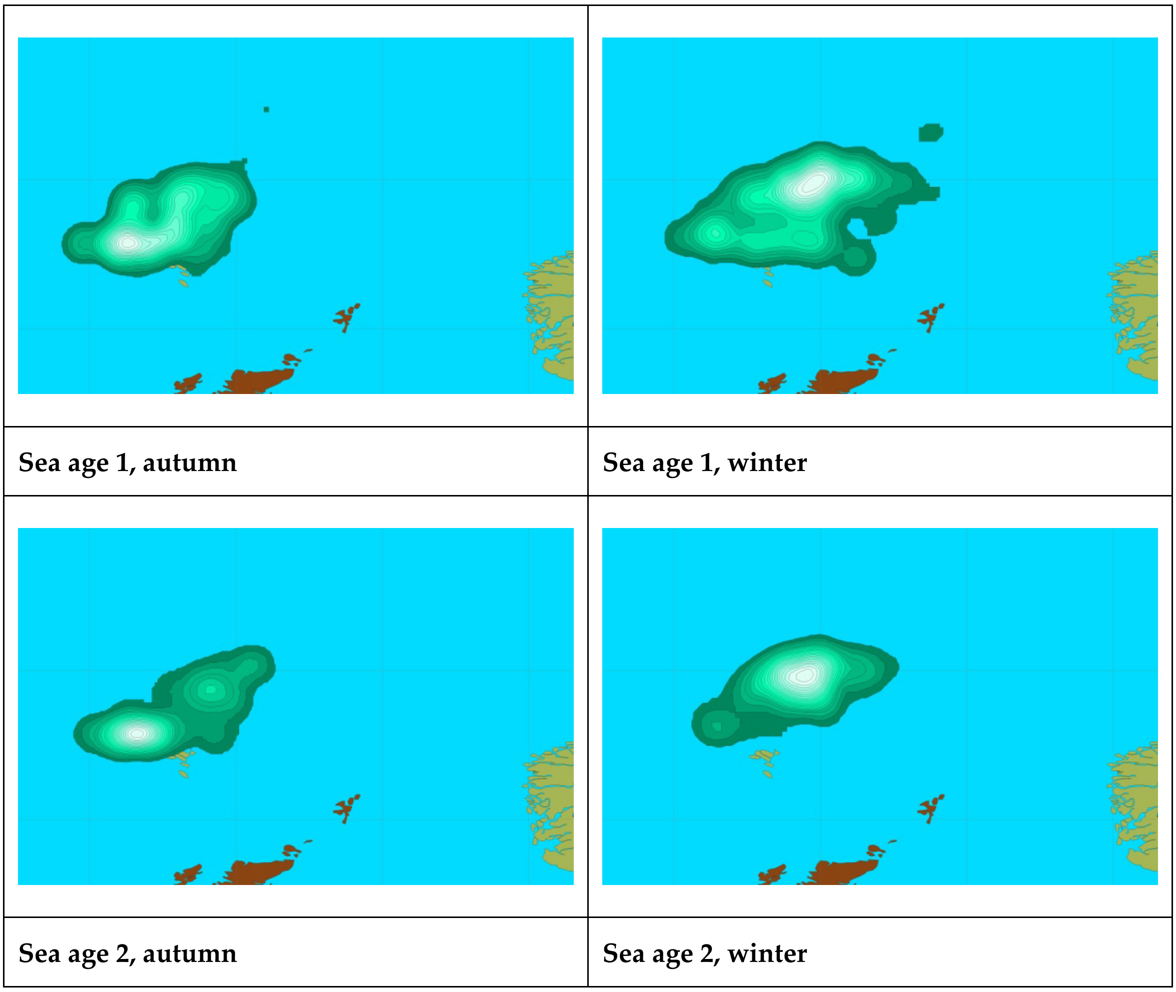

Figure 26. Kernel plots of salmon recaptures (numbers) north of the Faroes grouped by sea age 1 and 2 and by season, autumn (Nov-Dec) and winter (Feb-May).

4.5 Hypothesis: The distribution and migration of salmon at sea is independent of (fishing) season

To test this hypothesis all fish were grouped into season, one early or autumn (Nov-Dec) season and one late or winter (February–May) season. The results indicate a clear difference between the recaptures in autumn and winter. Early in the season the salmon were clustered to the southwest, and later to the northeast (see Global Moran's Index below and Figure 27). Again, the fishing effort (cpue) needs to be incorporated to account for potential influences from changes in the fishery.

Global Moran's Index Summary.

Moran's Index	0.227504
Expected Index	-0.000398
Variance	0.000000
Z Score	388.458483
p-value	0.000000

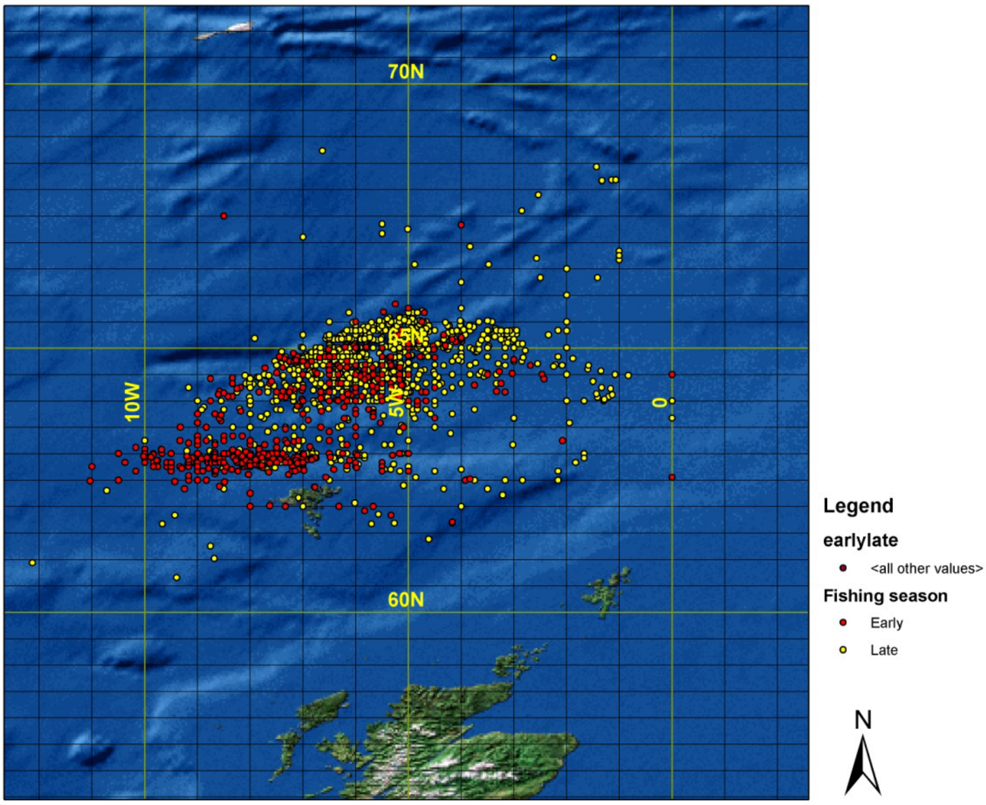

Figure 27. Distribution of recaptures by season north of the Faroes, early or autumn (Nov-Dec, red dots) and late or winter (Feb-May, yellow dots).

4.6 Hypothesis: The distribution and migration of European salmon caught at the Faroe Islands is independent of geographical origin of stocks (e.g. northern vs. southern stocks)

This hypothesis should test possible clustering of recaptures north of the Faroes between two geographical groups of release areas: the Southern and the Northern European countries. The Northern group is recognized as consisting of Norway, Sweden, Finland, Denmark, Iceland (north/east region), Russia, and the Southern group consists of Ireland, UK (England & Wales), UK (Scotland), UK (Northern Ireland), Iceland (north/east region) and France.

Owing to time and data restraints only a preliminary assessment of two smaller groups of countries was possible. The Northern stocks were itemized as Norway, Sweden and the UK (Scotland) and the southern stocks as Ireland and the UK (England & Wales). A visual inspection of the distribution of recaptures from these northern and southern stocks is suggestive of a more northerly location of recaptures from the Northern group (Figure 28). Clearly this observation needs to be examined in more detail with significance testing and incorporation of data indicating fishing effort.

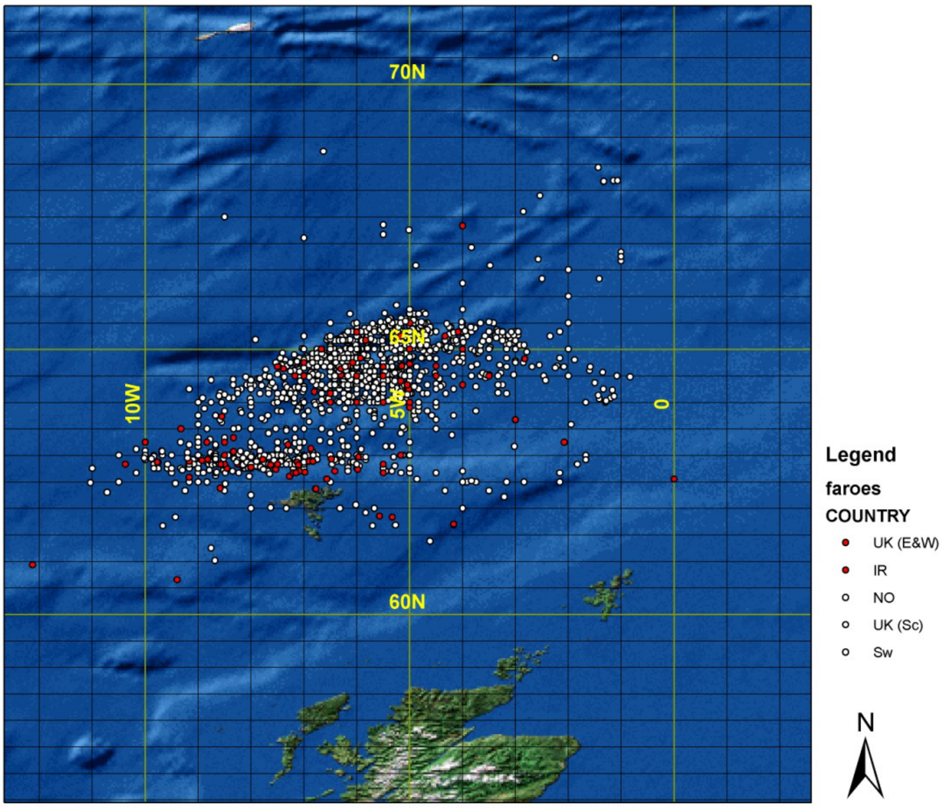

Figure 28. Distribution of salmon recaptures north of the Faroes between two geographical groups of release areas: A southern group comprising: Ireland and UK (England & Wales) and; a northern group comprising Norway, Sweden and UK (Scotland).

4.7 Environment

It should be expected that observed changes in the environment from around the mid 1990s may have influenced the distribution of salmon north of the Faroes. A SST value was interpolated (temporally and spatially) for each salmon recapture location. Figure 29 shows the years and months of the recaptured salmon with associated SST. Warm periods (the end of the 1980s) and cold periods (1982–1983, 1992–1995) are apparent; however this may well be a result of the different recovery locations.

The distributions of fish for autumn (Nov-Dec) and winter (Feb-Mar and May-Jun) periods are plotted on the distributions of the long-term mean SST for the same periods (Figure 30). The fish in Feb-Mar have a more North-South extension and are generally located in colder water than for the other two periods (see also Figure 29).

At each location, with recaptured fish, a SST anomaly was calculated. The anomaly was the difference between the ambient SST value and the long-term-mean SST for that month and location. This way the effects of both location and time of year are removed. The time-series of the individual SST anomalies together with the yearly and five year averages are plotted in Figure 31, salmon recaptures were found in relatively colder water during 1981–1984 and 1993–1996 and in relatively warmer water during 1985–1988. Similar SST variability can also be found north of the Faroes (Figure 32).

The location of the fish for these three mentioned periods for Nov-Dec (autumn) and Feb-Mar (winter) are shown in Figure 33. In winter fishery several fish were recaptured further north and thus in colder waters during 1981–1984 compared to autumn period. In winter 1985–1988 all fish were found in water with average temperatures above 4°C. In 1993–1996 the fish was not located further to the north but were found in colder water north of the Faroes. It may be proposed that this was probably a result of increased southwesterly winds (i.e. a high NAO index) over several years that caused an increased transport of Arctic waters to the area. A more southwards location of the fish was also found in autumn (1993–1996) compared to the other two periods.

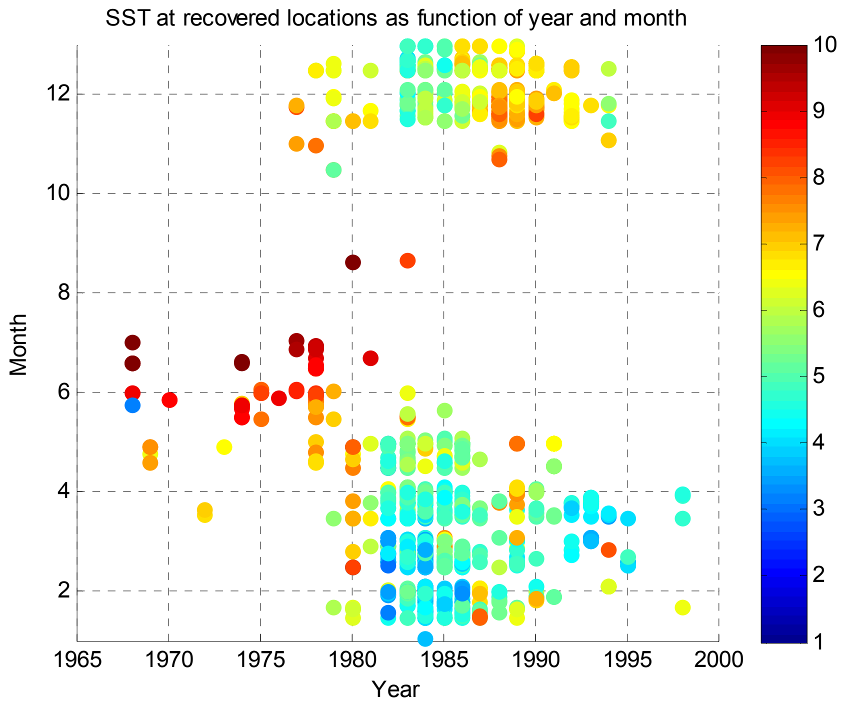

Figure 29. SST at the locations where fish were recaptured as a function of year and month.

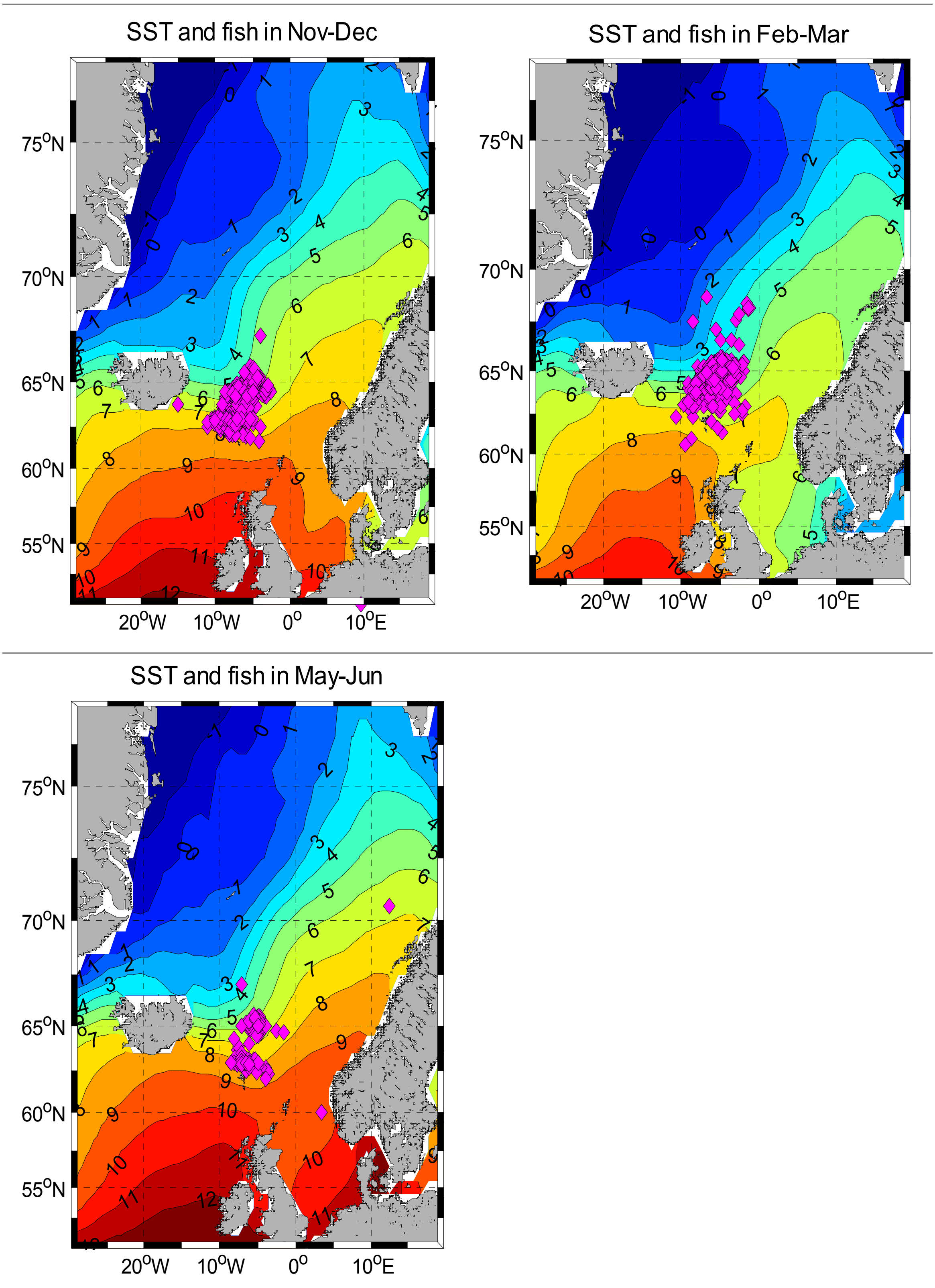

Figure 30. Averaged SST together with all recaptured fish for different months.

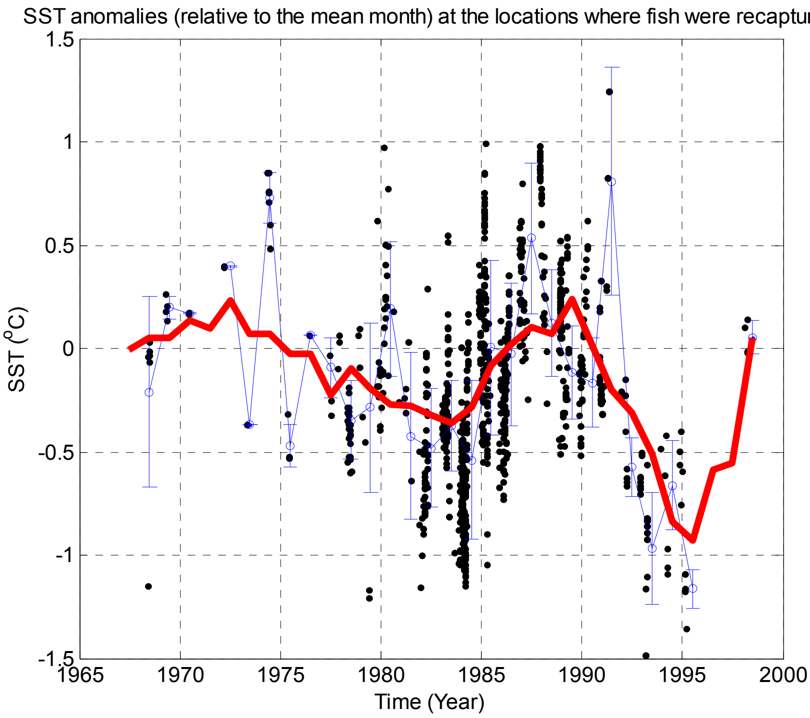

Figure 31. SST anomalies at the recaptured locations. The anomalies are relative to the long-time-mean month when the fish were recaptured. Black dots are individual recaptured SST anomalies, the blue line is yearly averaged with error bar (standard deviations) and the red line is five year running average.

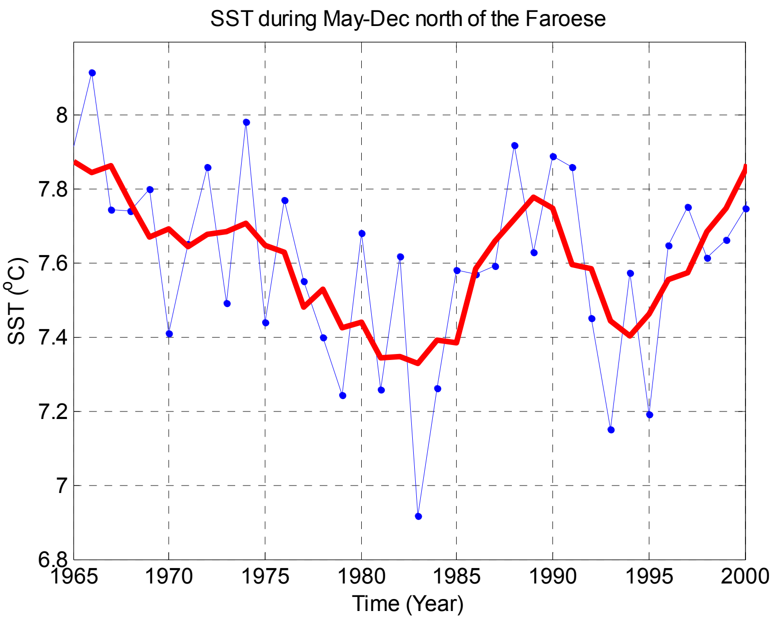

Figure 32. Mean SST during May-December at 64° N, 7° W (North of the Faroes). The Red line is the five year running average. Data are from Jensen *et al.* (2008) and are based on the monthly NOAA Extended Reconstructed SST (http://lwf.ncdc.noaa.gov/oa/climate/research/sst/sst.html).

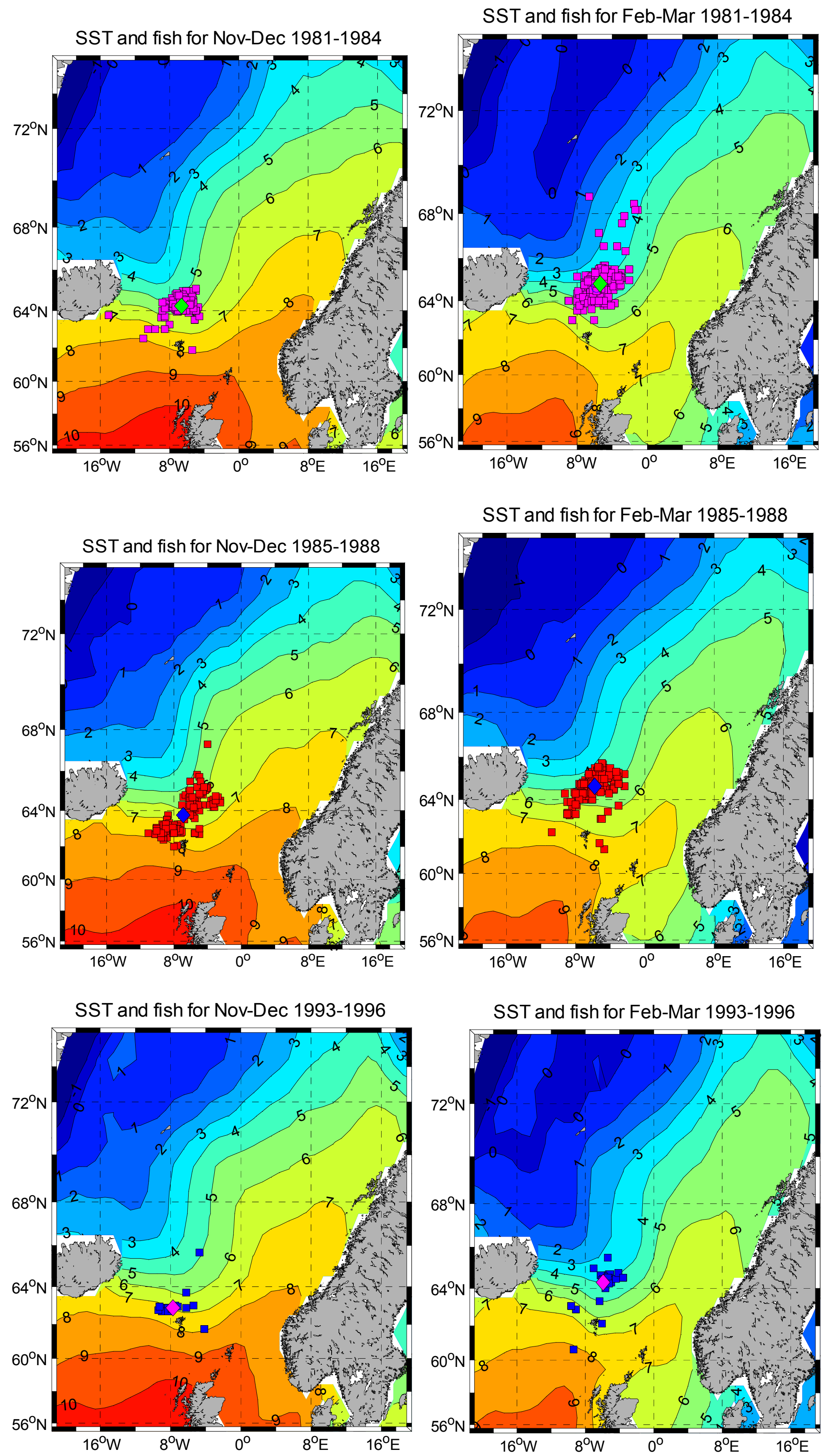

Figure 33. Averaged SST and location of recaptured fish for Nov-Dec (left figures) and Feb-March (right figures) in 1981–1984 (upper figures), 1985–1988 (middle figures) and 1993–1996 (lower figures). The diamond in each figure represents the centre of locations.

The hypothesis of the distribution and migration of salmon at sea being independent of (fishing) season has not been tested in the present report, but previous studies in the Faroese zone have revealed that the country of origin of the salmon caught in autumn differs from the composition in winter (Jacobsen *et al.*, 2001), supporting a rejection.

Preliminary analysis indicates that there are valuable patterns in the compiled dataset pertaining to spatial and temporal salmon distributions around the Faroes. But care needs to be taken analysing these in terms of significance testing, to prevent assumptions that patterns in the data are a reflection of salmon spatial and temporal distribution over traditionally established fishing grounds and effort influences, tagging effort or inherent frequency distribution elements in the dataset. It should be noted that in the analyses of a single parameter, e.g. sea age or country of origin, there is a chance that it may be confounded by inhomogeneous distribution in the catches (or fishing effort) over time. The effort is probably not randomly distributed during autumn and winter season fishery, thus further analyses need to include a time parameter such as season or month in the tests.

We were not able to test all hypothesis put forwards in the WKDUHSTI report 2007 owing to complexities in data compilation and data gaps. The foundation was laid however during the Workshop, with the creation of the common database holding release and recovery information and with digitized positions ready for multilayered GIS analyses.

5 References

Dempson, J. B., and Kristofferson, A. H. 1987. Spatial and temporal aspects of the ocean migration of anadromous Arctic char. American Fisheries Society Symposium, 1: 340–357.

Dempson, J.B., D.G. Reddin, M.F. O'Connell, J. Helbig, C.E. Bourgeois, C. Mullins, T.R. Porter, G. Lilly, J. Carscadden, G.B. Stenson, and D. Kulka. 1998. Spatial and temporal variation in Atlantic salmon abundance in the Newfoundland-Labrador region with emphasis on factors that may have contributed to low returns in 1997. DFO Atlantic Fisheries Res., Doc. 98/114, 161 p.

Doubleday, W.G., Rivard, D.R., Ritter, J.A. and Vickers, K.U. 1979. Natural mortality rate estimates for North Atlantic salmon in the sea. ICES CM 1979/M:26.

Elliott, J. M. 1977. Some methods for the statistical analysis of samples of benthic invertebrates. 2nd ed. Freshwater Biological Association scientific publication, no. 25. Ambleside: Freshwater Biological Association.

Friedland, K.D., D.G. Reddin, and J.F. Kocik. 1993. Marine survival of North American and European salmon: effects of growth and environment. ICES Journal of Marine Science, 50: 481–492.

Friedland K.D., L.P. Hansen, and D.A. Dunkley. 1998. Marine temperature experienced by postsmolts and the survival of Atlantic salmon, *Salmo salar* L. in the North Sea area. Fisheries Oceanography, 7: 22–34.

Hansen, L. P., and Pethon, P. 1985. The food of Atlantic salmon, *Salmo salar* L. caught by longline in Northern Norwegian waters. Journal of Fish Biology, 26: 553–562.

Hansen, L.P., and Jacobsen, J.A. 2000. Distribution and migration of Atlantic salmon, *Salmo salar* L., in the sea. *In* The ocean life of Atlantic salmon: Environmental and biological factors influencing survival. Ed. By Mills, D. Fishing News Books, Blackwell Science, pp. 75–87.

Hansen, L.P., and Jacobsen, J.A. 2003. Origin and migration of wild and escaped farmed Atlantic salmon, *Salmo salar* L., in oceanic areas north of the Faroe Islands. ICES Journal of Marine Science, 60: 110–119.

Holm, M., J.C. Holst, and L.P. Hansen. 1998. Spatial and temporal distribution of Atlantic salmon postsmolts in the Norwegian Sea and adjacent areas – origin of fish, age structure and relation to hydrographical conditions in the sea. ICES CM 1998/N:15, 8 pp.

Holm, M., J.C. Holst and L.P. Hansen. 2000. Spatial and temporal distribution of post-smolts of Atlantic salmon (*Salmo salar* L.) in the Norwegian Sea and adjacent areas. ICES Journal of Marine Science, 57: 955–964.

Holm, M., J.C. Holst, L.P. Hansen, J.A. Jacobsen, N. Ó Maoiléidigh and A. Moore 2003: Migration and distribution of Atlantic salmon post-smolts in the North Sea area and North East Atlantic. *In* Salmon on the edge. Ed. by Mills, D. Blackwell Science, Oxford, pp. 7–23.

Holst, J.C., Nilsen, F., Hodneland, K., and Nylund, A. 1993. Observations of the biology and parasites of postsmolt Atlantic salmon, *Salmo salar*, from the Norwegian Sea. Journal of Fish Biology, 42: 962–966.

Holst, J.C., Hansen, L.P. and Holm, M. 1996. Preliminary observations of abundance, stock composition, body size and food of postsmolts of Atlantic salmon caught with pelagic trawls in the NE Atlantic in the summers 1991 and 1995. ICES CM 1996/M:4. 8 pp.

ICES. 2001. Report of the Working Group on North Atlantic Salmon. ICES CM/ACFM:15, 290 pp.

ICES. 2002. Report of the Working Group on North Atlantic salmon. ICES CM 2002/ACFM: 14, 297 pp.

ICES. 2003. Report of the Working Group on North Atlantic Salmon. ICES, Copenhagen, 31 March – 10 April 2003. CM/ACFM:19, 310 pp.

ICES. 2007. Report of the Workshop on the Development and Use of Historical Salmon Tagging Information from Oceanic Areas (WKDUHSTI). ICES CM 2007/DFC:02.

Idler, D.R., S.J. Hwang, L.W. Crim, and D.G. Reddin. 1981. Determination of sexual maturation stages of Atlantic salmon (*Salmo salar*) captured at sea. Canadian Journal of Fisheries and Aquatic Sciences, 38: 405–413.

Jacobsen, J.A. 2000. Aspects of the marine ecology of Atlantic salmon (*Salmo salar* L.). PhD thesis. University of Bergen, Norway.

Jacobsen, J.A. and Hansen, L.P. 2001. Feeding habits of wild and escaped farmed Atlantic salmon, *Salmo salar* L., in the Northeast Atlantic. ICES Journal of Marine Science, 59: 916–933.

Jacobsen, J.A., R. A. Lund, L. P. Hansen, and N. Ó Maoiléidigh 2001: Seasonal differences in the origin of Atlantic salmon (*Salmo salar* L.) in the Norwegian Sea based on estimates from age structures and tag recaptures. Fisheries Research, 52:169–177.

Jakupsstovu, S.H. 1988. Exploitation and migration of salmon in Faroese waters. *In* Atlantic salmon: planning for the future. Proceedings of the Third International Atlantic salmon Symposium, Biarritz, France, October 21–23, 1986. Chapter 25, p. 458–482. Ed. by D.H. Mills and D. J. Piggins. Croom Helm, London.

Jutila, E., E. Jokikokko, I. Kallio-Nyberg, I. Saloniemi, and P. Pasanen. 2003. Differences in sea migration between wild and reared Atlantic salmon (*Salmo salar* L.) in the Baltic Sea. Fisheries Research, 60: 333–343.

Kallio-Nyberg, I., M. –L. Koljonen, and I. Saloniemi. 2000. Effect of maternal and parental line on spatial and temporal marine distribution in Atlantic salmon. Animal Behaviour, 60: 377–384.

Lear, W. H. 1976. Migrating Atlantic salmon (*Salmo salar*) caught by otter trawl on the Newfoundland continental shelf. J. Fish. Res. Board Can., 33: 1202–1205.

Ludwig, J.A., and Reynolds. J.F. 1988Statistical Ecology: A Primer on methods and Computing. John Wiley & Sons, Chichester.

May, A.W., and W.H. Lear. 1971. Digest of Canadian Atlantic salmon catch statistics. J. Fish. Res. Bd. Canada., Technical Report No. 270. 106 p.

Møller Jensen, J. 1980a. Recaptures of salmon at West Greenland tagged as smolts outside Greenland waters. Rapport de Procès-verbal de la Réunion Conseil International Exploration du Mer, 176: 114–121.

Møller Jensen, J. 1980b. Recaptures from international tagging experiments at West Greenland. Rapport de Procès-verbal de la Réunion Conseil International Exploration du Mer, 176: 122–135.

Parrish, B. B., and Horsted, S. Aa. 1980 (eds.). ICES/ICNAF Joint Investigation on North Atlantic Salmon. Rapport de Procès-verbal de la Réunion Conseil International Exploration du Mer, 176: 1–146.

Parrish, D. L., Behnke, R. J., Gephard, S. R., McCormick, S. D., and Reeves, G. H. 1998. Why aren't there more Atlantic salmon (*Salmo salar*)? Canadian Journal of Fisheries and Aquatic Sciences, 51 (Suppl. 1): 281–287.

Porter, T., and Ritter, J.A. 1984. Possible causes of low abundance of Atlantic salmon in Canada – 1983 confirm this is part of title. ICES CM (International Council for the Exploration of the Sea. Anadromous and Catadromous Fish Committee) 1984/M:28. 27 p.

Reddin, D.G., W.M. Shearer, and R.F. Burfitt. 1984. Inter-continental migrations of Atlantic salmon (*Salmo salar* L.). Cons. Int. Explor. Mer, C.M. 1984/M:11, 9 p.

Reddin, D.G. 1985. Atlantic salmon (*Salmo salar*) on and east of the Grand Bank. J. Northwest. Atl. Sci., 6:157–164.

Reddin, D.G. 1988. Ocean life of Atlantic salmon (*Salmo salar* L.) in the Northwest Atlantic. Chapter 26, p. 483–511. In. D. H. Mills and D. J. Piggins [Eds.] Atlantic salmon: planning for the future. Proceedings of the Third International Atlantic salmon Symposium, Biarritz, France, October 21–23, 1986. Croom Helm, London.

Reddin, D.G. and Shearer, W.M. 1987. Sea-surface temperature and distribution of Atlantic salmon in the Northwest Atlantic Ocean. American Fisheries Society Symposium, 1: 262–275.

Reddin, D. J., Stansbury, D. E., and Short, P. B. 1988. Continent of origin of Atlantic salmon (*Salmo salar* L.) caught at west Greenland. Journal du Conseiles international Exploration du Mer, 44: 180–188.

Reddin, D.G., and Short, P.B. 1991. Postsmolt Atlantic salmon (*Salmo salar*) in the Labrador Sea. Can. J. Fish. Aquat. Sci., 48:2–6.

Reddin, D.G., and Friedland, K. D. 1993. Marine environmental factors influencing the movement and survival of Atlantic salmon. Ch. 4: pp. 79–103. *In* Derek Mills [ed.] Salmon in the sea and new enhancement strategies. Fishing News Books, 424 p.

Reddin, D.G., and Friedland, K.D. 1999. A history of identification to continent of origin of Atlantic salmon (*Salmo salar* L.) at west Greenland. Fisheries Research, 43(1–3): 221–235.

Rice, A.L. and Lambshead, P.J.D. 1994. Patch dynamics in the deep-sea benthos: the role of a heterogeneous supply of organic matter. *In* Aquatic Ecology: scale, pattern and process. 34th Symposium of the British Ecological Society. Ed. by Giller, P.S., Hildrew, A.G., and D.G. Raffaelli. Blackwell Scientific Publications. Oxford. Pp.469–499.

Ritter, J.A. 1989. Marine migration and natural mortality of North American Atlantic salmon (*Salmo salar* L.). Can. MS Rep. Fish. Aquat. Sci., No. 2041. 136 p.

Rosseland, L. 1971. Fiske av atlantisk laks i internasjonalt farvann (Atlantic salmon fishing in international waters). Jakt-Fiske-Friluftsiv, 100: 190–195, 238–242. (In Norwegian).

Ruggles, C.P., and Ritter, J.A. 1980. Review of North American smolt tagging to assess the Atlantic salmon fishery of West Greenland. ICES 176:82–92.

Scarnecchia, D.L. 1984. Climatic and oceanic variations affecting yield of Icelandic stocks of Atlantic salmon (*Salmo salar*). Can. Fish. Aquat. Sci., 41: 917–935.

Shelton, R.G.J., J.C. Holst, W.R. Turrell, J.C. MacLean, I.S. McLaren, and N.T. Nicoll. 1997. Records of post-smolt Atlantic salmon, *Salmo salar* L., in the Faroe-Shetland Channel in June 1996. Fisheries Research, 31:159–162.

Spares, A.D., Reader, J.M., Stokesbury, M.J.W., McDermott , T., Zikovsky, L., Avery, T.S., and Dadswell, M.J. 2007. Inferring marine distribution of Canadian and Irish Atlantic salmon (*Salmo salar* L.) in the North Atlantic from tissue concentrations of bio-accumulated caesium 137. ICES Journal of Marine Science, 64: 394–404.

Swain, A. 1980. Tagging of salmon smolts in European rivers with special reference to recaptures off West Greenland in 1972 and earlier years. Rapport de Procès-verbal de la Réunion Conseilles international Exploration du Mer, 176: 93–113.

Tucker, S., I. Pazzia, D. Rowan, and J.B. Rasmussen. 1999. Detecting panmigration in Atlantic salmon (Salmo salar) using 137Cs. Can. J. Fish. Aquat. Sci., 56: 2235–2239.

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